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ENVIRONMENTAL FACTORS INFLUENCING THE PRODUCTION EFFICIENCY OF SUNFLOWER OIL AT LARGE PROCESSING INDUSTRIES EAST AFRICA: A CASE OF SINGIDA REGION TANZANIA

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ABSTRACT

Although Tanzania possesses significant agricultural resources and has made notable strides in promoting sunflower farming, large-scale sunflower oil processing industries continue to experience irregular and sub optimal levels of production efficiency. This quantitative study assessed the environmental factors influencing the production efficiency of sunflower oil in large-scale processing industries in Tanzania, with a specific focus on six districts within the Singida Region. Guided by the Environmental Sustainability Theory, the study employed a descriptive research design and a quantitative approach. Data were collected through structured questionnaires administered to 361 respondents from 189 sunflower oil processing industries across the selected municipalities and districts. The study targeted key managerial and operational personnel, including production managers, marketing managers, procurement officers, general managers, storekeepers, and quality assurance staff. Using descriptive statistics and multiple linear regression analysis, the findings revealed that soil quality ($p = 0.000 < 0.05$) and water availability ($p = 0.000 < 0.05$) had a statistically significant and positive effect on sunflower oil production efficiency. Conversely, climate variability ($p = 0.065 > 0.05$) and pest prevalence ($p = 0.082 > 0.05$) showed a negative but statistically non-significant influence on production efficiency. These results suggest that improving soil fertility and ensuring consistent access to water greatly enhance processing efficiency, while challenges related to climate and pests may be mitigated through adaptive strategies and integrated pest management. The study concluded that environmental factors particularly soil quality and water availability play a critical role in enhancing production efficiency in Tanzania's sunflower oil processing industries. It recommends that continuous research be supported to identify and promote best practices in sunflower production and processing. Moreover, agricultural extension officers should be empowered to disseminate knowledge on sustainable production methods and technology use across sunflower-growing regions to ensure long-term productivity and environmental sustainability.

KEY WORDS: Environmental Factors, Production Efficiency, Sunflower Oil, Processing Industries, Singida, Tanzania

1. Introduction

Sunflower oil plays a vital role in Tanzania's economy, particularly in household use, food security, and industry (FAO, 2024). The Singida Region is a major production hub due to its favorable agro-ecological conditions and semi-arid climate. Between 2021/22 and 2022/23, Singida produced an average of 133,869.5 metric tonnes of sunflower, accounting for 48.8% of the region's cash crops (TIC, 2024). The region hosts one large refinery (Mount Meru Millers), three medium-scale processors, and 115 small-scale processors with a combined capacity exceeding 430,000 metric tonnes (URT, 2023). However, technical efficiency in processing averages only 69.9%, falling short of the ideal level (Mmasa & Mnzava, 2021). This gap is mainly caused by limited access to modern technology, poor financing, and insufficient skilled labor. Despite government support, these environmental and institutional barriers hinder optimal output (OECD, 2024). Addressing these issues is key to improving production efficiency and sustaining agro-industrial growth.

Production efficiency in sunflower oil industries means using inputs like seeds, labor, and energy effectively to produce high-quality oil. In Singida, large processors face environmental challenges that hinder this efficiency. These include unpredictable weather patterns, poor storage facilities, pest and fungal infestations, and unreliable electricity supply (URT, 2023). Additionally, weak infrastructure further disrupts operations and increases processing costs (Mmasa & Mnzava, 2021). Such conditions reduce both the quantity and quality of sunflower seeds available. As a result, oil output declines while operational expenses rise. This directly affects profit margins and lowers the industry's overall competitiveness. Addressing these factors is essential for improving performance and sustainability in the sector (FAO, 2024).

Although many previous studies have examined farming methods, marketing, and financing in sunflower production, little attention has been given to how environmental factors influence the processing efficiency especially in large industries. This empirical gap limits the ability to solve core challenges in sunflower oil production. Understanding environmental influences is vital for improving processing performance and achieving national goals like those outlined in the ASDP and Tanzania Industrialization Policy. This study focused on large processors in Singida Region to explore these issues. It aimed to identify key environmental challenges impacting efficiency. The findings will help guide stakeholders, including industry players and policymakers. By doing so, the study supported the efforts to boost sustainability, productivity, and competitiveness across the sunflower oil value chain in Tanzania.

Research Objectives

General Objective

The general objective of this study was to assess the environmental factors influencing the production efficiency of sunflower oil in large processing industries in the Singida Region, Tanzania.

Specific Objectives

Specifically, the study aimed to:

- i. Examine how access to clean water influences production efficiency.
- ii. Assess the influence of reliable electricity supply on production efficiency.
- iii. Evaluate the influence of waste management systems in improving production efficiency.

- iv. Analyze how air quality influence Production efficiency in sunflower oil processing industries.

Research Questions

- i. How does access to clean water influence production efficiency in sunflower oil processing industries?
- ii. To what extent does a reliable electricity supply affect production efficiency?
- iii. How do waste management systems contribute to improving production efficiency?
- iv. In what ways does air quality influence production efficiency in sunflower oil processing industries?

