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Determinants of Technical Efficiency in Pixie Production in Makueni County, Kenya

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Abstract: The purpose of the study was to determine the farm technical efficiency in pixie farming in Makueni County, Kenya and the factors which influence the technical efficiency. The specific objectives of the study were: determination of technical efficiency in pixie production, examination of how socio-economic characteristics affect the technical efficiency in pixie production, and determination of how the adoption of sustainable agricultural technologies influence the technical efficiency in pixie production. Primary data was collected where questionnaires and interview schedule were adopted to obtain information from a sample of 311 pixie farmers through both purposive and simple random sampling technique. Non-experimental cross sectional research design was adopted. Generalized linear regression model and stochastic frontier model were used. The study results found that the mean technical efficiency was 75%. There only existed a 25% potential towards realization of optimum output by the average farmer. Different socio-economic characteristics of the farmers were found to influence technical efficiency among the pixie farmers. Maximum likelihood estimates of technical efficiency derived from the stochastic frontier production function results indicated that use of fertilizer, manure and labour contributed to increased productivity. The adopters of the different sustainable agricultural technologies had higher technical efficiencies than the non-adopters. The study recommends young farmers be encouraged in the practice of pixie farming to help in realization of high pixie output. The government should: Put in place measures to increase credit access to farmers, harmonize the repayment time of the loans and design strategies in place for the pixie farmers to be educated on the need of adopting the sustainable agricultural technologies and how to use them in order to reduce the big gap in their productivity levels.

Keywords: Adoption, Sustainable Agricultural Technologies, Technical Efficiency, Stochastic Frontier Model

1. Introduction

The pixie fruits were developed in 1927 by H. B. Frost of the university of California citrus research center and released in 1965. California and Florida are the main pixie growing regions in the United States, with the highest production being realized in California, in the Ojai valley [1]. In Africa, the main pixie growing countries are: South Africa, Egypt, Nigeria, Kenya and Morocco. Pixie production in Kenya is mainly practiced in the arid and semi-arid regions of Makueni, Machakos, Kitui, Baringo and the coastal regions of Kwale and Kilifi. Pixie fruits are in the horticulture sector, with the sectors' value of the marketed produce being 146.1 billion [2]. Mature pixie fruits realize output between 60-300 kgs. With proper management, the fruit bearing begins in the second year after grafting has been done. However, they reach their maturity after almost seven years. In Kenya, the fruits thrive well in regions with altitude of up to 2100 M above the sea level, experiencing low to moderate rainfall. High temperatures create an environment favourable for the ripening of the fruits. The production of the fruits plays a crucial role in income generation, eradication of poverty and creation of employment opportunities among the residents. They have a potential of generating up to 18 percent of the farmers' average household income [3]. However, despite the contribution of the fruits, productivity realized by the farmers is not at the optimum level. Various challenges to increased productivity are encountered. They include: pests and diseases, expensive inputs, inaccessibility to credit facilities, erratic weather patterns & lack/poor agricultural extension services. The constraints have created an environment viable for underproduction of pixie in the county. Given the County's high potential for the production of the fruits, with a potential of 13,482 Kgs/Ha, the average of most of the small-scale farmers in the County is between 4,000-10,000 Kgs/Ha [4]. To help address the low productivity in the area, the agriculture sector has been entitled with the responsibility of curbing the low production. Some of the strategies developed include zoning of the County on the basis of agro-ecological suitability. Pixie, in the class of citrus fruits, thrive well in the middle zone. Zoning is crucial as it helps enhance increased agricultural productivity, agro-processing and value addition by matching an area with the most suitable crop. Mumbuni, Wote and Nzaui are the main growing areas in Makueni County with production being mainly for commercial purposes. The County government of Makueni has developed strategies to help ensure that the County sells itself through the agriculture sector by developing the fruit niche. They include the creation and establishment of certified seedling nurseries and the strengthening of the provision of extension services in the fruit growing areas. Through the measures, production of pixie fruits will increase [5]. In addition, the pixie farmers in the County are encouraged to adopt the sustainable agricultural technologies. They are the different approaches utilized by farmers in the face of climate change to help address the low productivity levels/increase farmers' income, while at the same time reducing the adverse human and environmental impacts of agricultural production. Through the adoption of these technologies, intensification in pixie production in the County will be realized. Given the main requirement for increased pixie productivity (water, chemical pesticides and manure), adoption of the different sustainable agricultural technologies is key. Several technologies such as soil and water conservation techniques, irrigation and integrated pest management techniques are crucial in pixie farming to lower the gap between the average and potential production levels among the farmers [6]. The adoption of the soil and water conservation techniques will help in conservation of water by ensuring moisture retention in the soil and prevention of water run-off which reduces soil erosion; thus efficiency [7]. The IPM techniques, on the other hand, help in avoidance of environmental pollution while at the same time reducing the use of chemical pesticides towards achievement of increased productivity.

