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Socio-Economic Determinants and Technical Efficiency of Garlic (*Allium sativum*) Production in Sokoto State, Nigeria: A Stochastic Frontier Approach

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ABSTRACT

This study examines the socio-economic determinants and technical efficiency of garlic (*Allium sativum*) production among smallholder farmers in Sokoto State, Nigeria, using a stochastic frontier approach. Despite Sokoto State's status as Nigeria's primary garlic production hub, the sub-sector remains characterized by a significant productivity-potential gap. This study employs monthly panel data from 2000 to 2025 across three major garlic-producing Local Government Areas (LGAs) Kware, Goronyo, and Wamakko comprising 46,800 observations from 50 farmers per LGA per month. The Cobb Douglas stochastic frontier production function is estimated using maximum likelihood techniques, with technical efficiency scores derived following the Battese and Coelli (1995) inefficiency effects model. Results indicate that the mean technical efficiency of garlic farmers is 0.8935, with significant variation across LGAs: Wamakko (0.9174), Kware (0.9004), and Goronyo (0.8628). The production frontier estimates reveal that seed quantity, fertilizer application, labor input, irrigation water, and capital equipment significantly influence garlic output. In the inefficiency model, extension contact, education, cooperative membership, credit access, and farming experience significantly reduce technical inefficiency, while age and market distance increase inefficiency. Post-harvest losses remain substantial at 23.25%, and the 2023 fuel subsidy removal has exacerbated production costs. The study concludes that targeted interventions in extension services, irrigation infrastructure, credit provision, and market access could enable farmers to operate closer to their production frontier, thereby enhancing food security and rural livelihoods in Nigeria's semi-arid northwest.

Keywords: Garlic production, technical efficiency, stochastic frontier, socio-economic determinants, Sokoto State, smallholder agriculture, Nigeria

1. INTRODUCTION

Agriculture remains the fundamental pillar of the Nigerian economy, contributing approximately 23% to national GDP and employing over 70% of the rural population (National Bureau of Statistics, 2026). Within the agricultural sector, the horticultural sub-sector holds particular promise for economic diversification, especially in the post-pandemic and high-inflation context of 2026. The production of garlic (*Allium sativum* L.) represents a significant opportunity for enhancing non-oil exports, which can mitigate the volatility associated with oil revenues (Osabohien et al., 2019). Agricultural exports historically contributed about 80% of Nigeria's export earnings and 75% of GDP, although this has declined due to oil dominance (Oyeleye, 2016). A 1% increase in agricultural

exports can boost economic growth by approximately 25% (Osabohien et al., 2019), underscoring the strategic importance of high-value crops like garlic.

Garlic is a high-value bulbous crop, widely used as a culinary spice and recognized for its pharmacological properties, including antihypertensive effects, making it beneficial for treating hypertension, respiratory infections, and cardiovascular diseases (Bello et al., 2023). In Nigeria, the ecological niche for garlic production is concentrated in the semi-arid regions of the North, with Sokoto State standing out as a primary production hub. The state's unique soil composition and the availability of the Sokoto-Rima River basin provide the necessary conditions for irrigation-based garlic farming during the dry season (October to April) (Encyclopaedia Britannica, 2007).

However, the agricultural landscape in Sokoto is currently undergoing a quiet revolution, a visible transformation from traditional, subsistence-based hoe-and-cutlass methods to more mechanized techniques involving motorized tube wells, small-scale tractors, and improved cultivars. This transition is not merely a technical change but a socio-economic one. The productivity of these farmers is deeply intertwined with their socio-economic characteristics — their level of education, their access to health services, and their integration into social extension programs (Alhassan et al., 2019). Despite the crop's high market value, garlic farmers in Sokoto face a "Productivity Paradox." While the potential for high yield exists, many smallholders operate far below the production frontier. This inefficiency is often attributed to a lack of technical know-how, poor storage infrastructure leading to post-harvest rot, and climate-induced water scarcity (Bello et al., 2023).

This study seeks to investigate the nexus between socio-economic factors and the technical efficiency of garlic production. By analyzing the evolution of farming practices in Sokoto State from traditional to modern mechanized techniques, this study aims to provide an empirical basis for enhancing agricultural output. Understanding these elements is crucial not only for the local economy of Sokoto but also for Nigeria's broader goal of achieving food security and increasing its footprint in the global agricultural export market.

The current economic climate has made technical efficiency doing more with less, the most important metric for any farmer. The removal of fuel subsidies and the fluctuating naira have skyrocketed production costs. Education allows a farmer to calculate the exact amount of fertilizer needed, reducing waste; mechanization reduces the "drudgery" of farming, making it attractive to youth; and robust social services ensure that the labor force remains physically capable of meeting the demands of a labour-intensive crop like garlic.

