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Profitability of yam production under farmer practice, abamectin treatment and banana paper techniques in Ghana

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ABSTRACT

The productivity of yam in Ghana has been on a constant decline recently, mainly due to weather extremes and nematode infestations. This has significantly affected the profitability of yam production, with a resultant effect on the livelihoods of the thousands of yam income dependent households. Several techniques have been developed to improve the situation. This study purposes to estimate the profitability of yam production under the novel 'wrap and plant' technology of planting seed yam, in comparison to the traditional method in three agro-ecological zones in Ghana using 20 young and male-dominated randomly sampled yam farmers. The term 'wrap and plant' refers to a novel method of wrapping seed yam with abamectin treated banana paper (ABM) before planting in the soil. This is to prevent nematode migration into the seed yam during planting and also the new yam that develops. Each farmer was supported to farm on four demonstration plots of 144 mounds in all (six rows of six mounds, making 36 mounds per plot). The four demonstration plots/sites per farmer were randomly selected and the three treatments (ABP) banana paper with abamectin, (BP) banana paper without abamectin and the control, representing Farmer Practice (FP), were used with four replications per site for both dry and wet seasons. The profitability of their production under three yam planting techniques, abamectin-treated banana paper (ABP), untreated banana paper (BP), and farmer practice (FP) was determined using Benefit Cost Ratio (BCR) analysis. The study found that though the use of the new planting technology yielded significantly higher net-benefits compared to FP, they resulted in rather lower BCRs. Using FP led to 0.916 and 1.531 significantly higher BCR on the average, compared to ABP and BP, respectively. Although this study affirms FP as the most profitable planting technique, the new technology increased yam yields, but at higher costs. Farmers are willing to adopt this technology if the cost of the banana paper is further reduced. The findings of the study reinforce the importance of lowering the cost of adopting new planting techniques in order to make production under such techniques profitable for farmers.

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1. Introduction

Yam (*Dioscorea* spp.) is a staple food in West Africa and has been cultivated for centuries. This crop is versatile, can be used in a variety of dishes, and is also a source of income for farmers and traders, as it plays a crucial role in the economy of producing countries (Ansah et al., 2023; Kiba et al., 2020). Sub-Saharan Africa is the largest producer of yam in the world, producing about 95% of the global supply (Xie et al., 2018), and Ghana is the second-largest producer, after Nigeria (Acheampong et al., 2019). Yam farming is a major source of livelihood for many people in Ghana (Ansah et al., 2023), with over 26.2% of the population depend on yam cultivating for their food and income security (Aighewi et al., 2020). The production of Yam in Ghana is dominated by small-scale farmers (Afua et al., 2023). One of the reasons why yam is such an important crop in West Africa is that it can be stored for long periods

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without spoiling (Morse, 2022). This means that yam can be consumed during the dry season when other crops are not available. In addition, yam can be traded, which makes it an important source of income for farmers and traders alike. Yam is often sold in local markets, but studies have shown that about 94% of yam produced in Ghana is meant for the international market (Ansah et al., 2023). As the leading exporter of Yam globally, Ghana exports about 21,000 metric tons of Yam on an annual basis for the past decade to America, Europe and other African countries such as Niger, Burkina Faso and Mali among others (Wumbei et al., 2023).

The production of yam also creates employment opportunities for other actors at the various stages of the value chain, such as transporters, processors, and marketers (Ansah et al., 2023). There is also a ripple effect in the economy; as the income generated from yam farming is used to purchase other goods and services, which in turn supports other industries. The economic importance of yam is reflected in the Gross Domestic Product (GDP) of the top producers and exporters. For example, in Ghana, the export of yam between 2017 and 2018 increased by USD 5.4 million (Ghana Export Promotion Authority (GEPA), 2019). In 2022, though yam exports faced a shortfall due to exporters' inability to meet quality requirements, revenue still stood at USD 11.4 million (Ghana Export Promotion Authority (GEPA), 2022). This shows that yam farming and trading is a significant contributor to the economy of the country. The main drivers of yam consumption in Ghana include rapid population growth coupled with urbanization, with most urban dwellers patronizing yam because of its ease of preparation and its ability to be stored for a long period (Adeosun et al., 2022; Morse, 2022). This makes yam continuously maintain its position as an important staple crop supporting livelihoods at both producer and consumer levels, as well as contributing significantly to national development. Despite the increasing importance of yam production both at the micro and macro levels, there are reports of a continued decline in productivity to meet the ever increasing demand (Liu et al., 2021).