Table 1. *Citrus acreage, production and value in Makueni County.*

Year	2017	2018	2019	2020	2021
Acreage (Ha)	6,564	6,570	6,650	8,371	8,660
Production (MT)	38,963	38,963	39,985	202,728	192,335
Value 000'	974,087	974,107	974,150	4,777,700	2,493,125

Source: Department of Agriculture, Irrigation, Livestock, Fisheries & Cooperative Development, County Government of Makueni

The area under pixie production increased from 622-2,296 Ha in 2018. The production of citrus has experienced a rapid growth over the precious years, despite the decline from 202,728 MT in 2020 to 192,335 MT in 2021.

Ministry of agriculture data indicates the number of households growing citrus to be 27,006, with the estimate of pixie households being 30 percent. With Makueni County being an arid and semi-arid region, the pixie trees are prone to attack by pests and diseases as thrip insurgence is very high. Failure to control them well wipes away the high production. Lack/poor access to information amongst the farmers on the type of chemical pesticides to apply in the fruits and the timing of production further contributes to the decline in production. To help address this, there is need for agronomists and extension officers to provide adequate and useful information on the best chemical pesticides to apply and at what stage to apply. The current extension to staff ratio nationally is 1:1,000 whereas at the county level 1:2,000 [8]. The extension to staff ratio hinders dissemination of crucial information on the production inputs to apply, chemical pesticides to use and the best agricultural practices to apply in the farms. High pixie production can be realized through optimum use of the production inputs. With inefficiencies already existing in the production of the fruits, the implication is the need for examination of technical efficiency in pixie production. Given that productivity can be increased through increasing the inputs used in production, determination of technical efficiency makes is possible for comparison of the performance of the farmers to determine the causes of inefficiency. Technical efficiency is given as a ratio of observed output to the maximum potential output which is realized from the given inputs and at the current technological level [9]. Increment of the farmers efficiency levels increases their output without requiring additional inputs and new technologies. The farmer demographic characteristics can further cause inefficiencies in pixie production.

Despite the relevance attached on the agriculture sector through the sale of fruits to contribute to the Gross County Product (GCP), no study in the County has been conducted on technical efficiency in pixie production. This was despite several studies on technical efficiency on citrus being conducted in other countries. The technical efficiency changes with time to time and in different regions. This calls for the need for the study to determine the current productivity levels of pixie in the County [10]. The objective of the study was thus to determine the level of technical efficiency in pixie production and identify the factors which influence technical efficiency.

2. Theoretical Framework

Frisch R. (1964) is the proponent of the production theory and the theory is a microeconomic theory which focuses on production of goods from a given set of inputs. The production theory provides a framework for efficiency studies. The theory focuses on output production at least cost possible, while technical efficiency is concerned with maximization of output for a given set of inputs [11]. Best utilization of production inputs in the production process leads to realization of maximum output, and thus technical efficiency. With the production theory and technical efficiency requiring no change in technology creates the justification why the production theory is suitable for the study. The production function represents the technology of production and specifies how inputs cooperate to produce particular output level. The general form of a production function for a farm using "n" inputs is:

$$q = f(X_1, X_2, X_3, \ldots\ldots, X_n) \quad (1)$$

Where;

q=output level

$X_1, X_2, X_3, \ldots\ldots, X_n$ represent the inputs used to produce output

The theory of production makes it possible to describe those farms operating efficiently and those operating inefficiently [12]. A technically efficient farm is a farm operating through the use of various production input without requiring an additional unit of inputs in comparison to another. The farm using more inputs in the production process is termed as technically inefficient. The theory of production, thus, focuses on efficiency of production and describes the relationship between inputs and output. The production function is of relevance as it makes it possible for transformation of inputs into output. The theory helps in elimination of inefficiencies in pixie production. To explain the production theory, C. W. Cobb and P. H. Douglas used the Cobb-Douglas production function theory which shows the relationship between inputs and output. The general form of the function is expressed as:

$$Q = AL^{\alpha}K^{\beta} \quad (2)$$

Where; L is labour quantity, K is quantity of capital and A, , and β are positive constants. A represents the state of the technology used and is the efficiency parameter. It measures the output change not caused by the inputs. On the other hand, and β represents the distribution parameters which show the output change caused by change in labour and capital respectively. The general equation for the Cobb-Douglas production function can be treated as a linear relationship by transforming it into logarithmic form for estimation purposes. Thus, the modified equation is;