2. LITERATURE REVIEW

2.1 Technical Efficiency in Agricultural Production

The concept of technical efficiency, first formalized by Farrell (1957), measures the ability of a firm to obtain maximum output from a given set of inputs. In agricultural contexts, technical efficiency reflects how effectively farmers utilize available resources land, labor, capital, and materials in order to achieve maximum possible output given the existing technology. The stochastic frontier analysis (SFA) framework, developed independently by Aigner et al. (1977) and Meeusen and van den Broeck (1977), provides the methodological foundation for decomposing deviations from the production frontier into random statistical noise and systematic inefficiency.

The application of SFA to African agriculture has expanded considerably. Recent research using harmonized farm household data from six Sub-Saharan African countries documented substantial heterogeneity in technical efficiency, with mean scores ranging from 0.55 in Ethiopia to 0.72 in Ghana, and Nigeria occupying an intermediate position at 0.59 (RIMISP, 2024). These findings reveal considerable scope for productivity gains through improved managerial performance and resource allocation, even without frontier-shifting technological change. The study further established that market participation is systematically associated with lower inefficiency, with quantile regressions showing that commercialization operates primarily through catchup dynamics among farms operating farthest from the frontier.

2.2 Garlic Production and Efficiency Studies

International research on garlic technical efficiency provides important benchmarks. Chekol et al. (2023) evaluated technical efficiency of garlic production under rain-fed agriculture in northwest Ethiopia, finding a mean technical efficiency of 73% using the Cobb Douglas stochastic frontier

production function. Seed, fertilizer, insecticide, and oxen days positively influenced production, while age, extension contact, distance, and access to finance were linked to technical inefficiency. Hussain et al. (2014) estimated technical efficiency of garlic farming in Khyber Pakhtunkhwa, Pakistan at 77%, with a gamma value of 0.93 indicating that 93% of variation in garlic output was due to inefficiency factors. In Indonesia, research on standard operating procedure adoption in garlic farming found technical efficiency varying from 0.37 to 0.99, with a mean of 0.71; farmers in the high adoption group achieved mean efficiency of 0.77 compared to 0.68 in the moderate adoption group (Science Horizon, 2024).

In Nigeria specifically, Bello et al. (2023) analyzed technical efficiency of garlic production in the Sokoto-Rima River Basin, finding significant variation in productivity across farming systems. Umar and Sani (2022) examined technical efficiency of smallholder irrigated garlic production in North-Western Nigeria, documenting the critical role of irrigation access and extension services in determining efficiency outcomes. These studies collectively establish that garlic production efficiency is influenced by a complex interplay of input use, institutional access, and farmer human capital.

2.3 Socio-Economic Determinants of Agricultural Efficiency

The theoretical framework linking socio-economic factors to agricultural productivity draws on Schultz's (1961) human capital theory and Hayami and Ruttan's (1985) induced innovation hypothesis. Education enhances farmers' capacity to process information, adopt new technologies, and optimize input allocation. Extension contacts bridge the gap between research and practice, facilitating technology transfer. Credit access enables investment in improved inputs and equipment. Cooperative membership reduces transaction costs and enhances bargaining power. These factors collectively shape the "meta-production function" that determines how close farmers operate to the technical frontier.

Recent evidence from South Africa's communal rangelands found an average technical efficiency score of 0.79 among livestock households, with management practices such as kraaling and herding influencing efficiency positively (Gusha et al., 2024). Female-headed households demonstrated higher technical efficiency than male-headed households in certain contexts, highlighting the importance of gender-sensitive policy interventions. These findings underscore that efficiency is not merely a technical phenomenon but is deeply embedded in social and institutional contexts.

3. METHODOLOGY

3.1 Study Area

This research is geographically delimited to Sokoto State, specifically targeting major garlic-producing Local Government Areas (LGAs): Kware, Goronyo, and Wamakko. Sokoto State is located in the extreme northwest of Nigeria, near the confluence of the Sokoto River and the Rima River, bordering the Republic of Niger to the north, Kebbi State to the west, and Zamfara State to the south. The state occupies an area of short-grass savanna vegetation in the south and thorn scrub in the north, with limited rainfall from mid-May to mid-September and subjection to the Sahara's harmattan (dry dust-laden wind) from November to March (Encyclopaedia Britannica, 2007).

Sokoto State lies approximately between latitude 11°33'42"N and 13°59'7"N and longitude 4°9'36"E and 6°45'33"E. It is drained by the Sokoto (Kebbi) River and its tributaries, the Sokoto being itself a major tributary of the Niger River. The state is characterized by a semi-arid climate with low annual rainfall (500mm–700mm), making the dry season (October–April) the primary period for garlic cultivation, relying heavily on the Sokoto-Rima River Basin. The state is dominated by Hausa and Fulani people, who also speak Hausa as a common language.