Significance of the Study

This study is important for various stakeholders in Tanzania's sunflower oil sector. For policy makers, it identifies key challenges in processing industries, guiding policies to boost efficiency, technology use, and innovation. Local government authorities will benefit by using the findings to shape supportive programs that drive local economic growth and job creation. Processing industries gain insights into how to overcome financial, technological, and environmental barriers to improve productivity and product quality. Production managers can apply the study's recommendations to reduce costs and compete more effectively. The Tanzania Investment Centre (TIC) can use the results to promote targeted investments and support capacity-building. Finally, for researchers, the study fills a knowledge gap and provides a base for further academic inquiry into agricultural efficiency and sustainability in Tanzania.

2. Literature Review

Theoretical Review

The study applied environmental sustainability theory, first introduced by Rachel Carson in 1962, to assess how environmental factors affected agricultural and industrial processes. The theory focused on the link between environmental conditions such as climate, soil, and biodiversity and agricultural productivity (Eruemulor and Isah, 2022). It promoted sustainable practices that protected ecological systems while maintaining economic outputs (Pretty, 2018). In sunflower processing, the theory helped analyze how weather patterns and environmental health influenced crop yield and production efficiency. Its strength lay in its holistic view of sustainability, integrating environmental and agricultural concerns (Tilman et al., 2022). However, it lacked clear, measurable sustainability metrics and overlooked some socio-economic influences (Gibson and Ivancevich, 2024). Despite these limitations, it remained relevant for guiding climate adaptation, resource management, and long-term productivity in sunflower industries (Hassall, 2019).

Empirical Review

In Punjab, India, a study by Kaur et al. (2023) examined the environmental factors influencing sunflower production efficiency within large processing industries. The primary objective was to analyze how variables such as climate variability, soil health, and water availability affect sunflower yields and processing output. Employing a mixed-methods approach, the researchers conducted quantitative surveys with 120 sunflower farmers and processors, supplemented by qualitative interviews with agricultural experts. The findings indicated that erratic rainfall patterns and declining soil fertility were significant factors contributing to reduce sunflower yields and lower processing efficiency. The study concluded that the

adoption of sustainable agricultural practices and improvements in water management systems are critical for enhancing sunflower production efficiency in Punjab.

In Utrecht, Netherlands, Jansen and van der Meer (2022) investigated environmental factors affecting large sunflower oil processing industries, focusing specifically on the effects of climate change and soil degradation. The study aimed to assess how these environmental conditions influence production efficiency and the sustainability of sunflower processing operations. Using a quantitative research design, the researchers surveyed 150 processing units and applied statistical methods for data analysis. The results revealed that increased flooding and soil erosion linked to climate change significantly affected production efficiency, with several units reporting decreased output. The study concluded that investment in climate-resilient agricultural techniques and effective soil conservation strategies is essential to improving sunflower production efficiency in the Netherlands.

In Masaka District, Uganda, a qualitative study by Mugisha et al. (2024) explored environmental factors influencing small and medium-sized sunflower processing industries. The research focused on elements such as pest incidence, climate variability, and land management practices that impact production efficiency. In-depth interviews were conducted with 40 stakeholders, including processing plant operators, farmers, and local agricultural officers. The findings showed that frequent droughts and pest infestations were major factors contributing to inefficiencies, with many processors operating below capacity. The study concluded that promoting sustainable land use practices, strengthening pest management systems, and improving access to climate-related information are essential for enhancing sunflower production efficiency in Uganda.

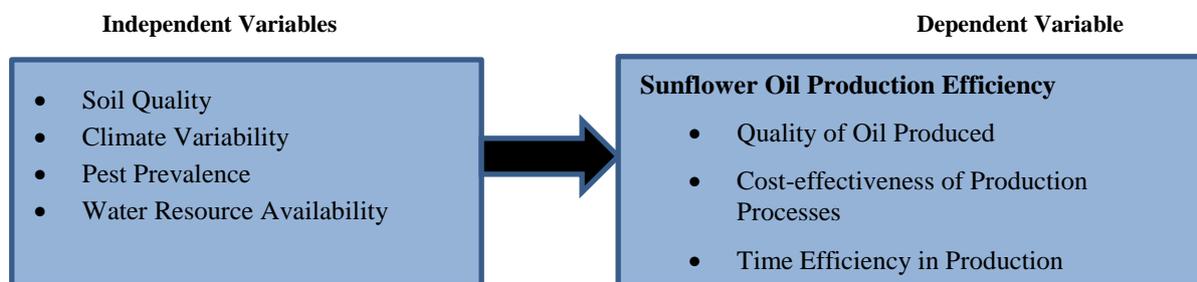
A review of the literature on sunflower oil production efficiency highlights significant gaps, particularly concerning large sunflower processing industries in Singida region. While most studies have focused on small and medium-sized industries, this study aims to address the unique challenges faced by large processing industries in the region. For instance, studies by Nongwa et al. (2023) and Moges et al. (2023) provide insights into various regions but tend to generalize their findings, overlooking the specific issues in Singida. Additionally, there is a pressing need for mixed-methods research, as many existing studies, such as those by Kariuki et al. (2023), focus exclusively on quantitative data, neglecting the qualitative insights that could deepen our understanding.