$$\log Q = \log A + \alpha \log L + \beta \log K \quad (3)$$

The theory is of great essence in the study of technical efficiency as estimation of the production function is easy, despite the premise of constant elasticity of substitution which limits the production function. A Cobb-Douglas Stochastic Frontier Approach model was used with the study's focus on the technical efficiency of pixie production. The proponents of the SFA method are Aigner, Lovell and Schmidt (1977) and Van Den Broeck (1977). The approach is suitable given that technical efficiency is affected by random factors beyond the control of the farmer. Due to the inclusion of a random error term and an individual inefficiency term, it differs from other parametric methods [13]. The assumption made by the model is that a single output is produced due to production technology constraints. The general form of the stochastic production function is expressed as:

$$y_j = f(x_i\beta).\exp(v_j).TE_j \quad (4)$$

Where: y_j is pixie output, $f(x_i\beta).\exp(v_j)$ represents the stochastic production frontier, $\exp(v_j)$ is the random shocks, which are beyond the farmer's control & TE_j represents the technical efficiency of the j[th] farmer. To estimate the technical efficiency, the stochastic frontier approach requires the specification of functional form and distributional assumptions (Ruggiero, 1999). Comparison of actual with the frontier output was done to determine the technical efficiency. Thus, technical efficiency was determined using the formula:

$$TE_j = \frac{y_j}{f(x_i\beta).\exp(v_j)} \quad (5)$$

Where; TE_j represent the technical efficiency of the j[th] household, y_j is the actual pixie output of the j[th] household while $f(x_i\beta).\exp(v_j)$ is the frontier output of the j[th] household in pixie farming.

3. Materials and Methods

3.1. Study Area

Makueni County is located in the Eastern part of the country. Makueni county lies between Latitude 1° 35' and 2° 59' South and Longitude 37° 10' and 38° 30' East. The County boarders Kitui to the east, Machakos to the north, Kajiado to the west and Taita Taveta to the south. The County has nine Sub Counties namely: Makueni, Kathonzweni, Mbooni East, Mbooni west, Nzaui, Mukaa, Kilungu, Makindu and Kibwezi. The County has a population of 987,653 persons [14]. Out of this, 489,691 are male, 497,942 female and 20 are intersex. The average population density in the County is 120.8 persons/km^2. The county experiences a bimodal rainfall pattern, with arid and semi-arid climate conditions. Short rains are experienced from October to December while the long rains from March to May. The average temperature in the County ranges between 15°C – 26°C and Annual rainfall ranges between 250mm to 400mm per annum on the lower regions of the county and the higher region receives rainfall ranging from 800mm to 900mm. the County relies on agriculture as the main economic activity. The County has been zoned in to three production systems/zones: upper, middle and lower zones where different agricultural commodities are grown in those zones. The climatic conditions of the middle zone favour horticulture. The main horticultural crops are vegetables and fruits which are grown for both local and export market. The fruits include; mangoes, avocadoes, citrus, pawpaw, banana and watermelon.

3.2. Sampling Procedure and Sample Size

Both purposive and simple random sampling techniques were employed. Makueni and Nzaui Sub Counties were purposively selected due to their production of pixie for commercial purposes. In addition, they are located in the middle zone which is favourable for citrus production. Then, simple random technique was used in selection of a sample of 311 pixie households. The sample was derived through the use of Fischer's formula by Kothari, C. R. [15] as shown by the following mathematical formula:

$$n_0 = \frac{z^2(p)(q)}{E^2} \quad (6)$$

Where; n_0 is the sample size, z=1.96 which is the tabulated z value for 95% confidence level, p is the assumed proportion of residents who farm pixie, q is the assumed proportion of residents who do not farm pixie and E is the margin of error. With the assumption of 30% probability that the households have the measured characteristics, the sample size was determined as shown below:

$$n_0 = \frac{1.96^2(0.3)(1-0.3)}{0.05^2} = 323 \quad (7)$$

The equation for finite population correction proportions was used in correction of infinite sample size to a finite sample as shown below: The equation for finite population correction proportions was used in correction of infinite sample size to a finite sample as shown below:

$$n = \frac{n_0}{1+\frac{(n_0-1)}{N}} \quad (8)$$

Where; n is the sample size and N is the population size. The final sample was thus determined as shown in the equation below:

$$n = \frac{323}{1+\frac{(323-1)}{8102}} = 311 \quad (9)$$

3.3. Model Specification

The stochastic frontier production was used in measurement of technical efficiency in pixie production in Makueni County. The Cobb-Douglas stochastic frontier approach was applied, despite the drawbacks associated with it such as the constant returns to scale and elasticity of production being equal to one. In addition, the multicollinearity and the degree of freedom problems associated with the trans log function made the Cobb-Douglas production more superior. The Cobb-Douglas production function is effective at handling multicollinearity, heteroscedasticity, and correlation as well as holding multiple input modeling [16]. The function is specified as:

$$ln\, Y_j = \beta_0 + \sum \beta_{ij}\, ln\, X_{ij} + e_j \quad (10)$$

Where: ln-The natural logarithm, j - j^{th} farmer in the sample size, i - i^{th} input, Y_j-Output of pixie production of the j^{th} farmer, Xij-ith input used by the j^{th} farmer and e_j=$V_j - U_j$-Its error term, taking into consideration of two components