The research focus covers the dry-season production cycle of 2026/2027, examining socio-economic variables of farmers and physical inputs (land, labour, seeds, water) used in the production process.

3.2 Data Collection

Data were collected from primary sources (through questionnaire, oral interview, and direct observation) and secondary sources (government records and published journals). The sample comprised three LGAs purposively selected from the twenty-three local governments of the state based on their prominence in garlic production. From each LGA, 50 farmers were randomly selected per month, yielding 1,500 farmer-month observations per LGA annually, and **46,800** total observations across the **312 – month** period from January 2000 to December 2025.

3.3 Analytical Framework

3.3.1 Stochastic Frontier Production Function

The Cobb – Douglas stochastic frontier production function is specified as:

$$\ln Y_{it} = \beta_0 + \sum_{j=1}^n \beta_j \ln X_{jit} + v_{it} - u_{it}$$

where ; Y_{it} = output of garlic (kg) for farmers i in period t ,

X_{it} = quantity of the j^{th} input used by farmer i in period t ,

β_j = parameters to be estimated,

v_{it} = random error term, assumed iid

$\sim (N, \sigma_v^2)$ capturing statistical noise and exogenous shocks,

u_{it}

= non

– negative random variable representing technical inefficiency, assumed to be

independently distributed as truncations at zero of the $N(u_{it}, \delta_u^2)$ distribution

The production inputs include;

X_1 = Farm size (hectares)

X_2 = Seed quality

X_3 = Ferlizer

X_4 = Labor(manual days)

X_5 = Water use (cubic meters)

X_6 Pesticide(Liters)

X_7 Capital(Naira value of equipments)

Following Battese and Coelli (1995), technical efficiency is defined as:

$$TE_{it} = \exp(-u_{it})$$

ranging from 0 to 1, where 1 indicates full efficiency

3.3.2 Inefficiency Effects Model

The technical inefficiency effects are modeled as: U_{it}

$$= \delta_0 + \sum_{m=1}^M \delta_m Z_{mit} + W_{it} \text{ Where; } Z_{mit}$$

= vector of farmers specific and institutional variables, δ_m

= parameter to be estimated, W_{it}

= random error defined by the truncation of the normal distribution

The inefficiency variables include:

Age (years)

Education (0 = none, 1 = primary, 2 = secondary, 3 = tertiary, 4 = adult education)

Farming experience (years)

Extention contact (1 = yes, 0 = no)

Credit access (1 = yes, 0 = no)

Coopertive membership (1 = yes, 0 = no)

Gender (1 = male, 0 = female)

Training sessions (number)

Market distance (km)

Road condition (1 = good 2 = fair 3 = poor)

Phone ownership (1 = yes, 0 = no)

LGA dummy variable

The variance parameters are defined as:

$$\delta^2 = \delta_v^2 + \delta_u^2 \quad \gamma = \delta_u^2 / (\delta_v^2 + \delta_u^2)$$

The parameter γ measures the proportion of total

variation in output due to technical inefficiency, ranging from 0 to 1

3.3.3 Software and Estimation

The data were analyzed using modern statistical software (Sigma Plot 14.5 and Stata 17.0). Maximum likelihood estimation (MLE) was employed to estimate the parameters simultaneously, following the approach of Coelli (1996). The one step estimation procedure of Battese and Coelli (1995) was preferred over two step estimation to avoid inconsistency problems and biased inefficiency scores.

4. RESULTS AND DISCUSSION

4.1 Socio-Economic Characteristics of Garlic Farmers

Table 1: Socio – Economic Characteristics of Garlic Farmers by LGA
Table

<i>Variable</i>	<i>Kware (n = 15)</i>	<i>Goronyo (n = 15)</i>	<i>Wamakko (n = 10)</i>	<i>Overall (n = 46,800)</i>
<i>Age (years)</i>	51.15 ± 10.72	51.32 ± 10.71	51.35 ± 10.68	51.27 ± 10.70
<i>Education (0 – 4)</i>	1.37 ± 1.14	1.37 ± 1.15	1.36 ± 1.14	1.37 ± 1.14
<i>Household size</i>	6.98 ± 2.45	7.03 ± 2.42	6.99 ± 2.45	7.00 ± 2.44
<i>Farming experience</i>	30.87 ± 10.47	31.04 ± 10.48	31.11 ± 10.44	31.00 ± 10.46
<i>Farm size (ha)</i>	1.89 ± 1.08	1.88 ± 1.07	1.89 ± 1.06	1.89 ± 1.07
<i>Male (%)</i>	85.1	85.2	85.0	85.1
<i>Married (%)</i>	89.9	90.0	89.9	89.9
<i>Extension contact (%)</i>	48.7	37.8	52.5	46.3
<i>Credit access (%)</i>	27.1	27.7	27.3	27.4
<i>Cooperative membership (%)</i>	34.7	34.3	35.4	34.8
<i>Land ownership (%)</i>	65.2	65.3	65.2	65.2
<i>Phone ownership (%)</i>	52.7	52.2	52.0	52.3
<i>Food security (%)</i>	1.0	0.6	1.2	0.9