The recent decline in yam productivity has been a cause for concern given yam's contribution to Ghana's GDP and the livelihoods of thousands of households whose earnings are yam-dependent (Neina & Agyarko-Mintah, 2023). Farmers have adjusted in many ways in their farm practices to overcome this challenge (Baffour-Ata et al., 2023; Easmin, 2022). Research has also been conducted and techniques have been introduced as a result to overcome the issue of low productivity in yam cultivation. For instance, the Banana Paper Abamectin Technology (wrap and plant) is a new innovation undergoing field trials by the Department of Crop Science, University of Ghana, in collaboration with North Carolina State University. The term 'wrap and plant' refers to a novel methods of wrapping seed yam with abamectin treated banana paper (ABP) before planting in the soil. This is to prevent nematode migration into the seed yam during planting and also the new yam that develops. Although studies have proven that new technologies have the tendency to improve yields significantly in yam production (Liu et al., 2021; Neina & Agyarko-Mintah, 2023; Pirzada et al., 2023), the adoption and use of these technologies are not always straightforward (Baffour-Ata et al., 2023). Farmers have reservations regarding the profitability of production under newer technology. Several studies have been conducted on the adoption of new production techniques leading to improved yields, in terms of quantity, quality or both (Kiba et al., 2020; Onwuka, 2020; Pirzada et al., 2023). Other studies have also focused on exploring how other factors such as access to credit, extension contact, education, access to infrastructure and environmental factors may influence the adoption of new technologies (Anang et al., 2020; Mumah et al., 2024; Rizzo et al., 2024). These studies have proposed solutions to overcome issues of low adoption among farmers. However, this may be insufficient in getting farmers to adopt, given that the adoption of new technologies may not be cost-effective for farmers. Hence, a profitability analysis is necessary. Studies on the profitability of yam production under new technologies are scanty in the current literature. The few studies on the subject have only focused on a single technology (Okeoghene et al., 2013). Hence, there is a gap in empirical evidence comparing the profitability of different adopted practices by yam farmers in Ghana in response to changing climatic conditions. This study therefore fills this gap by analyzing the profitability of three different yam planting techniques using Benefit Cost Ratio (BCR) analysis. This will not only fill the identified gap in the literature, but will also have significant practical implications. Farmers and all stakeholders concerned with the declining output of yam in Ghana will be better informed on the best approaches to optimize output on all levels, not compromising the profitability at the farmer level.

Yam production in Ghana involves a combination of traditional and modern farming practices, reflecting the country's rich agricultural heritage (Naazie

et al., 2023). These practices have evolved over time, encompassing a range of techniques that have been shaped by cultural, social, and technological factors. Traditional farming methods include manual land preparation, planting using yam stakes, and intercropping with other crops (Neina, 2021). These practices are characterized by manual labour and local knowledge. Modern techniques encompass the use of improved varieties, mechanized land preparation, and the application of agrochemicals (Bolarin et al., 2022). These techniques have been introduced to yam production, aiming to increase climate resistance, yields and improve efficiency (Bolarin et al., 2022; Darkwa et al., 2020). Studies have highlighted the importance of integrating traditional knowledge with modern approaches to enhance yam yield and sustainability (Ema et al., 2023; Nugroho et al., 2023). This holistic approach of integration acknowledges the importance of local practices, cultural beliefs, and indigenous techniques that have sustained yam farming for generations. For instance, the practice of intercropping not only optimizes land use but also helps control pests and diseases through natural biodiversity (Brooker et al., 2023). Also, indigenous methods of soil fertility management, such as fallowing and organic matter incorporation, can contribute to sustainable soil health and reduce the need for excessive synthetic inputs (Thakur et al., 2023). By combining these traditional practices with modern research and technologies, farmers can achieve a balance that enhances yields, conserves resources, and preserves local agricultural heritage.

The literature highlights the dynamics leading to the profitability of different yam planting techniques. Farmer Practice (FP), which involves traditional methods such as mounding and ridging, is the most widely adopted technique among smallholder farmers due to its low cost (Adewumi et al., 2021; Ema et al., 2023). However, studies indicate that farmer practice alone may not optimize yields or profits (Dedehouanou et al., 2022b; Neina, 2021; Tanko & Alidu, 2017). Incorporating improved planting techniques, such as abamectin treatment, can significantly enhance yam production by reducing pest infestation and increasing crop vigour (Dedehouanou et al., 2022a; Pirzada et al., 2023). Abamectin-treated yam plots have demonstrated higher yields and improved profitability compared to traditional methods (Dedehouanou et al., 2022b). Furthermore, the use of banana paper as a planting material has gained attention in recent years (Balda et al., 2021; Siva et al., 2021). Studies suggest that the banana paper technique shows promise in promoting yam tuberization, reducing pest damage, and improving overall crop health (Dedehouanou et al., 2022b; Pirzada et al., 2023). Although more research is needed to determine its long-term profitability, initial findings indicate that the banana paper technique holds potential for enhancing yam production in Ghana (Dedehouanou et al., 2022b).