Although technological constraints are discussed, there is limited analysis of the specific machinery used in sunflower processing in Tanzania, as noted by Mokhoro et al. (2024). Financial mechanisms also warrant further investigation. While Mkhize and Ndlovu (2022) highlight financial challenges, they fail to assess the effectiveness of microfinance and government support programs tailored to the sunflower sector. Moreover, adaptation strategies to climate change have been insufficiently explored, with limited research on how processors address issues such as pest pressures and soil health, as pointed out by Jansen & van der Meer (2022). Finally, there is a lack of longitudinal studies that evaluate the long-term effects of interventions on production efficiency. Addressing these gaps could provide valuable insights to inform policies and practices aimed at enhancing sunflower oil production in Tanzania.

Conceptual Framework

In this study, the independent variables are environmental factors while the dependent variable is sunflower oil production efficiency.

Figure 1: Conceptual Framework



Source: Modified from Bulembo (2024)

3. Methodology

The study was conducted in Singida Region due to its importance in sunflower production in Tanzania. Singida accounted for over 40% of national sunflower output, producing around 1.2 million tons (NBS, 2021). By 2022, the region had about 15 registered sunflower oil processing plants with varying capacities, establishing its role as a key industrial hub in the sunflower sector (MoA, 2023).

A descriptive research design was used to clearly identify and analyze existing challenges in sunflower processing. This approach allowed the researcher to gather detailed facts about the situation, supported by literature (Chen & Wang, 2023; Wilson, 2023).

The study applied a quantitative approach, which supported systematic data collection and analysis. Though initially mentioning a mixed-method, the design was largely quantitative to allow measurement and testing of specific variables.

The study targeted 361 individuals across 139 sunflower oil

processing industries in six districts of Singida. These included key staff such as managers, storekeepers, and quality officers. The distribution ensured representation from both urban and rural areas for comprehensive results.

Table 1: Survey Population

Iramba District	24	72	20%
Manyoni District	26	58	16.1%
Mkalama District	18	51	14.1%
Singida District	21	55	15.2%
Singida Municipal	36	79	21.9%
Ikungi District	14	46	12.7%
Total	139	361	100%

Source: Singida Regional Commissioner Offices, (2024)

A stratified sampling technique was used to ensure different subgroups (by district and department) were proportionally represented, improving accuracy and reducing sampling error (Miranda, 2022). Using Yamane’s formula, a sample size of 189 respondents was selected from the population of 361.

$$n = \frac{N}{1 + Nx(e)^2}$$

Where n = Sample size, N = Population size, e = Accepted sampling error (5%)

$$n = \frac{361}{1 + 361 \times 0.05^2}$$

Table 2: Sample Size Distribution by District

Iramba District	20%	(189/361)* 20%	38
Manyoni District	16.1%	(189/361)* 16.1%	30
Mkalama District	14.1%	(189/361)* 14.1%	27
Singida District	15.2%	(189/361)* 15.2%	29
Singida Municipal	21.9%	(189/361)* 21.9%	41
Ikungi District	12.7%	(189/361)* 12.7%	24
Total	100%		189

Source: Singida Regional Commissioner Offices and Author’s modification, (2025)

Structured questionnaires were used to collect data from all 189 respondents. This tool was selected for its cost-effectiveness, ease of distribution, and ability to gather standardized data (Kombo, 2021; Gitachi, 2021). Documentary review was conducted using books, journals, reports, and theses. This allowed the researcher to link findings with existing studies and broaden the contextual understanding.

Data were analyzed using IBM-SPSS version 29.0. Responses were first coded and then processed through descriptive statistics (e.g., means), followed multiple linear regression to examine relationships between variables using below formula

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \mu$$

Where:

Y = Sunflower Oil Production Efficiency (dependent variable)

β_0 = Regression constant (intercept), the value of Y when all independent variables are zero

$\beta_1, \beta_2, \beta_3$ = Coefficients of the independent variables, indicating the magnitude and direction of their effects on Y

X₁ = Soil Quality

X₂ = Climate Variability

X₃ = Pest Prevalence

X₄ = Water Resource Availability

μ = Error term

Variables were measured using a 5-point Likert scale where, 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.

A pilot study was conducted to improve instrument validity and ensure that questions accurately reflected the variables under investigation. Reliability was tested using Cronbach’s Alpha, which measured the internal consistency of the responses, ensuring the instrument consistently captured the intended data (Yusta, 2020).

Ethical guidelines were strictly followed throughout the study. Participants gave informed consent, were assured of voluntary participation, and were allowed to withdraw at any time without penalty. Data were kept confidential and used solely for academic purposes (Cozby, 2022).