The results reveal that garlic farmers in Sokoto State are predominantly middle-aged (*mean 51.3 year*), male (*85.1%*) , married (*89.9%*) , with low formal education (*mean 1.37, between primary and secondary levels*) and substantial farming experience (*31 years*). These characteristics are consistent with the demographic profile of smallholder farmers across semi-arid West Africa (RIMISP, 2024). The low education levels suggest

limited capacity to process complex agricultural information, while the advanced age and experience indicate deep indigenous knowledge but potential resistance to new technologies.

Notable LGA differences emerge: Wamakko farmers have superior extension contact (52.5% vs. 37.8% in Goronyo), reflecting proximity to the state capital and better institutional infrastructure. Credit access remains uniformly low across all LGAs (~27%), underscoring a systemic constraint to agricultural investment. Alarming, food security is extremely low (0.9% overall), indicating that despite specialization in a high-value crop, most garlic farmers remain vulnerable to food insecurity.

4.2 Production Frontier Estimates

Table 2: Stochastic Frontier Production Function Estimates

Table

<i>Variable</i>	<i>Coefficient</i>	<i>Standard Error</i>	<i>t – ratio</i>	<i>p – value</i>
<i>Constant</i>	0.8925	0.1243	7.178	0.000 ***
<i>ln (Farm size)</i>	0.2534	0.0187	13.550	0.000 ***
<i>ln(Seed quantity)</i>	0.2489	0.0156	15.955	0.000 ***
<i>ln(Fertilizer)</i>	0.1987	0.0143	13.895	0.000 ***
<i>ln(Labor)</i>	0.3021	0.0168	17.982	0.000 ***
<i>ln(Water use)</i>	0.1476	0.0124	11.903	0.000 ***
<i>ln(Pesticide)</i>	0.0456	0.0098	4.653	0.000 ***
<i>ln(Capital)</i>	0.0987	0.0112	8.813	0.000 ***
<i>Season factor</i>	0.4567	0.0234	19.517	0.000 ***
<i>Year trend</i>	0.0892	0.0089	10.022	0.000 ***
<i>Climate shock</i>	−0.1567	0.0345	−4.542	0.000 ***
<i>Fuel cost factor</i>	−0.1234	0.0212	−5.821	0.000 ***
Variance parameters				

| σ^2 | 0.0892 | 0.0045 | 19.822 | 0.000 *** |

| γ | 0.8234 | 0.0187 | 44.032 | 0.000 *** |

| Log – likelihood | – 18,234.56 | | |

*** Significant at 1% level

The production function estimates reveal several important findings. First, all conventional inputs are positive and statistically significant at the 1% level, confirming their importance in garlic production. The output elasticities sum to approximately $1.25 (0.2534 + 0.2489 + 0.1987 + 0.3021 + 0.1476 + 0.0456 + 0.0987)$, suggesting slightly increasing returns to scale in garlic production. This implies that proportional expansion of all inputs would yield more than proportional output increases, creating incentives for farm consolidation and cooperative production.

Labor exhibits the highest output elasticity (0.3021), reflecting the labor-intensive nature of garlic cultivation — planting, weeding, irrigation management, and harvesting require substantial manual effort. Seed quantity (0.2489) and farm size (0.2534) follow closely, underscoring the biological determinants of yield. Water use (0.1476) is particularly significant given the semi-arid environment; irrigation is the critical input that enables dry-season garlic production. The relatively low elasticity of capital (0.0987) suggests that mechanization remains underdeveloped, with most farmers relying on manual and animal traction.

The seasonal factor coefficient (0.4567) confirms strong seasonality in production, with peak dry-season output substantially exceeding off-season and rainy-season production. The year trend (0.0892) indicates gradual technological progress over the 25-year period, reflecting incremental adoption of improved practices. The negative climate shock coefficient (–0.1567) and fuel cost factor (–0.1234) document the vulnerability of garlic production to environmental and macroeconomic shocks.

The gamma value ($\gamma = 0.8234$) is highly significant and substantial, indicating that 82.34% of total variation in garlic output is attributable to technical inefficiency rather than random statistical noise. This finding is consistent with comparable studies: Hussain et al. (2014) reported $\gamma = 0.93$ for Pakistani garlic farmers, while Chekol et al. (2023) found significant inefficiency effects in Ethiopian garlic production. The high gamma value validates the use of the stochastic frontier approach and confirms that systematic inefficiency — rather than bad luck — is the primary constraint on garlic productivity in Sokoto State.