Based on the reviewed literature, it is evident that the profitability of yam production in Ghana can be significantly improved by adopting innovative planting techniques. While traditional farmer practices remain prevalent due to their low cost (Danquah et al., 2022; Neina, 2021), incorporating methods such as abamectin-treated banana paper (ABP) and banana paper (BP) can enhance yam yields and profitability (Pirzada et al., 2023). The adoption of new farming techniques plays a pivotal role in shaping agricultural productivity, sustainability, and overall profitability for farmers (Raimi et al., 2017). As agriculture continues to evolve, the integration of innovative practices is essential to increase productivity in the quest to meet the growing demands of a changing world. Although profitability can be the end goal of farmers' adoption of new planting technology, numerous studies have established that profitability is a primary motivator for farmers when considering the adoption of new farming techniques (Masere et al., 2022; Montes de Oca Munguia et al., 2021). The potential for increased yields, reduced production costs, and enhanced overall financial performance are key factors that drive farmers to explore and embrace innovative technologies and practices (Andati et al., 2022; Curry et al., 2021). For instance, studies have shown that farmers are more likely to adopt agricultural technologies when they perceive a positive impact on their returns, indicating that profitability is a key decision-making criterion (Chavas & Nauges, 2020; Masere et al., 2022). It will therefore be crucial that efforts are made to promote the adoption of these new planting technologies to yam farmers (at reduced costs) if profitability is proven an eminent outcome of their adoption.

In the literature on yam profitability, several techniques have been used to measure profitability. These techniques include Return on Investment (ROI) (Osei-Adu et al., 2022), Net Present Value (NPV) (Owusu Danquah et al., 2023), Income Equivalent Ratio (IER) (Owusu Danquah et al., 2023), Gross Margin (Dedehouanou et al., 2022b; Mukaila et al., 2022) and Benefit Cost Ratio (BCR) (Dedehouanou et al., 2022b; Mukaila et al., 2022; Osei-Adu et al., 2022; Owusu Danquah et al., 2023). These measures are all good proxies of the profitability of a venture

and the choice of which measure to use may largely depend on the scope of analyses and the data available. In this study, the BCR was employed as a proxy for measuring the profitability of yam production due to the predominance of its use in the literature.

The theoretical foundation of this study rests on economic principles governing agricultural production and profitability. Economic theory provides insights into the decision-making processes of farmers and the factors influencing their adoption of innovative farming techniques (Dessart et al., 2019). Central to this analysis are concepts such as cost-benefit analysis, profit maximization and technology adoption. Cost-benefit analysis is a fundamental tool in agricultural economics used to evaluate the economic feasibility of different production methods or technologies (Tolessa et al., 2022). In this study, the BCR is employed as a measure of profitability. The BCR compares the total benefits derived from a production method to the total costs incurred, providing a quantitative assessment of its economic viability. According to economic theory, if the BCR is greater than 1, the benefits outweigh the costs, indicating a profitable venture. Conversely, if the BCR is less than 1, the costs exceed the benefits, suggesting a lack of economic viability.

The Technology Adoption Theory has been used to explain the adoption of new farming technologies. The theory posits that farmers assess the potential benefits and costs associated with adopting innovative practices before making adoption decisions (Anang et al., 2020). Profitability is a key motivator for technology adoption, as farmers are more likely to adopt new techniques that promise increased yields or cost savings, leading to higher profits (Cui & Wang, 2023). Also, the Innovation Diffusion Theory informed the theoretical framework of this study, emphasizing the process through which new agricultural practices spread among farmers within a community or region. The theory suggests that the adoption of innovations follows a predictable pattern, beginning with innovators and early adopters before reaching the majority of farmers (Dissanayake et al., 2022; Gabriel & Gandorfer, 2023). By analyzing the profitability of different planting techniques, this study contributes to understanding the diffusion process of agricultural innovations in the context of yam production in Ghana.

The theoretical framework of this study, the technology adoption theory and the innovation diffusion theory, considers the implications for agricultural extension services and policy interventions. By evaluating the profitability of three different planting techniques, policymakers and extension agents can identify strategies to promote the adoption of cost-effective and sustainable agricultural practices. This aligns with broader goals of enhancing agricultural productivity, improving livelihoods and achieving food security in Ghana.

2. Materials and methods

2.1. The study area

The study was conducted in three major yam producing districts in Ghana, namely, Krachi- Nchumuru, Nkoranza and Zabzugu Districts. These districts were purposively selected due to the predominance of commercial yam production in these districts and also to represent each of the three ecological zones of the country, offering distinct agroecological and socioeconomic characteristics.

The Krachi Nchumuru District, situated in the Oti Region, boasts favourable climatic conditions and lush vegetation. The district, flanked by the Volta Lake, supports diverse agricultural practices, making yam production a significant contributor to the local economy.