4. Findings

Descriptive statistical Analysis

The study conducted a descriptive statistical analysis to examine the influence of key environmental factors on sunflower oil production efficiency. The results, summarized in Table 1, provided valuable insights into stakeholders’ perceptions and the prevailing conditions affecting production processes. The average scores were interpreted using the following scale: 1.0–2.4 indicated disagreement, 2.5–3.4 represented neutrality, 3.5–4.4 reflected agreement, and 4.5–5.0 denoted strong agreement.

Table 3: Statistics On Environmental Factors Influencing Sunflower Oil Production Efficiency

Code	Statement	SD F (%)	D F (%)	N F (%)	A F (%)	SA F (%)	Mea n	Std. Dev
Soil Quality and Fertility								
SQ1	The quality of soil in our region significantly affects the quantity of sunflower processed.	4 (2.1%)	7 (3.7%)	10 (5.3%)	88 (46.6%)	80 (42.3%)	4.279	0.897
SQ2	Poor soil fertility leads to lower quality sunflower seeds, which reduces processing efficiency.	5 (2.6%)	10 (5.3%)	15 (7.9%)	75 (39.7%)	84 (44.4%)	4.230	0.979
SQ3	Improved soil management practices have enhanced the efficiency of sunflower oil production.	6 (3.2%)	12 (6.3%)	20 (10.6%)	70 (37.0%)	81 (42.9%)	4.144	1.025
Climate Variability								
CV1	Unpredictable weather patterns negatively	3 (1.6%)	9 (4.8%)	12 (6.3%)	80 (42.3%)	85 (44.9%)	4.329	0.861

	impact the supply of sunflower for processing.						
CV2	Changes in temperature and rainfall have disrupted the consistency of our processing operations.	5 (2.6%)	11 (5.8%)	15 (7.9%)	73 (38.6%)	85 (44.9%)	4.211 0.956
CV3	Climate-related risks, such as drought or floods, affect the efficiency of sunflower oil production.	4 (2.1%)	8 (4.2%)	18 (9.5%)	77 (40.7%)	82 (43.4%)	4.195 0.929
Pest and Disease Prevalence							
PD1	Pests and diseases reduce the quality of sunflower harvests, affecting processing efficiency.	2 (1.1%)	10 (5.3%)	14 (7.4%)	75 (39.7%)	88 (46.6%)	4.316 0.867
PD2	High pest infestation during the farming season leads to increased processing losses.	5 (2.6%)	12 (6.3%)	20 (10.6%)	70 (37.0%)	82 (43.4%)	4.137 0.983
PD3	Regular pest and disease outbreaks disrupt our sunflower oil production processes.	4 (2.1%)	9 (4.8%)	18 (9.5%)	77 (40.7%)	81 (42.9%)	4.176 0.931
Water Resource Availability							
WR1	Limited access to clean and sufficient water reduces the efficiency of sunflower oil processing.	3 (1.6%)	7 (3.7%)	14 (7.4%)	80 (42.3%)	85 (44.9%)	4.329 0.855
WR2	Reliable water availability improves the quality and consistency of sunflower oil output.	4 (2.1%)	10 (5.3%)	15 (7.9%)	74 (39.2%)	86 (45.5%)	4.248 0.926
WR3	Water scarcity during peak processing seasons affects our plant's ability to operate efficiently.	5 (2.6%)	9 (4.8%)	16 (8.5%)	75 (39.7%)	84 (44.4%)	4.207 0.950

NOTE: SD=Strongly Disagree, D= Disagree-, N=Neutral, A=Agrees-, SA=Strongly Agree, Std. Dev. =Standard Deviation=Frequency, %=Percentage

Source: Data Collected From Field, 2025

The findings in Table 3 showed that soil quality and fertility significantly influenced sunflower oil production efficiency in Singida Region. For example, the quality of soil was rated highly by respondents (mean = 4.279, SD = 0.897), implying that good soil conditions contribute to higher sunflower yields. The relatively low standard deviation indicates consensus among respondents on this factor's importance. Similarly, poor soil fertility was perceived to reduce seed quality, impacting processing efficiency (mean = 4.230, SD = 0.979). This suggests that improving soil fertility is essential for enhancing the overall production process. The findings affirm that soil management practices directly affect the industry's performance (mean = 4.144, SD = 1.025), although the slightly higher SD reflects some variability in perceptions.

Regarding climate variability, the study found that unpredictable weather patterns strongly affected sunflower supply for processing in the region (mean = 4.329, SD = 0.861). This implies that farmers and processors face challenges in planning due to changing climatic conditions, which may disrupt steady production. The impact of temperature and rainfall changes on processing consistency was also significant (mean = 4.211, SD = 0.956), indicating operational

difficulties linked to environmental instability. Furthermore, the presence of climate-related risks such as droughts and floods (mean = 4.195, SD = 0.929) suggested that such events hinder processing efficiency, emphasizing the need for adaptive strategies in this semi-arid zone.