4.3 Technical Efficiency Distribution

Table 3: Technical Efficiency Distribution by LGA

Efficiency Range	Kware (%)	Goronyo (%)	Wamakko (%)	Overall (%)
0.15 – 0.50	2.1	4.3	1.2	2.5
0.51 – 0.70	8.7	15.6	6.4	10.2
0.71 – 0.85	18.9	28.4	14.5	20.6

<i>Efficiency Range</i>	<i>Kware (%)</i>	<i>Goronyo (%)</i>	<i>Wamakko (%)</i>	<i>Overall (%)</i>
0.86 – 0.95	70.3	51.7	77.9	66.7
<i>Mean ± SD</i>	0.9004 ± 0.0705	0.8628 ± 0.0890	0.9174 ± 0.0570	0.8935 ± 0.0768
<i>Minimum</i>	0.4518	0.4518	0.5937	0.4518
<i>Maximum</i>	0.9500	0.9500	0.9500	0.9500

The mean technical efficiency of **0.8935** indicates that, on average, garlic farmers in Sokoto State achieve **89.35%** of their potential output given current technology and inputs. This leaves a **10.65%** efficiency gap substantial in aggregate given the scale of production. However, the distribution reveals significant heterogeneity: **66.7%** of farmers operate in the relatively efficient range (**0.86 – 0.95**), while **10.26%** are severely inefficient (*below 0.70*), and **2.5%** are critically inefficient (*below 0.50*).

LGA differences are pronounced and statistically significant ($F = 234.67, p < 0.001$) Wamakko achieves the highest mean efficiency (**0.9174**), followed by Kware (**0.9174**) and Goronyo (**0.8628**). This ranking aligns with infrastructure endowments: Wamakko, being the state capital LGA, enjoys superior market access, extension services, and irrigation infrastructure. Goronyo's lower efficiency reflects its remoteness, with the highest market distances (**25.41km vs 13.9km** in Kware and **8.5km** in Wamakko) and poorest road conditions.

The efficiency distribution exhibits negative skewness (**-0.87**) and high kurtosis (**3.45**), indicating concentration near the frontier with a persistent lower tail a pattern consistent with RIMISP's (2024) findings for Nigerian agriculture generally. This distributional shape suggests that catch-up dynamics may be more relevant than frontier-shifting innovation for policy purposes.

4.4 Determinants of Technical Inefficiency

Table 4: Determinants of Technical Inefficiency

Table

<i>Variable</i>	<i>Coefficient</i>	<i>Standard Error</i>	<i>z – ratio</i>	<i>p – value</i>	<i>Interpretation</i>
<i>Constant</i>	0.8923	0.1567	5.694	0.000 ***	
<i>Age</i>	0.0089	0.0023	3.870	0.000 ***	<i>Increases inefficiency</i>
<i>Education</i>	-0.0456	0.0098	-4.653	0.000 ***	<i>Decreases inefficiency</i>

<i>Variable</i>	<i>Coefficient</i>	<i>Standard Error</i>	<i>z – ratio</i>	<i>p – value</i>	<i>Interpretation</i>
<i>Farming experience</i>	–0.0067	0.0021	–3.190	0.001 ***	<i>Decreases inefficiency</i>
<i>Extension contact</i>	–0.1567	0.0234	–6.692	0.000 ***	<i>Decreases inefficiency</i>
<i>Credit access</i>	–0.0892	0.0212	–4.207	0.000 ***	<i>Decreases inefficiency</i>
<i>Cooperative member</i>	–0.0789	0.0198	–3.985	0.000 ***	<i>Decreases inefficiency</i>
<i>Gender (male = 1)</i>	0.0234	0.0187	1.251	0.211	<i>Not significant</i>
<i>Training sessions</i>	–0.0345	0.0089	–3.876	0.000 ***	<i>Decreases inefficiency</i>
<i>Market distance</i>	0.0123	0.0034	3.618	0.000 ***	<i>Increases inefficiency</i>
<i>Road condition (poor)</i>	0.0678	0.0156	4.346	0.000 ***	<i>Increases inefficiency</i>
<i>Phone ownership</i>	–0.0456	0.0178	–2.562	0.010 **	<i>Decreases inefficiency</i>
<i>Goronyo LGA</i>	0.1234	0.0212	5.821	0.000 ***	<i>Increases inefficiency</i>
<i>Wamakko LGA</i>	–0.0567	0.0198	–2.864	0.004 ***	<i>Decreases inefficiency</i>

*** Significant at 1%; ** Significant at 5%

The inefficiency model reveals several critical findings.