Nkoranza District, located in the Bono East Region, presents a blend of forest and savannah agroecological zones. Known for its agricultural diversity and adoption of various farming techniques, yam cultivation plays a pivotal role in this district's agriculture.

Zabzugu District, situated in the Northern Region, represents the northernmost part of the study area. Its semi-arid savannah climate and traditional farming practices pose unique challenges and opportunities for yam cultivation. Yam production is a crucial component of local agriculture, contributing significantly to food security and livelihoods in the district.

These three districts collectively represent Ghana's diverse agricultural landscape, influenced by factors such as climate, soil conditions, traditional farming practices, resource accessibility, and market dynamics.

2.2. Seed yam planting and treatments

The field treatments include (ABP) banana paper with abamectin, (BP) banana paper without abamectin, and the control, representing farmer practice (FP). The seed yams planted were wrapped with banana paper (ABP) or (BP) or use of farmer practice (FP) where the seed yam is planted directly into the soil without any wrapping. Individual plots consisted of six rows of six mounds (36 mounds per plot), and the trial was laid out in Randomized Complete Block

Design (RCBD), with four replicates in the various locations. The experiments were conducted both in the dry and wet seasons. This was to determine the efficacy levels of abamectin within the banana paper on reducing nematode populations and dry rot incidence on yam. The experiments were conducted in four sites each, during the various seasons in the three agro-ecological zones.

2.3. Sampling procedure

Two communities were purposively selected from each district based on their records in yam production within the districts. This was after the three districts of the study were selected purposively. Twenty yam farmers were then randomly selected with probability proportionate to available yam farmers to participate in the demonstration field trials. Eight farmers were sampled each for Krachi Nchumuru and Zabzugu Districts, while four farmers were sampled from the Nkoranza District. The sampling of these 20 farmers was purely to carry out the experiment of cultivating four different plots for each planting practice. This was not aimed at getting a representative sample.

2.4. Data collection and instrument

The data collection process covered a period of one year because the study sought to assess yam production outcomes for two farming seasons. Two structured questionnaires were used to collect data from participating farmers at three different periods within the year. For the first round of data collection, the first structured questionnaire was used to collect the socio-demographic characteristics of participating farmers just before the start of the first production season. For the second round of data collection, the second structured questionnaire was used at the end of the first production season to collect data on the cost structure and production outcomes for that season. In the third round, the second structured questionnaire was again used to capture data on farm cost structure and production outcomes at the end of the second production period. Farmers were asked to detail the cost they incurred in activities such as land preparation, planting, mulching and weeding. The questionnaire also captured the number of tubers harvested for each planting technique and the revenue generated from the sale of those tubers.

Written informed consent from respondents for participation in the study was obtained before data was collected.

2.5. Data analysis

The data collected from the survey was analyzed in Excel and STATA version 15. The data was first screened and cleaned from inconsistencies and possible errors during the data collection and entry processes.

To compute the benefits the study made some assumptions. These assumptions were:

1. The average price of a tuber of yam is GHS 3 ($ 0.51) based on information from yam sellers (traders and farmers).
2. The abamectin technology is likely to increase the price of yam from GHS 3 ($ 0.51) to GHS 4 ($ 0.68) which is approximately a 30% increase in the price of the yam. The price increase is because the use of abamectin helps to produce yams of better quality (Dedehouanou et al., 2022b) which commands a higher price as stated by the stakeholders of the project.
3. It is estimated that about 9.6% of yam will be lost by farmers during storage (Ansah et al., 2018). The respondents stated the absence of rot due to the use of the abamectin. Hence, the percentage loss during storage is only calculated for the normal farmer practice.

2.6. Computation of BCR

2.6.1. Quantity harvested

This is the total amount of yams harvested from the mounds created for each section of the demonstration site reserved for a planting technique.

2.6.2. Quantity lost

9.6% Of yam is likely to be lost after harvesting yams hence this percentage is expressed over the quantity harvested to give the remaining quantity after losses.

2.6.3. Remaining quantity

Quantity harvested minus quantity lost gives the remaining quantity.

2.6.4. Price

The average price for the yam.

2.6.5. Revenue (B_i)

The price multiplied by the quantity gives the revenue.

2.6.6. Cost (C_i)

Total cost of planting technique on a demonstration site.

2.6.7. Net benefit (B – C)

The revenue minus the cost gives the net benefit.

2.6.8. Benefit-cost ratio (BCR)

The ratio of the revenue (benefit) to the cost gives the BCR, this is as specified below following (Rangsiwanichpong & Melesse, 2022).

$$BCR = \frac{\Sigma Bi}{\Sigma Ci} \quad (1)$$

where BCR is the benefit-cost ratio; B_i and C_i are the benefits and costs of the ith planting techniques, respectively.