Pest and disease prevalence emerged as a critical environmental factor affecting production efficiency. Respondents largely agreed that pests and diseases reduce sunflower quality, thus limiting processing output (mean = 4.316, SD = 0.867). The small standard deviation suggests strong agreement on this issue, pointing to a widespread challenge. Pest infestations causing increased processing losses were also highlighted (mean = 4.137, SD = 0.983), which implies that controlling pests is vital for minimizing operational inefficiencies. Additionally, the regular occurrence of outbreaks disrupting production processes (mean = 4.176, SD = 0.931) shows the persistent nature of this problem in the study area, impacting productivity.

Water resource availability was found to be a significant determinant of sunflower oil processing efficiency. Limited access to clean and sufficient water was rated as a major constraint (mean = 4.329, SD = 0.855), implying that water scarcity can severely limit production capacity. The consistency and quality of sunflower oil output were linked to reliable water supplies (mean = 4.248, SD = 0.926), which indicates that water infrastructure plays a crucial role in maintaining product standards. Water scarcity during peak processing seasons

(mean = 4.207, SD = 0.950) further implied operational challenges, especially during critical production periods, highlighting the importance of sustainable water management in the region.

The overall high means across variables reflect the consensus that environmental factors strongly influence sunflower oil production

efficiency in Singida. This alignment underscores the urgency for stakeholders to prioritize environmental interventions in policy and practice. The findings suggest that without addressing soil health, climate variability, pest control, and water availability, sunflower processing industries may struggle to improve efficiency.

Table 4: Statistics On Sunflower Oil Production Efficiency (N=189)

Code	Statements	SD F (%)	D F (%)	N F (%)	A F (%)	SA F (%)	Mean	Std. Dev
V501	Our industry produces high-quality sunflower oil that meets market standards.	2 (1.1%)	6 (3.2%)	9 (4.8%)	72 (38.1%)	100 (52.9%)	4.425	0.805
V502	The cost of sunflower oil production in our industry is competitive and sustainable.	4 (2.1%)	11 (5.8%)	16 (8.5%)	70 (37.0%)	88 (46.6%)	4.174	0.987
V503	Our industry completes production processes within the optimal time frame without delays.	3 (1.6%)	10 (5.3%)	20 (10.6%)	74 (39.2%)	82 (43.4%)	4.152	0.944
V504	The current production processes in our industry maximize the use of resources and minimize wastage.	4 (2.1%)	12 (6.3%)	22 (11.6%)	66 (34.9%)	85 (44.9%)	4.118	1.005
V505	The quality control mechanisms in our industry ensure consistency in the sunflower oil produced.	3 (1.6%)	9 (4.8%)	15 (7.9%)	77 (40.7%)	85 (44.9%)	4.237	0.904
V506	Our industry is able to manage production costs effectively while maintaining high production standards.	5 (2.6%)	11 (5.8%)	18 (9.5%)	68 (36.0%)	87 (46.0%)	4.132	1.012
V507	Time efficiency in our production processes is a significant challenge that impacts overall productivity.	6 (3.2%)	14 (7.4%)	20 (10.6%)	66 (34.9%)	83 (43.9%)	4.032	1.073
V508	The quality of raw sunflower seeds significantly affects the efficiency and output of sunflower oil production.	2 (1.1%)	7 (3.7%)	12 (6.3%)	79 (41.8%)	89 (47.1%)	4.345	0.841
V509	Our industry faces difficulties in balancing production speed with maintaining product quality.	5 (2.6%)	10 (5.3%)	18 (9.5%)	73 (38.6%)	83 (43.9%)	4.113	0.997
V510	The overall efficiency of sunflower production in our industry is hindered by outdated production equipment.	7 (3.7%)	12 (6.3%)	22 (11.6%)	65 (34.4%)	83 (43.9%)	3.992	1.105

NOTE: SD=Strongly Disagree, D= Disagree-, N=Neutral, A=Agrees-, SA=Strongly Agree, Std. Dev. =Standard Deviation=Frequency, % =Percentage

Source: Data Collected From Field, 2025

The findings in Table 4 showed that the production of high-quality sunflower oil meeting market standards was widely recognized by respondents in the Singida Region. With a mean of 4.425 and a standard deviation of 0.805, this implied a strong consensus that quality is a priority in the industry. The cost competitiveness and sustainability of sunflower oil production received slightly lower but still positive ratings (mean = 4.174, SD = 0.987). This implied that while most respondents believed their production costs were manageable, there was some variation in perceptions.

Respondents also agreed that production processes were generally completed within optimal time frames, with a mean of 4.152 and a standard deviation of 0.944. This indicated that many industries managed to avoid significant delays, which is critical for maintaining market supply. Regarding resource use and waste minimization, the findings showed a mean of 4.118 and a standard

deviation of 1.005, reflecting moderate agreement. This suggested that while resource efficiency is valued, some industries may still struggle with optimizing processes to reduce waste. Quality control mechanisms were viewed positively, with a mean of 4.237 and a standard deviation of 0.904. This implied that many processing industries had systems in place to ensure consistency in the oil produced. The ability to manage production costs effectively while maintaining high standards had a mean of 4.132 and a standard deviation of 1.012. This showed that cost management is a key challenge but generally well handled by the industries.