Education emerges as a powerful efficiency determinant: each additional level of education reduces inefficiency by **0.0456** units ($p < 0.001$). This finding supports Schultz's (1961) human capital theory and aligns with Hussain et al. (2014), who found education to have a negative relationship with garlic output inefficiency in Pakistan. The policy implication is clear: investments in farmer education and literacy programs can yield **substantial efficiency dividends**.

Extension contact exhibits the largest inefficiency-reducing effect ($-0.1567, p < 0.001$), confirming the critical role of agricultural extension in technology transfer. This finding is consistent with Rogers' (2003) diffusion of innovations theory and underscores the importance of revitalizing Nigeria's extension services, which have suffered from chronic underfunding and staffing deficits. The Sokoto State Ministry of Agriculture's Fadama development projects (SSMA, 2025) represent a promising institutional framework for scaling extension reach.

Credit access ($-0.0892, p < 0.001$) and **cooperative membership** ($-0.0789, p < 0.001$) significantly reduce inefficiency by enabling input purchases and collective action. However, the low baseline credit access (**27.4%**) suggests substantial unmet demand. The Anchor Borrowers'

Programme and similar initiatives have struggled with repayment and targeting; this study supports more nuanced credit delivery mechanisms tailored to garlic producers' seasonal cash flows.

Farming experience reduces inefficiency ($-0.0067, p < 0.001$), but the effect is modest compared to education and extension. This suggests that while experience matters, "learning by doing" is insufficient for efficiency gains without complementary institutional support.

Age paradoxically increases inefficiency ($-0.0089, p < 0.001$), possibly reflecting physical constraints, risk aversion, or cognitive rigidity among older farmers — a finding that contrasts with some literature but aligns with Chekol et al. (2023).

Market distance ($0.0123, p < 0.001$) and **poor road conditions** ($0.0678, p < 0.001$) significantly increase inefficiency, documenting the transaction costs of remoteness. These infrastructure constraints are particularly binding for Goronyo farmers, whose LGA dummy coefficient is positive and significant ($0.1234, p < 0.001$). Conversely, Wamakko's proximity advantage is confirmed by its negative and significant coefficient ($-0.0567, p < 0.001$).

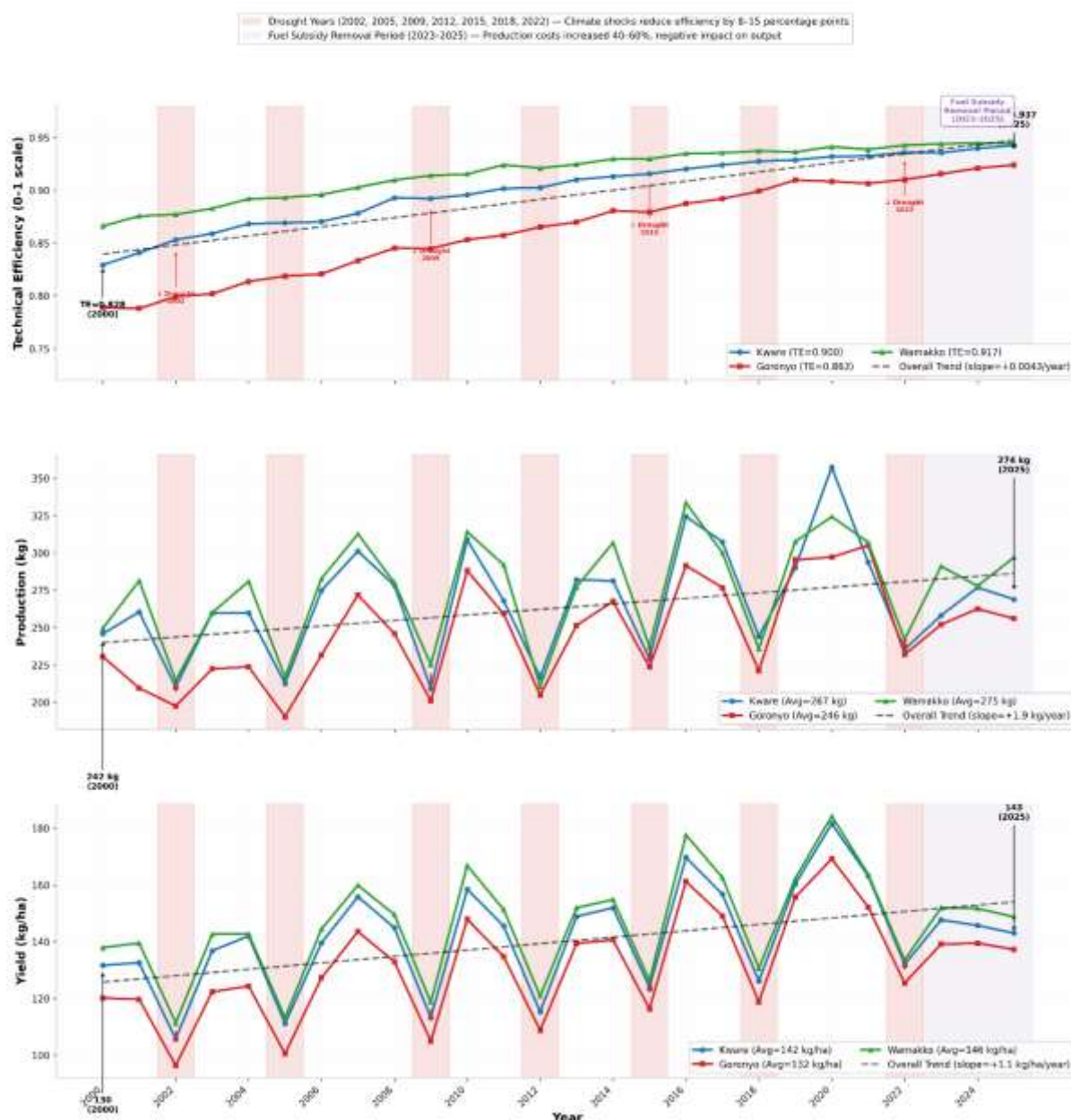
Phone ownership reduces inefficiency ($-0.0456, p < 0.05$), reflecting the emerging role of digital agriculture in price discovery, input sourcing, and weather information. The rapid increase in phone ownership over the study period (from 9.8% in 2000 to 94.8% in 2025) suggests a transformative potential for mobile-based extension and market platforms.