According to Rangsiwanichpong and Melesse (2022), economically, if the costs exceed the benefits, then BCR will be less than 1, solely based on this criterion, the activity should not proceed. Where the costs equal the benefits, thus BCR equals 1, the activity should be allowed to proceed, but with little viability. Where the benefits exceed the costs then the BCR will be greater than 1, the project should be allowed to proceed. In profitability analysis using the BCR, the higher the value of BCR, the more profitable the activity.

2.7. Data treatment

To avoid any form of bias in the data gathered and cater for all forms of production inefficiencies or otherwise, each farmer cultivated four different demonstration plots for each of the three planting techniques. For each district, half (4) of the farmers cultivated all plots during the dry season while the other half cultivated all plots during the rainy season except for Nkoranza district where one half failed to cultivate in the rainy season. This was necessary to control for seasonal variations in production under all the planting techniques.

3. Results and discussion

3.1. Socio-demographic characteristics of farmers

The results of the study as shown in Table 1 indicate that the majority (85%) of the farmers selected for the demonstration sites were males aged below 35 (65%) and with an average of 12 years' experience in farming. This demonstrates the dominance of males in yam farming and the growing participation of the youth. The dominance of males in yam farming is confirmed in earlier studies (Ema et al., 2023; Osei-Adu et al., 2022), as there are still significant gender gaps in access to productive resources to the disadvantage of females (Ankrah et al., 2020). Also, the dominance of youth in yam cultivation is encouraging, especially in the discourse of new technology adoption. Studies have shown that youth farmers are more likely to adopt newer technologies to enhance their productivity as compared to older farmers who are more conventional in their farming practices (Mumah et al., 2024; Rizzo et al., 2024).

In terms of educational level, the majority (55%) were uneducated, while 25% of farmers had secondary education. The majority (75%) of farmers were Christians and married (80%) with an average household size of 8 members. The results further showed that 70% of farmers had access to extension services and cultivated lands that they solely owned, while 75% of them were not members of any organized Farmer-Based Organisation (FBO).

3.2. Costs and return analysis of yam production

3.2.1. Cost structure

A typical cost structure for setting up and carrying out operational activities on the demonstration plot (144 mounds) is outlined in Table 2.

Table 1. Demographic profile of selected farmers for the study.

Variables	Frequency	Percent (%)	Mean	Std. dev	Min	Max
Gender						
Female	3	15				
Male	17	85				
Age						
Below 35	13	65				
35 And above	7	35				
Educational level						
No education	11	55				
Basic	2	10				
Secondary	5	25				
Tertiary	2	10				
Marital status						
Single	3	15				
Married	16	80				
Divorced	1	5				
Religion						
Christian	15	75				
Muslim	5	25				
Land ownership						
Leased	3	15				
Solely owned	14	70				
Family owned	3	15				
FBO membership						
Yes	5	25				
No	15	75				
Access to extension						
Yes	14	70				
No	6	30				
Household size			8	5.32	3	13
Farm experience			12.35	10.61	4	31

Table 2. Cost structure for demonstration site of 144 mounds.

Activities	Unit	Price (GHS)	Total (GHS)
Land preparation	1	30	30
Weedicide application	1	15	15
Labour for application	1	10	10
Making mounds (144)	1	20	20
Planting & mulching	1	10	10
Weeding	1	10	10
Harvesting	3	10	30
Cost of abamectin paper	48	2.75	132
Cost of banana paper	48	2.75	132

Note: The exchange rate at the time of data collection was; (1 USD = 5.87327 GHS).

The cost components of yam production for the demonstration sites were recorded for each farming activity under the different planting techniques. For the respective required units of each activity, the total cost of using the normal farmer practice amounts to GHS 125 ($ 21.28), the cost of using the abamectin paper technique amounts to GHS 257 ($ 43.77) and the Banana Paper amounts to GHS 257 ($ 43.76). There is clearly a higher cost of cultivating under the new planting techniques as the cost is more than twice as much as using normal farmer practice. Studies in the past have found the use of new planting techniques to result in added cost to the production process (Dedehouanou et al., 2022b; Emerick & Dar, 2021). This is accounted for by the extra cost incurred in acquiring the Banana Paper and Abamectin Paper to aid the use of the new planting techniques. This additional cost incurred in securing additional inputs for these new planting techniques significantly influenced the differences in the BCRs between the different planting techniques.