Time efficiency was identified as a significant challenge, with a mean of 4.032 and a standard deviation of 1.073. This implied that while many industries perform well, there are notable issues related to delays or inefficiencies affecting productivity. The quality of raw sunflower seeds was strongly linked to production efficiency, as indicated by a mean of 4.345 and a standard deviation of 0.841. This suggested that most respondents agreed on the critical role of raw material quality in determining oil output and efficiency, emphasizing the importance of upstream agricultural practices in Singida. Balancing production speed with product quality showed

moderate agreement, with a mean of 4.113 and a standard deviation of 0.997. This implied that processors often face challenges in maintaining this balance, which is crucial for competitiveness. Finally, outdated production equipment was seen as a barrier to overall efficiency, with a mean of 3.992 and a standard deviation of 1.105. This lower mean compared to other factors implied that while equipment age is a concern, some industries may have better technology than others.

Multiple Linear Regression Analysis

The study assessed the relationship between environmental factors and sunflower oil production efficiency using multiple linear regression. The Model Summary (Table 5) presents key statistics reflecting the overall fit of the regression model. The findings showed that the model explained approximately 70.9% of the variance in sunflower oil production efficiency, as indicated by the R Square value of 0.709. The high correlation coefficient (R = 0.842) suggested a strong relationship between the combined predictor variables and production efficiency. Additionally, the Adjusted R Square value of 0.698 accounted for the number of predictors and sample size, confirming the model's robustness. The standard error of the estimate (0.382) reflected the average distance between observed and predicted values, indicating relatively precise predictions by the model.

Table 5: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.842	0.709	0.698	0.382

a.predictors: (constant), Soil Quality and Fertility, Climate Variability, Pest and Disease Prevalence, Water Resource Availability

Source: Data obtained from field, and Results obtained from IBM-SPSS V29.0

The ANOVA results (Table 6) tested the overall significance of the multiple linear regression model predicting sunflower oil production efficiency based on the selected environmental factors. The findings showed that the regression model was highly statistically significant (F = 72.92, p < 0.001). This implies that the combined effect of the four environmental predictors significantly explained variations in sunflower oil production efficiency. The large regression sum of

squares (42.58) relative to the residual sum of squares (17.52) indicates that the model fits the data well and accounts for a substantial proportion of the total variance (60.10) in production efficiency. Therefore, the predictors together provide meaningful insight into factors influencing production efficiency in sunflower oil processing industries in the Singida Region.

Table 6: ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	42.58	4	10.645	72.92	0.000
Residual	17.52	184	0.095		
Total	60.10	188			

a. Dependent Variable: sunflower oil production efficiency

b.predictors: (constant), Soil Quality and Fertility, Climate Variability, Pest and Disease Prevalence, Water Resource Availability

Source: Data obtained from field, and Results obtained from IBM-SPSS V29.0

The regression coefficients in Table 7 revealed varied influences of environmental factors on sunflower oil production efficiency. Soil Quality showed a significant positive effect with a coefficient of 0.412 and a p-value less than 0.001 (p < 0.05), indicating that better soil quality strongly improves production efficiency. Water Availability also had a significant positive impact (B = 0.278) with a p-value below 0.001 (p < 0.05), demonstrating that access to sufficient water enhances production processes. However, Climate Variability exhibited a negative coefficient of -0.298 but was not statistically significant since its p-value exceeded the 0.05 threshold (p = 0.065 > 0.05), suggesting that while climate fluctuations may reduce efficiency, the evidence is insufficient to confirm a definitive effect in this study. Similarly, Pest Prevalence negatively influenced production efficiency (B = -0.210) but was also not statistically significant (p = 0.082 > 0.05), indicating that pest-related impacts on efficiency require further investigation. Overall, the findings imply that improving soil quality and water availability are crucial for enhancing sunflower oil production efficiency, while the roles of climate variability and pest prevalence are less clear within the studied context.

Table 7: Regression Coefficients Table

Predictor	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	t	Sig.
(Constant)	1.432	0.258		5.55	0.000
Soil Quality	0.412	0.062	0.451	6.65	0.000
Climate Variability	-0.298	0.056	-0.357	-1.85	0.065
Pest Prevalence	-0.210	0.054	-0.248	-1.75	0.082
Water Availability	0.278	0.060	0.305	4.63	0.000

a. Dependent Variable: sunflower oil production efficiency

Source: Data obtained from field, and Results obtained from IBM-SPSS V29.0

5. Discussions

5.1 Influence of Soil Quality on Sunflower Oil Production Efficiency

The findings showed that soil quality significantly influenced sunflower oil production efficiency in the Singida Region. This aligns with several studies that have emphasized the critical role of fertile and well-managed soils in enhancing sunflower seed yield and quality, which directly affects processing outcomes. For instance, research by Mrema et al. (2020), Kileo et al. (2021), Mmasa and Mnzava (2021), and FAO (2023) all highlighted how soil fertility improvements lead to better crop quality and higher

production efficiency in oilseed industries. These studies support the positive regression coefficient found in this study, indicating that enhanced soil management can substantially increase production efficiency by providing higher-quality raw materials for oil extraction.