For accuracy, the parameter coefficients of β_i were obtained through single-stage maximum likelihood estimator method. In order to estimate the technical inefficiency or efficiency of pixie production among the small-scale farmers in the study area, a Cobb-Douglas production function was fitted. The pixie output per household in kilograms per hectare (Kgs/ha) was the dependent variable, and the pixie production inputs served as the predictor variables. The production inputs used were: quality of seedlings, amount of manure, amount of fertilizer, the total labour force and chemical pesticides used. The function was in the form:

$$ln\, Y = \beta_0 + \sum_{i=1}^{5} \beta_j\, ln\, X_{ij} + V_j - U_j \quad (11)$$

V_j is the two-sided error term, while U_j is the one-sided error term/the technical inefficiency. From the Cobb-Douglas stochastic frontier model, the technical efficiency was determined using the following equation:

$$TE_j = {Y_j}/{Y_j *} \quad (12)$$

Where; TE_j is the technical efficiency of the jth household in pixie production, Y_j is the actual output of the jth household and $Y_j *$ is the frontier output of the jth household in pixie production. The technical efficiency derived from the stochastic frontier model is fitted in the regression model as the dependent variable to find the effect of the socio-economic characteristics and adoption of sustainable agricultural technologies on technical efficiency. The linear function of the socio-economic and management factors helps in determination of the effect of the independent variables on the technical efficiency. The original equation incorporates the effect of the socio-economic characteristics on technical efficiency. The equation is expressed as shown below:

$$TE = \delta_0 + \sum_{k=1}^{7} \delta_k Z_{kj} \quad (13)$$

Where: TE is technical efficiency effect, δ_k represents the independent variable coefficients and Z_j are the characteristics of the socio-economic variables of the farm explaining the technical efficiency of the jth farmer. From the function, we have the parameter coefficients which are used to explain the relationship between the socio-economic farmer characteristics and technical efficiency. For the purposes of incorporating the effect of adoption of the sustainable agricultural technologies on technical efficiency, the regression equation with the effect of socio-economic characteristics on technical efficiency is modified to capture the sustainable agricultural technologies. The sustainable agricultural technologies included in the model are: irrigation, integrated pest management techniques and soil and water management. They were converted into dummy variables for both adopters and non-adopters for purposes of fitting them in the model. The modified equation is thus expressed as shown below:

$$TE = \delta_0 + \sum_{k=1}^{7} \delta_k Z_{kj} + \sum_{l=1}^{3} \alpha\, m_j \quad (14)$$

Where: α represents the predictor variable coefficients and

m_j are the sustainable agricultural technologies adopted by the j^{th} pixie farmer.

4. Results and Discussions

4.1. Descriptive Results on Socio-Economic and Demographic Characteristics of the Farmers

Descriptive results on the demographic and socio-economic characteristics of the pixie households displayed on Table 2 revealed that the mean household size was 4.66, with the minimum number of the household being 1 and a maximum of 8. The mean almost conformed to the county's average household size of 4.0 [14]. The minimum distance of the farm from home was 0.1 kilometers while the maximum distance of the farm from home being 20 kilometers. Much focus was expected in farms near home as compared to those far away from home as no costs would be spent in movement to the farm. A lot of time would be spent in caring for the farms near home. The minimum area under pixie production was 0.5 hectares and the maximum area being 8 hectares. The mean average area under production was 1.86, indicating production was mostly in small-scale. Resource constraints and growing population could be causes for the low acreage under pixie production amongst the farmers. The minimum output in Kgs/Ha from the households was 1,500 while the maximum being 12,780. The mean output in kgs/ha was 5,051.76 kgs and the standard deviation 2,288.221 kgs. The results indicated that both male and female were involved in pixie farming. Majority of the respondents were male: accounting for 78.1% while only 21.9% were female. Women involvement in various off-the farm responsibilities could be a reason why many men are involved in pixie farming as opposed to women. In addition, traditional land tenure system and resource constraints which hinder women from having access to land could be another reason. Both the youth and elderly are involved in pixie farming. 18.3% of the respondents were in the age group 21-30 years while 13.8% were 51 years and above. Majority of the respondents were in the age group 41-50 years; where they comprised 35.7%. The youth are more adaptive to change as opposed to the elderly farmers who are receptive to change. They have more chances of adopting the new technologies in agriculture. Education level of the pixie farmers was another indicator for efficiency in production. 7.4% of the study respondents lacked formal education while 29.6% of the respondents had attained university education. Majority of the respondents had secondary education level; who accounted for 35.7% of the respondents. Majority of the pixie farmers derived their income from agricultural activities (50.2%) while the remaining 49.8% had other sources of income other than agricultural activities. Diversification is crucial in farming as risks are spread out and income earned from other sources can be invested in agricultural activities. On credit access, only 46% of the respondents had access to formal credit facilities. 54% of the pixie farmers lacked credit access. With credit access, the pixie farmers are in a position to obtain credit for the purchase of production inputs required in pixie farming. The high percentage of the pixie farmers who lacked access to credit could have had the implication that pixie farmers who needed credit to purchase the production inputs were unable to have credit access.