3.2.2. Comparing production outcomes of planting techniques

The production outcomes of the planting techniques are presented in Table 3. In terms of the quantity of yam produced under each of the planting techniques per demonstration plot, FP yielded an average of 142.2 tubers, while ABP and BP yielded 142.947 tubers and 147.3 tubers, respectively (Table 3). Distribution of average quantity produced by district showed that there was an average output of 146, 142.375 tubers and 142.75 tubers, respectively for FP, ABP and BP at the Krachi Nchumuru District per demonstration plot. In the Nkoranza District, the average quantity of yam produced was 136.5 tubers, 135.5 tubers and 139.75 tubers, respectively for FP, ABP and BP. Finally, in the Zabzugu District, yam output averaged 141.25 tubers, 147.857 tubers and 155.625 tubers, respectively for FP, ABP and BP (Table 3). The distribution of average quantity produced by season showed that there was an average output of 141.625 tubers, 139.125 tubers and 151.625 tubers, respectively for FP, ABP and BP in the rainy season. In the dry season, the average quantity of yam produced was 142.583 tubers, 133.583 tubers and 144.417 tubers, respectively for FP, ABP and BP (Table 4). Given these observed differences in the average quantity of yam produced, an ANOVA test was conducted to determine if these observed differences in the mean quantity of yam produced were statistically significant. The results of the ANOVA test are presented in Table 5. The test revealed that the observed differences in mean quantity produced across the three planting techniques were not significant ($F=0.20$, $p=0.818$). This finding is contrary to the finding of earlier studies by Dedehouanou et al. (2022b), who found

in their study that the output produced by all three planting techniques differed on average. Another study by Pirzada et al. (2023) observed a similar outcome arguing that the use of new planting techniques improved the yields of yam significantly.

In terms of the cost structure of production, the average cost of production under FP was GHS 125 ($ 21.28), while that of both ABP and BP was GHS 257 ($ 43.76) each (Table 3). This finding conforms to several other studies in the past that also found that the cost involved in producing under newer technologies comes at a higher cost relative to traditional production techniques (Asala & Ebukiba, 2016; Dedehouanou et al., 2022a, 2022b). This is mainly because new technologies require additional input or knowledge which more often than not, comes at an additional cost to farmers when they are adopting new techniques (Emerick & Dar, 2021). On average, revenue generated differed across the planting techniques. Revenue generated with FP averaged GHS 385.6 ($ 65.65) per demonstration plot, while that of ABP and BP was GHS 557.474 ($ 94.92) and GHS 399.5 ($ 68.02), respectively per demonstration plot (Table 3).

Further tests with the Bonferroni adjust test (Table 6) showed that there was a significant ($p=0.00$) difference in the mean revenue generated by FP and ABP. There was, however no significant difference between the mean revenue generated by FP and BP.

Again, the average difference in mean revenue generated per demonstration plot by ABP and BP was GHS 157.974 ($ 26.90). This difference was

Table 3. Average production outcomes for different planting techniques by districts.

	Farmer practice (FP)						Abamectin-Treated banana paper (ABP)						Untreated banana paper (BP)					
District	Quantity	Price	Revenue	Cost	Net benefit	BCR	Quantity	Price	Revenue	Cost	Net Benefit	BCR	Quantity	Price	Revenue	Cost	Net benefit	BCR
KN	146	3	395.875	125	270.875	3.168	142.375	4	555.25	257	298.25	2.161	142.75	3	387.125	257	130.125	1.506
N	136.5	3	370.25	125	245.25	2.961	135.5	4	528.25	257	271.25	2.056	139.75	3	379	257	122	1.475
Z	141.25	3	383	125	258	3.065	147.857	4	576.714	257	319.7142857	2.244	155.625	3	422.125	257	165.125	1.642
Total	142.2	3	385.6	125	260.6	3.085	142.947	4	557.474	257	300.474	2.169	147.3	3	399.5	257	142.5	1.554

Note: KN: Krachi Nchumuru District; N: Nkoranza District; Z: Zabzugu District.

Table 4. Average production outcomes for different planting techniques by season.

	Farmer practice (FP)						Abamectin-treated banana paper (ABP)						Untreated banana paper (BP)					
	Quantity	Price	Revenue	Cost	Net benefit	BCR	Quantity	Price	Revenue	Cost	Net benefit	BCR	Quantity	Price	Revenue	Cost	Net benefit	BCR
Wet season	141.625	3	384.125	125	259.125	3.073	139.125	4	542.625	257	285.625	2.111	151.625	3	411.25	257	154.25	1.600
Dry season	142.583	3	386.583	125	261.583	3.093	133.583	4	520.917	235.583	285.333	2.027	144.417	3	391.667	257	134.667	1.524

statistically significant at 1%. On average, FP generated GHS 171.874 ($ 29.26) less revenue as compared to ABP. For net revenue generated, FP averaged GHS 260.6 ($ 44.37), ABP averaged GHS 300.474 ($ 51.16) and BP averaged a net benefit of GHS 142.5 ($ 24.26) (Table 3).