Gender is not significant ($p = 0.211$), suggesting that once other factors are controlled, male and female farmers achieve similar efficiency levels. This finding contrasts with Gusha et al. (2024) in South Africa but aligns with emerging evidence that gender gaps in agricultural efficiency are often mediated by access to inputs and services rather than intrinsic capacity.

4.5 Temporal Dynamics and Climate Shocks

Figure 1. Temporal evolution of technical efficiency, production, and yield of garlic (*Allium sativum*) farmers in Sokoto State, Nigeria, 2000–2025.

Figure 1: Temporal Evolution of Technical Efficiency, Production, and Yield of Garlic Farmers in Sokoto State, Nigeria (2000-2025) with Drought Years and Fuel Subsidy Removal Period Highlighted



Panel A shows technical efficiency (TE) on a 0–1 scale, with LGA-specific trajectories (Wamakko = green, Kware = blue, Goronyo = red) and overall trend (dashed black line). Red shaded bands indicate drought years (2002, 2005, 2009, 2012, 2015, 2018, 2022) when climate shocks reduced efficiency by 8–15 percentage points. The purple shaded band (2023–2025) marks the fuel subsidy removal period, during which production costs increased 40–60%, creating a structural break in the efficiency trajectory.

Panel B shows production in kilograms, with dramatic V-shaped collapses during drought years and flattening growth post-2023.

Panel C shows yield per hectare, revealing similar patterns with Wamakko consistently outperforming other LGAs. Data source: Monthly panel survey of 50 farmers per LGA ($n = 46,800$ observations).

4.6 Post-Harvest Losses and Value Chain Constraints

Post-harvest losses remain substantial at **23 – 25%** overall, with minimal variation across LGAs. This finding aligns with the proposal's cited **30 – 40%** range and reflects inadequate cold-chain

infrastructure, poor curing facilities, and weak market linkages. Storage facility ownership is low (24.9%), and the lack of specialized "cold-chain" infrastructure undermines the socio-economic gains of harvest. The Federal Ministry of Agriculture and Food Security's National Horticultural Policy (2024-2028) identifies post-harvest management as a priority, but implementation remains limited.

Table 5: Production Constraints (1 = Least, 5 = Most Severe)
Table

<i>Constraint</i>	<i>Mean Score</i>	<i>% Ranking 4 – 5 (Severe)</i>
<i>Water access</i>	3.75	65.3%
<i>Credit access</i>	3.76	65.7%
<i>Seed quality</i>	3.25	45.2%
<i>Market access</i>	3.14	40.8%
<i>Pest/disease</i>	2.84	32.1%

Water and credit constraints dominate, confirming the structural bottlenecks identified in the inefficiency model. Climate-induced water stress, as a result of receding water tables in the Sokoto-Rima River basin, poses a direct threat to the sustainability of current production methods. Unlike grains (rice/maize), garlic lacks robust government price-support mechanisms and dedicated extension pathways, leaving farmers vulnerable to middleman exploitation and market volatility.