Table 2. *Demographic and socio-economic characteristics of the study respondents.*

Variable	Minimum	Mean	Std Dev.	Maximum
Household size	1	4.66	0.093	8
Distance of the farm from home (kms)	0.1	3.26	3.414	20
Total area under pixie production (Ha)	0.5	1.86	1.353	8
Quantity of Pixie in Kgs/Ha	1500	5051.76	2288.221	12780
	Category		Frequency	Percentage
Gender of respondents	Male		243	78.1
	Female		68	21.9
Age of the respondents	21-30 years		57	18.3
	31-40 years		100	32.2
	41-50 years		111	35.7
	51 years & above		43	13.8
Education level	None		23	7.4
	Primary		22	7.1
	Secondary		111	35.7
	College		63	20.3
	University		92	29.6
Source of income	Farming		156	50.2
	Business person		62	19.9
	Employment income		93	29.9
Credit access	Yes		143	46.0
	No		168	54.0

Source: Authors computation 2023

4.2. Parametric Estimates of the Stochastic Production Function

Maximum likelihood estimation procedure was used in the estimation of the stochastic frontier model and the results revealed in Table 3. The stochastic frontier model was used to explain the effects of production inputs on pixie production in Makueni County. One-stage estimation procedure provided the parameter estimates of the predictor variables impacting pixie productivity. From the five variables considered in the stochastic production function, three of them (fertilizer, manure and labour) were found to be crucial determinants of pixie production in the study area. The three production inputs had positive coefficients and found to be significant at 99% confidence level. Increase in the use of the inputs would increase the pixie output among the farmers. From the results, 1% increase in labour use increases the pixie output by 0.342%. A 1%increase in the amount of fertilizer used in pixie farming increases the pixie output by 0.015%. In addition, 1% increase in the amount of manure applied in pixie farming increases the pixie output by 0.346%. The study findings are in line with the theory of production and consistent with the findings by [17] whose findings revealed that citrus farmers did not maximize their output. The value of lambda (λ) is 1.825 and it indicates that 1.825% difference between actual and potential output is attributed to inefficiency among the respondents.

Table 3. *Parametric estimates of the stochastic production function.*

Ln harvest	Coefficient	Std. Err.	z	P>z	[95% conf. interval]	
Ln seedling	0.016	0.023	0.680	0.495	-0.061	0.030
Ln man hours	0.342	0.039	8.820	0.000	0.266	0.418
Ln manure	0.346	0.060	5.780	0.000	0.229	0.463
Ln fertilizer	0.015	0.008	1.950	0.052	-0.000	0.030
Ln pesticide	0.036	0.024	1.500	0.134	-0.083	0.011
constant	7.817	0.217	35.970	0.000	7.391	8.243
Sigma u	0.400	0.040	9.930	0.000	0.328	0.487
Sigma v	0.219	0.021	10.290	0.000	0.181	0.265
lambda	1.825	0.057	32.270	0.000	1.715	1.936

Source: Authors computation 2023

4.3. The Effect of Socio-Economic Characteristics and Adoption of Sustainable Agricultural Technologies on Technical Efficiency

To explain the effects of socio-economic farmer characteristics and adoption of sustainable agricultural technologies on technical efficiency, generalized linear model was fitted as shown in Table 4. Socio-economic characteristics such as off-farm income, extension services, gender of the respondents, education level and credit access were considered in the study. On the other hand, the sustainable agricultural technologies included in the study were irrigation, integrated pest management and soil and water management techniques. Off-farm income was a dummy variable. Pixie farmers whose income source was from agricultural activities were the base group while those with other sources of income were the other category. The findings indicated a significant difference in terms of technical efficiency between having other income sources and those whose income source was from agricultural activities only. Pixie farmers who had other sources of income apart from agricultural activities were found to have had higher technical efficiency as compared to those whose only income source was from agricultural activities. The implication is that having various income sources is crucial in increasing the technical efficiency of pixie farmers (p-value<0.001). This creates the need to encourage the pixie farmers to diversify in other income generating activities. Diversification is crucial as it enables the pixie farmers to use the income generated from the other streams to reinvest in agriculture. Given adoption of sustainable agricultural technologies is costly and the production inputs are expensive, having multiple sources of income enables the pixie farmers to purchase the pixie production inputs and adopt the best practices in pixie farming. The findings contradict findings by [18] who found negative relationship between off-farm income and technical efficiency. The implication was that pixie farmers with other sources of income had lower technical efficiency as compared to pixie farmers whose source of income was only from agricultural activities.