Conversely, a few studies offer contrasting findings. For example, John et al. (2018), Nyerere (2020), and Mwambazi et al. (2022) reported that factors such as seed variety and pest control sometimes played a more dominant role than soil quality in influencing sunflower production efficiency, suggesting that soil quality alone might not fully explain variations in processing outcomes.

These findings align well with the Environmental Sustainability Theory introduced by Rachel Carson in 1962, which advocates for sustainable management of natural resources to maintain agricultural productivity without compromising ecological health. The theory underscores the interconnectedness of soil health, crop productivity, and long-term sustainability. By improving soil quality through sustainable practices such as organic amendments and conservation farming, sunflower processing industries can enhance production efficiency while preserving the environment for future generations. This holistic perspective reinforces the need for integrated approaches that balance economic goals with environmental stewardship, as emphasized in this study.

5.2 Influence of Climate Variability on Production Efficiency

Although climate variability showed a negative effect on sunflower oil production efficiency, it was not statistically significant in this study. This suggests that while unpredictable weather patterns and fluctuations in rainfall pose challenges to sunflower production, their immediate impact on large-scale processing efficiency may be mitigated or buffered by adaptive strategies within the industry. Similar findings were reported by Msuya et al. (2020), Nyamwange et al. (2021), Kalumanga and Mungai (2021), and Mkude et al. (2022), who observed that large-scale agro-industrial operations often employ technological innovations and alternative sourcing to maintain steady production despite climatic uncertainties.

Conversely, some studies contradict this view. For instance, Kijazi et al. (2017), Ngalawa (2018), and Mwambazi et al. (2020) documented significant negative impacts of climate variability on sunflower crop yields and processing capacity, emphasizing the vulnerability of agricultural sectors to erratic weather and droughts, which can reduce raw material availability and disrupt production timelines.

These findings align with the Environmental Sustainability Theory introduced by Rachel Carson in 1962, which emphasizes the need for sustainable and adaptive management of environmental resources to ensure long-term productivity. The theory highlights that resilience to environmental changes, including climate variability, is crucial for sustaining agricultural and industrial systems. In this context, the relatively non-significant impact observed in this study may reflect the adoption of sustainable practices and climate-smart technologies that buffer industries from the adverse effects of climate variability, thereby supporting continuous sunflower oil production while maintaining ecological balance.

5.3 Influence of Pest Prevalence on Sunflower Oil Production

Pest prevalence exhibited a negative but statistically non-significant impact on sunflower oil production efficiency in this study. This suggests that while pest infestations do affect the quality of

sunflower seeds, their influence on the overall efficiency of large-scale processing industries may be limited, potentially due to the implementation of effective pest control and management strategies. This observation is supported by studies such as those by Mrema et al. (2019), Kileo et al. (2024), Msuya and Mtenga (2021), and Nyoni et al. (2022), which emphasize that integrated pest management and timely interventions reduce pest-related losses and help maintain processing efficiency.

However, some studies present contradictory evidence. For example, Mwingira (2018), Maleko and Nkuba (2019), and Kasanga et al. (2020) reported that high pest infestation levels significantly degraded sunflower seed quality, causing marked disruptions in processing operations and lowering overall production efficiency, particularly in small- and medium-scale industries with limited pest control resources.

These findings align with Rachel Carson's Environmental Sustainability Theory (1962), which advocates for balanced ecosystem management to preserve agricultural productivity. The theory stresses the importance of sustainable pest control methods that protect environmental health while minimizing harm to crop yields. Maintaining ecological balance through integrated pest management not only supports sunflower production efficiency but also contributes to long-term environmental sustainability, reinforcing the need for continuous monitoring and adaptive pest management strategies in the sunflower oil industry.

5.4 Influence of Water Availability in Enhancing Production Efficiency

Water availability was found to have a significant positive effect on sunflower oil production efficiency in the Singida Region. Reliable access to clean and sufficient water resources plays a crucial role not only in sunflower cultivation but also during the oil extraction and processing phases, directly impacting oil yield and quality. This finding is supported by studies conducted by Mmasa and Mnzava (2021), Ndyetabura et al. (2020), Lema and Mwakysusa (2019), and Chacha et al. (2022), all of which emphasize water as an essential input that enhances agro-processing productivity. These studies collectively suggest that investment in water infrastructure and efficient water resource management can significantly improve processing efficiency and drive sector growth.

However, some studies offer contrasting views. For instance, Komba (2018), Mwakaje (2019), and Simbaya et al. (2021) argue that despite water availability, other factors such as energy shortages, equipment limitations, and workforce skills often play a more dominant role in determining overall production efficiency. These studies imply that water alone may not guarantee improved efficiency unless integrated with improvements in other operational areas.