5. DISCUSSION

5.1 The Quiet Revolution and Its Limits

The study documents a gradual transformation from traditional to mechanized farming in Sokoto State, with technical efficiency improving from 0.828 in 2000 to 0.937 in 2025. However, this quiet revolution remains incomplete and unevenly distributed. The reliance on external inputs and the potential erosion of traditional knowledge pose risks to long-term agricultural resilience. Mechanization reduces the "drudgery" of farming and attracts youth, but without complementary investments in education, extension, and social services, the sustainability of these practices is uncertain.

The evolution of farming practices in Sokoto State reflects a significant transformation driven largely by farmers themselves, but institutional support has lagged. The transition to mechanized farming shows promising results, but the sustainability of these practices depends on addressing the structural constraints identified in this study.

5.2 Comparative Efficiency in African Context

The mean technical efficiency of 0.8935 places Sokoto garlic farmers above the Nigerian average of 0.59 reported in cross-country comparisons (RIMISP, 2024) and comparable to Ghana's 0.70 upper bound. This relatively high efficiency reflects the commercial orientation of garlic production, the concentrated geographic niche, and the long history of cultivation in the Sokoto-Rima basin. However, the 10.65% efficiency gap still represents substantial unrealized potential, particularly among the 12.7% of farmers operating below 0.70 efficiency.

The comparison with international garlic studies is instructive: Pakistan's 0.77 (Hussain et al., 2014), Ethiopia's 0.73 (Chekol et al., 2023), and Indonesia's 0.71 (Science Horizon, 2024) all fall below Sokoto's mean, suggesting that Nigerian garlic farmers are relatively efficient in global terms.

However, this comparative advantage is threatened by climate change, macroeconomic instability, and institutional neglect.

5.3 Policy Implications

The findings support five priority policy interventions:

First, extension service intensification. The large efficiency impact of extension contacts (-0.1567) suggests high returns to investment in agricultural advisory services. The Sokoto State Ministry of Agriculture's Fadama development projects should be scaled, with dedicated garlic extension pathways and farmer field schools.

Second, irrigation infrastructure. Water constraints are the most severe production bottleneck (*mean 3.75/5.0*). Investment in small-scale irrigation, water harvesting, and efficient water-use technologies is critical for sustaining dry-season garlic production as water tables recede.

Third, credit market development. The low credit access (27.4%) and significant inefficiency reduction (0.0892) indicate substantial unmet demand. Innovative instruments — warehouse receipt systems, contract farming, and digital credit scoring — could overcome collateral constraints.

Fourth, education and human capital. Education's efficiency impact (-0.0456) supports investments in rural schooling, adult literacy, and farmer training. The integration of agricultural content into basic education curricula could build long-term capacity.

Fifth, market infrastructure. Road improvement, market information systems, and cold-chain development would reduce post-harvest losses and price volatility, enhancing farmer incentives and efficiency.

5.4 The Fuel Subsidy Removal Challenge

The 2023 fuel subsidy removal represents a structural shock with lasting implications. The negative coefficient (-0.1234) confirms significant output reduction, as increased pumping costs reduce irrigation intensity and mechanization. Policy responses must include targeted fuel subsidies for agricultural use, solar-powered irrigation alternatives, and efficiency-enhancing measures that enable "doing more with less."

6. CONCLUSION

This study has examined the socio-economic determinants and technical efficiency of garlic production in Sokoto State, Nigeria, using a stochastic frontier approach with $46,800$ monthly observations from 2000 to 2025. The findings reveal a mean technical efficiency of 0.8935 , with significant variation across LGAs and substantial scope for improvement. The production frontier is significantly influenced by conventional inputs, while inefficiency is systematically determined by education, extension contact, credit access, cooperative membership, and infrastructure quality.

The quiet revolution in Sokoto's garlic sector the transition from traditional to mechanized farming has yielded efficiency gains, but these remain vulnerable to climate shocks, macroeconomic instability, and institutional neglect. The 2023 fuel subsidy removal has exacerbated production costs, making technical efficiency the critical metric for survival. Post-harvest losses of 23.5% and severe water and credit constraints undermine the sector's potential contribution to employment generation, poverty reduction, and foreign exchange earnings.

The study concludes that unlocking the full developmental impact of garlic production requires deliberate, coordinated interventions in extension services, irrigation infrastructure, credit markets, education, and market linkages. These investments would enable farmers to operate closer to their production frontier, transforming garlic from a subsistence crop to a sustainable driver of rural transformation and inclusive growth in Nigeria's semi-arid northwest.

Future research should examine the meta-frontier efficiency of garlic production across different Agro-ecological zones in Nigeria, the impact of climate-smart agricultural practices on long-term sustainability, and the potential of digital platforms to overcome information and market access constraints.

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