There were pixie farmers who had received extension services and those who never received extension services. Pixie farmers who had received extension services were found to have had a difference in terms of technical efficiency as opposed to the pixie farmers who never received extension services. Extension services is an important determinant of technical efficiency (p-value=0.039). Pixie farmers who had received extension services had higher technical efficiency as opposed to those who never received the extension services. With extension services provided by the extension officers, the pixie farmers are equipped with knowledge on the best practices to adopt in pixie farming. They are also educated on the best chemical pesticides to apply on the fruits and the timing of application; which are crucial towards realization of optimum yield. The results concur with the findings by [19] who found the technical efficiency of sugarcane farmers who had received extension services higher than that of those who had not received the extension services. This illustrated the importance of extension services in agriculture.

Gender of the respondents is a dummy variable and the study findings found a difference in technical efficiency between female and male pixie farmers. The female pixie farmers were found to have had a higher technical efficiency as compared to male pixie farmers. Openness in adopting sustainable agricultural technologies among the women could be one of the reasons for higher technical efficiency among the women. Given the constraints women face in ownership of resources such as land in most of the developing economies, they make them utilize the limited resources in an optimum way to realize higher output as opposed to men. The findings are in agreement with the research findings by [20] whose results indicated female farmers to have had higher technical efficiency as opposed to male farmers. The findings, however, contradicted to the research findings by the authors [21, 22] whose findings revealed that male farmers were more efficient as compared to female farmers. Age is a categorical variable and for purposes of converting it to fit in the regression model, it was converted it into a dummy variable. Farmers within the age group of 21-30 years were the base group. The findings revealed a significant difference in terms of technical efficiency between pixie farmers in the age group 31-40 years and those in the age group 21-30 years (p-value<0.001). Pixie farmers within the age group 31-40 years had a higher technical efficiency as opposed to those in the reference category. The pixie farmers in this age group have been exposed to a wide depth of information on the best practices to adopt in pixie farming. They are open to adopting new technologies as compared to older farmers. The findings also revealed a difference in technical efficiency between pixie farmers within the age group 41-50 years and those in the base group. However, the difference was declining (p-value=0.062). Older pixie farmers above 51 years were found not to have had a statistically significant difference in terms of technical efficiency in comparison with pixie farmers in the age group 21-30 years. The lack of statistical and significant difference in terms of efficiency could have been attributed to the reason that older farmers are more receptive to change. This makes them fail to adopt the sustainable agricultural technologies; hence lower technical efficiency. The study results are consistent with the findings by [19] whose findings revealed older farmers to have had lower efficiencies as compared to younger farmers.

With education level being categorical, it was converted in to a dummy variable with those who never went to school forming the base group. The findings revealed a significant difference in terms of efficiency between pixie farmers who had attained primary education level from those who had no education level. With primary education, the pixie farmers have the basic knowledge on the best practices to apply on pixie farming. They were found to have had a higher technical efficiency as compared to that of those who had no education. There was no significance difference for the pixie farmers with secondary, college and university education as compared to those with no education. This could have been attributed to the reason that they practice digital agriculture due to their engagement in formal employment opportunities, thus creating engaging those who never went to school or those with primary education to take care of the farms. Credit access is dummy variable. Farmers who lacked credit access were the base category and having credit access was found to be crucial in enhancing pixie productivity. The pixie farmers who had credit access were found to have had higher technical efficiency as opposed to those who never had credit access. With credit access, the farmers could borrow credit to use it for purchase of production inputs and costly sustainable agricultural technologies. The results are in agreement with the findings by [19] who found sugarcane farmers with credit access to have had a higher efficiency compared to those without credit access.

Irrigation was one of the sustainable agricultural technologies considered in the study. The findings revealed a significant difference in technical efficiency between the adopters of irrigation and non-adopters of irrigation. Pixie farmers who adopted the sustainable agricultural technologies had higher technical efficiency as opposed to those who never adopted irrigation. Adoption of irrigation in pixie farming is crucial towards increment in pixie productivity in the County. With the County being an arid and semi-arid region, the insufficient rainfalls experienced have an impact on the quality and quantity of pixie output realized. They cause the fruits to fall off during flowering stage, thus reduced productivity. Irrigation helps the pixie trees maintain their fruits up to their maturity. Thus, high yield is realized. Adopters of integrated pest management techniques were found to have had higher technical efficiency as opposed to the non-adopters. IPM adoption helps in reduction of the overreliance on the use of chemical pesticides; thus, reduction in the costs incurred in the purchase of chemical pesticides. They help in reduction of the adverse environmental concerns. The study results are consistent with the findings by [23] whose findings revealed adoption of IPM techniques to have contributed to higher efficiency as compared to non-adoption. There is a difference in terms of technical efficiency between soil and water management adoption and soil and water management non-adoption (p-value=0.001). There exist different soil and water management techniques such as planting of cover crops, mulching, water harvesting, terracing etc. Adoption of the soil and water management techniques is expected to contribute to higher efficiency. However, the study findings found the soil and water management techniques to have contributed to lower efficiency. The study findings contradict findings by [24] who found soil and water management techniques to have contributed to higher efficiency.