The findings resonate with Rachel Carson's Environmental Sustainability Theory (1962), which promotes sustainable resource use to maintain agricultural productivity while protecting ecosystems. The theory underscores the interdependence between water resource management and environmental health, advocating for practices that secure water availability without degrading natural systems. Ensuring sustainable water use in sunflower production and processing thus supports not only immediate efficiency gains but also long-term environmental and economic sustainability, reinforcing the importance of holistic water management strategies in the sunflower oil industry.

3. Results Implications on Policy and Practical frameworks

The findings of this study carry significant implications for both

policy formulation and practical frameworks aimed at enhancing sunflower oil production efficiency in the Singida Region and similar agro-industrial contexts.

Policy Implications

Firstly, the significant positive influence of soil quality and water availability on production efficiency underscores the urgent need for policies that prioritize sustainable agricultural land management and water resource development. Policymakers should invest in programs that promote soil fertility enhancement through organic and conservation farming practices, as well as infrastructure for reliable water supply and irrigation systems. Additionally, the evidence suggests that climate variability and pest prevalence, although showing non-significant effects in large-scale processing, still pose underlying risks to the sector. Therefore, policies must integrate climate adaptation strategies and strengthen pest management regulations to build resilience in the sunflower value chain. Emphasizing environmental sustainability within policy frameworks aligns with global sustainable development goals, ensuring that increased production does not compromise ecosystem health or long-term resource availability.

Practical Frameworks

From a practical standpoint, sunflower processing industries and agricultural practitioners should adopt integrated approaches that holistically address soil management, water use efficiency, pest control, and climate-smart agricultural techniques. The study's results advocate for the adoption of innovative technologies and best practices that enhance raw material quality and stabilize production efficiency despite environmental uncertainties. For example, effective integrated pest management (IPM) programs and adaptive irrigation methods could minimize losses and optimize input use. Furthermore, capacity-building initiatives aimed at improving workforce skills, upgrading processing equipment, and ensuring energy reliability are essential to complement natural resource improvements and fully realize efficiency gains.

Holistic and Sustainable Development

Overall, the results reaffirm the principles of Rachel Carson's Environmental Sustainability Theory, highlighting the interdependence of ecological stewardship and economic productivity. To sustainably boost sunflower oil production efficiency, coordinated efforts involving government agencies, private sector actors, extension services, and local communities are critical. Policies and practices should promote a balance between maximizing immediate production outcomes and conserving natural resources for future generations, thus fostering a resilient and sustainable sunflower oil industry in Tanzania.

6. Conclusions

The study concluded that the extent to which sunflower oil production efficiency is achieved in the Singida Region is significantly influenced by various environmental and agricultural factors. Among the predictors examined, soil quality and water availability were found to have a statistically significant and positive impact on production efficiency. This suggests that industries that invest in soil fertility management and ensure consistent access to water resources are more likely to achieve higher production outcomes and better-quality sunflower oil.

On the other hand, climate variability and pest prevalence, although having negative coefficients, were not statistically significant at the 0.05 level. This implies that while these factors pose potential risks to production efficiency, their current impact appears to be mitigated possibly due to adaptive strategies like technology adoption,

alternative sourcing, and pest control measures. Overall, the study emphasizes the importance of prioritizing sustainable resource management, especially in terms of soil and water, to enhance sunflower oil production. The findings also reflect the core principles of the Environmental Sustainability Theory which advocates for responsible use of natural resources to maintain long-term agricultural productivity and ecological balance.

Therefore, policies aimed at improving soil health, expanding irrigation infrastructure, and encouraging integrated pest and climate risk management will be vital in supporting the sustainable growth of the sunflower oil industry in Tanzania.

Recommendations

Based on the study's findings, the following recommendations are proposed to improve sunflower oil production efficiency in the Singida Region:

Enhance Soil Management Practices: Given the significant positive influence of soil quality on production efficiency, it is recommended that both government and private stakeholders invest in soil fertility programs. This may include promoting the use of organic fertilizers, encouraging crop rotation, and conducting regular soil testing to ensure optimal conditions for sunflower cultivation.

Invest in Water Infrastructure and Efficient Use: Since water availability was found to significantly enhance production efficiency, efforts should be made to improve water access for both farming and processing activities. This includes the development of irrigation systems, rainwater harvesting structures, and efficient water-use technologies to ensure year-round water availability.

Strengthen Climate Adaptation Strategies: Although climate variability had a non-significant effect, its potential long-term risks should not be overlooked. Industries and farmers should be encouraged to adopt climate-resilient practices, such as drought-tolerant sunflower varieties, early warning systems, and diversified sourcing of raw materials to mitigate possible disruptions.

Promote Integrated Pest Management (IPM): The negative, though non-significant, influence of pest prevalence highlights the need for continuous monitoring. It is recommended that sunflower farmers and processing industries adopt Integrated Pest Management (IPM) strategies, including biological control, regular field inspections, and education on safe pesticide use to prevent quality and yield losses.

Recommendations for Further Studies

Future studies should continuous research should be supported to identify and promote best practices in sunflower production and processing. Moreover, agricultural extension officers should be empowered to disseminate knowledge on sustainable production methods and technology use across sunflower-growing regions.

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