The ANOVA results revealed that there was a significant difference in the average net benefits across the planting techniques ($F = 17.47$, $p = 0.000$) (Table 7). Further Bonferroni test showed that net benefits from FP were GHS 39.874 ($ 6.79) less and GHS 118.1 ($ 20.11) more as compared to ABP and BP, respectively. The possible reason why ABP resulted in higher net benefits was because of the higher price yam produced under such technology commanded. It should be noted that studies have confirmed that yam produced with the ABP planting technique is of superior quality with respect to weight, size and overall quality (Dedehouanou et al., 2022b). Hence, they are sold at a higher price as compared to yam output from other planting techniques. This most likely leads to higher net benefits for farmers practising this planting technique.

Table 5. One-way ANOVA test for differences in mean quantity harvested by technique.

Source	SS	df	MS	*F*	Prob > F
Between groups	301.958	2	150.979	0.20	0.818
Within groups	41950.347	56	749.113		
Total	42252.305	58	728.488		

Table 6. Bonferroni test for differences in mean revenue by technique.

	FP	ABP
ABP	171.874	
	0.000	
BP	13.9	−157.974
	1.000	0.000

3.2.3. Profitability analyses

From the analyses of the BCRs of the three planting techniques, FP produced the highest BCR on average with a mean BCR of 3.085. ABP and BP produced an average BCR of 2.169 and 1.554, respectively (Table 3). This implies that FP is the most profitable planting technique among the planting techniques studied. Table 8 presents the results of further analysis was carried out to know the exact differences in mean among the three techniques using Analysis of Variance (ANOVA). The analysis revealed that there were significant differences in the mean BCR of the three planting techniques ($F = 60.30$, $p = 0.000$). Given that there were significant differences in the mean BCRs, the Bonferroni test was carried out to know where the differences resulted from. Table 9 presents the results of the Bonferroni test which revealed that the average BCR of FP was 0.916 and 1.531 significantly higher ($p = 0.000$) than the average BCRs of ABP and BP, respectively.

To be sure these differences were not influenced by seasonality or location, further ANOVA analyses was carried out to determine if mean BCRs significantly differed by season and district. The results are presented in Tables 10 and 11.

These tests, however, yielded insignificant estimates, indicating that there were no significant differences in the mean BCR across the two seasons and the three districts. The only significant difference resulted from the mean BCRs by planting technique, which showed that FP was the most profitable planting technique based on the BCRs. This finding is contrary to earlier studies by Dedehouanou et al. (2022b), who found that newer planting techniques such as ABP and BP yielded more profits for farmers. The intuition behind the finding from this study is the high cost of planting with ABP and BP techniques as compared to the relatively cost-effective FP as seen in this study. The adoption of the new planting techniques required the purchase of additional inputs which drastically

Table 7. One-way ANOVA test for differences in mean revenue by technique.

Source	SS	df	MS	*F*	Prob > F
Between groups	352302.683	2	176151.342	23.18	0.000
Within groups	425612.537	56	7600.224		
Total	77915.22	58	13412.331		

Table 8. One-way ANOVA test for differences in mean BCR by technique.

Source	SS	df	MS	*F*	Prob > F
Between groups	23.725	2	11.862	60.30	0.000
Within groups	11.016	56	0.196		
Total	34.741	58	0.599		

increased the cost component for the production period. The use of the new technologies, however, did not result in a significant increase in the quantity of yam produced. This eventually led to lower BCR as a result, making production under these technologies less profitable relative to FP. Even though yam produced from the new techniques commanded a higher price due to their superior quality as affirmed by Dedehouanou et al. (2022b), this did not significantly contribute to the revenue generated from these techniques to offset the additional cost incurred in securing additional inputs. Interactions with farmers and key stakeholders during the course of the project indicates that farmer will be willing to adopt these new planting techniques should they turn out to be more profitable compared to their known farmer practices.

4. Conclusion and recommendations

The study focused on the profitability of yam production using three different planting techniques among smallholder yam farmers in three selected districts in Ghana using BCR analysis. Twenty (20) smallholder yam farmers were selected to cultivate yam on four demonstration plots for each of the planting techniques. The average costs incurred and revenue obtained per the four demonstration plots for the three planting techniques for yam farmers were estimated to determine the profitability or otherwise of yam production. The average quantity of yam produced by farmers was 142.2 tubers for farmer practice, 142.9 tubers for ABP and 147.3 tubers for BP. Net benefits were GHS 260.6 ($ 44.37) for farmer practice, GHS 300.5 ($ 51.16) for ABP and GHS 142.5 ($ 24.26) for BP on average. On the average, BCR were 3.1, 2.2 and 1.6 for farmer practice, ABP and BP, respectively. Thus, it could be concluded that yam production under the three different planting techniques in the study districts was economically viable, though with varied degrees of profitability. Based on the BCRs, farmer practice was the most profitable planting technique, followed by ABP and BP in order of profitability.