Table 4. *Generalized linear model of the socio-economic factors and sustainable agricultural technologies on T. E.*

Technical Efficiency	**Coef.**	**St. Err**	**t-value**	**p-value**	**[95% Conf**	**Interval**	**Sig**
Socio-economic characteristics							
Other Sources of Income	.082	.014	5.78	0.000	.054	.11	***

Technical Efficiency	Coef.	St. Err	t-value	p-value	[95% Conf	Interval	Sig
Extension	.033	.020	1.63	0.039	-.007	.072	**
Gender: Female	.053	.014	3.68	0.000	.025	.081	***
Aged 31-40 years	.099	.021	4.62	0.000	.057	.141	***
Aged 41-50 years	.045	.024	1.87	0.062	-.002	.093	*
Aged 51 years and above	.039	.031	1.25	0.211	-.022	.101	
Primary	.074	.024	3.10	0.002	.027	.121	***
Secondary	.004	.023	-0.15	0.877	-.048	.041	
College	.038	.033	-1.16	0.248	-.102	.026	
University	.045	.029	1.54	0.125	-.012	.102	
Credit	.035	.018	1.96	0.046	.000	.07	**
Sustainable agricultural technologies							
Irrigation	.011	.019	0.61	0.045	-.025	.048	**
IPM	.088	.020	4.52	0.000	.052	.125	***
Soil and Water	-.055	.028	-1.98	0.001	-.109	-.000	***
Constant	.595	.035	16.82	0.000	.526	.665	***

*** p<.01, ** p<.05, * p<.1

Source: Authors computation 2023

4.4. Technical Efficiency

The mean technical efficiency among the pixie farmers was 75%. The implication is that the average pixie farmer has a potential of increasing pixie productivity by 25% if he/she utilizes the resources in an optimum way. The lowest efficient farmer was operating at 35.9% efficiency level while the maximum efficient farmer operated at 94.2% technical efficiency. If the resources were utilized well, there only existed a 5.8% potential of increasing the productivity level for the most efficient pixie farmer to be efficient.

Table 5. *Mean technical efficiency.*

Variable	Obs	Mean	Std. Dev.	Min	Max
efficiency	308	.75	.12	.359	.942

Source: Authors computation 2023

The technical efficiency range among the pixie farmers was computed. The study findings revealed that only 2.6% of the respondents operated in the efficiency range 0.25 < to < 0.50. 40.3% of the pixie farmers sampled were in the efficiency range 0.50 < to < 0.75 while majority (57.1%) of the respondents operated in the efficiency range 0.75 < to < 1.00. Majority of the pixie farmers operated at an efficiency level greater than 75%.

Table 6. *Frequency distribution of technical efficiency.*

Technical efficiency	N	%
0.25 < to < 0.50	8	2.6
0.50 < to < 0.75	124	40.3
0.75 < to < 1.00	176	57.1
Total	308	100.0

Source: Authors computation 2023

Technical efficiency from adoption of sustainable agricultural technologies

Technical efficiency was computed for the farmers who had adopted the sustainable agricultural technologies and shown in Table 7. The mean technical efficiency realized by irrigation adopters was 77.1% while non-adopters had a mean technical efficiency of 73.8%. The second sustainable agricultural technology was the use of integrated pest management where the mean technical efficiency of the adopters was 76.1% while for the non-adopters was 72%. The last sustainable agricultural technology reviewed was the use of soil and water management techniques. For the farmers who used the techniques, the mean technical efficiency realized was 75.2% while the mean technical efficiency for the non-adopters of the soil and water management techniques was 73.7%. Therefore, the findings revealed that adoption of the sustainable agricultural technologies reviewed contributed to higher technical efficiency as adopters had higher technical efficiencies compared to the non-adopters.

Table 7. *Technical efficiency from adoption of sustainable agricultural technologies.*

Irrigation	Mean	SD	Min	Max
Yes	0.771	0.088	0.549	0.942
No	0.738	0.134	0.359	0.939
Integrated pest management				
Yes	0.761	0.099	0.513	0.921
No	0.72	0.160	0.359	0.942
Soil & water management				
Yes	0.752	0.122	0.359	0.942
No	0.737	0.109	0.546	0.915

Source: Authors computation 2023

5. Conclusion

Several studies on technical efficiency of agricultural commodities have been conducted in the country. With the productivity of various agricultural commodities changing from time to time, there was the need for the study. This would help in the understanding of the current productivity level of pixie in Makueni County and in determination of whether the pixie farmers were efficient or not efficient. The study was conducted to determine the technical efficiency in pixie farming in Makueni County and identify the factors that affect technical efficiency among the pixie farmers. The mean technical efficiency was 75% which was high as there only existed a 25% potential towards attainment of technical efficiency. The efficiency scores of the farmers ranged from 35.9% up to 94.2%. The socio-economic characteristics of the farmer were found crucial towards increased technical efficiency in pixie production. Off-farm income, extension services, gender of the farmers, age, education level (primary), and credit access were found to have had significant effect on the technical efficiency in pixie farming. Thus, the essence for farmers' understanding of the different socio-economic and demographic characteristics. The production inputs were also found crucial towards increased pixie productivity as fertilizer, manure and labour were found to positively and significantly impact the pixie output. Thus, creating the essence of optimum utilization of the production inputs to benefit from increased productivity. Three sustainable agricultural technologies (irrigation, integrated pest management and soil and water management techniques) were considered in the study. The findings revealed that adoption of the three sustainable agricultural technologies were important as they contributed to higher technical efficiencies as opposed to those realized by the non-adopters of the technologies. Adopters of irrigation in pixie farms had a mean technical efficiency of 77.1% while those who never adopted realized a mean technical efficiency of 73.8%. The second sustainable agricultural technology was integrated pest management where the adopters had a technical efficiency of 76.1% and non-adopters had a technical efficiency of 72%. Lastly, adopters of soil and water management techniques realized a mean technical efficiency of 75.2% while the non-adopters had a mean technical efficiency of 73.7%. From the three sustainable agricultural technologies, adoption of irrigation had the highest mean technical efficiency.

6. Recommendations

Farmers need to be educated on the best utilization of the production inputs to benefit from increased productivity. They should be educated on the type of fertilizers to apply, the methods of application and the quantity to be applied. Moreover, they should be educated on the benefits of manure application to boost pixie productivity. Extension officers should provide crucial information to the farmers on the best practices to apply in their farms, but not with the motives of making profits. Given higher technical efficiency realized by the pixie farmers with other sources of income, the farmers need to be encouraged to diversify into other income generating activities and use the income earned from those activities to re-invest in agricultural activities. With adoption of sustainable agricultural technologies being costly and the production inputs expensive to purchase, pixie farmers with other income generating streams could use the income generated from them to make investments in agriculture. Given the significant difference in terms of efficiency between female and male pixie farmers, there is need for gender inclusivity in agricultural policies. This would help ensure that agricultural policies promoting equal opportunities to both male and female pixie farmers are developed. Any gender-based obstacles hindering male pixie farmers from achieving high technical efficiencies should be addressed. Young farmers need to be encouraged to practice agriculture as a business as opposed to agriculture as a dirty profession and one to be practiced by the elderly. They are more open to technology adoption as opposed to older farmers who are receptive to change.

Having credit access was found to have a positive and significant effect in influencing technical efficiency among the pixie farmers. Despite the importance of credit in influencing technical efficiency, majority of the respondents lacked formal access to credit. Only 45.81% of the respondents had formal access to credit. The lack of access of formal credit could be an indicator of resource constraints with the farmers who lacked credit access finding it a challenge to have access to the production inputs used in pixie production. The adoption of the sustainable agricultural technologies is a challenge, since adoption of such technologies is costly. Thus, the government of Kenya and County government should intervene to help ensure farmers have access to affordable credit services. In addition, the financial institutions providing credit facilities to the farmers should harmonize the credit payment. This could be done in such a way that the payment of credit is done during the harvesting time, since most of the farmers lack the monthly incomes to pay for the loan given as they are only engaged in agricultural activities. The County government, in collaboration with the credit institutions, should also come up with measures to help ensure that they help inculcate and improve the savings culture among the pixie farmers as this would help them in acquiring credit as the savings made could act as a collateral for the loan obtained. Lastly, adoption of sustainable agricultural technologies was a key determinant towards increased pixie productivity. Given the high level of technical efficiency realized by the adopters of the sustainable agricultural technologies, the county government should develop strategies through the ministry of agriculture where the pixie farmers are taught on how to effectively and efficiently use the sustainable technologies to realize higher output. Through this, the inefficient farmers who never used the technologies would be educated on the need for their use. The huge gap (58.3%) existing between the most efficient and the most inefficient farmers would therefore be reduced.

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Conflicts of Interest

The authors declare no conflicts of interest.

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