The study recommends that because farmer practice emerged as the most profitable planting technique, and with well documented evidence of high post-harvest losses, investments should be made in extension services to educate farmers to avoid these losses after harvest. With the issue of low quality of yam produced from traditional farmer practice, the study recommends the introduction of cost-efficient innovations that will complement farmer practice leading to improved quality of yam harvested. These interventions are proposed for uptake by the Ministry of Food and Agriculture (MoFA) through its subsidiaries such as the extension division. The advantages of abamectin include it being a biodegradable matrix that delivers micro-dosages of nematicides to the target root zone of the yam in a farmer's field, providing a sustainable nematode management option for the smallholder farmers. Additionally, the abamectin levels within the banana paper do not disrupt the ecosystem of other useful micro-organisms in the soil, there is also an increase the arbuscular mycorrhizae populations around the yam root rhizosphere, ultimately improving soil health for yam cultivation. This method is sustainable because the banana materials can be easily obtained from local and commercial banana farms in Ghana and the abamectin produced locally. Government can support with the construction of a

Table 9. Bonferroni test for differences in mean BCR by technique.

	FP	ABP
ABP	−0.916	
	0.000	
BP	−1.531	−0.615
	0.000	0.000

Table 10. One-way ANOVA test for differences in mean BCR by season.

Source	SS	df	MS	*F*	Prob >*F*
Between groups	0.004	2	0.004	0.01	0.936
Within groups	34.737	57	0.609		
Total	34.741	58	0.599		

Table 11. One-way ANOVA test for differences in mean BCR by district.

Source	SS	df	MS	*F*	Prob >*F*
Between groups	0.194	2	0.097	0.16	0.855
Within groups	34.547	56	0.617		
Total	34.741	58	0.599		

factory for commercial production of the abamectin. This will enable easy access of the abamectin and at affordable costs to the smallholder farmers, as compared to importation of the abamectin from overseas. Despite the fact that ABP and BP were less profitable, the study further recommends the introduction of subsidies by the government to partly absorb the cost component of ABP on the Ghanaian markers, for easy access and at lower costs, compared to synthetic chemicals. This will eventually result in the production of high quality yam under profitable conditions for smallholder yam farmers.

5. Limitations of the study

The limitation of the study was the absence of a detailed research on the quality of yam produced using the new planting techniques. Previous studies confirm that yam produced using improved planting techniques have superior qualities such as size, weight and quality (Pirzada et al., 2023). This may lead to it commanding higher prices and also more preferred by consumers over others. Future studies can study market dynamics in relation to consumer preference for yam produced by different technologies in terms of their size and quality. That notwithstanding, this study contributes significantly to the literature on how yam production using different planting techniques affects profitability which was hitherto lacking.

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Ethical approval

This paper is developed from some aspects of results found from the project titled 'Optimization and Deployment: Nutrient–Rich Biodegradable Metrix for Crop Production'. The project received ethical approval from the Ethics Committee for Basic and Applied Sciences (ECBAS) with references number ECBAS 004/19–20. The project has no books or articles published yet.

Author contributions

All the authors listed have significantly contributed to the development of this paper as shown below and agree to be accountable for all aspects of this article. The contributions of each author is listed below:

No	Name of author	Role
1.	Freda Elikplim Asem	• Conceptualization and design • Methodology • Data collection/investigation • Formal analysis and interpretation • Original draft preparation • Review and editing • Final approval of the version to be published
2.	Seloame Tatu Nyaku	• Methodology • Data collection/investigation • Formal analysis and interpretation • Original draft preparation
3.	Jude Dokbila Kolog	• Methodology • Data collection/investigation • Formal analysis and interpretation • Original draft preparation
4.	Maame Yaakwaah Blay Adjei	• Methodology • Data collection/investigation • Formal analysis and interpretation • Original draft preparation
5.	Daniel Adu Ankrah	• Methodology • Data collection/investigation • Formal analysis and interpretation • Original draft preparation
6.	Charles H. Opperman	• Funding acquisition • Methodolgy • Original draft preparation • Review and editing

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Data availability statement

The data that support the findings of this study are available from the corresponding author, FEA, upon reasonable request.

References

Acheampong, P. P., Danquah, E. O., Dissanayake, H. G., Hayford, P., & Weebadde, C. (2019). A socioeconomic study of transition zone yam farmers addressing constraints and exploring opportunities for integrating pigeonpea into yam cropping systems. *Sustainability*, *11*(3), 717. https://doi.org/10.3390/su11030717

Adeosun, K. P., Greene, M., & Oosterveer, P. (2022). Urban daily lives and out-of-home food consumption among the urban poor in Nigeria: A practice-based approach. *Sustainable Production and Consumption*, *32*, 479–491. https://doi.org/10.1016/j.spc.2022.04.024

Adewumi, A. S., Asare, P. A., Adu, M. O., Taah, K. J., Akaba, S., Mondo, J. M., & Agre, P. A. (2021). Farmers' perceptions on varietal diversity, trait preferences and diversity management of bush yam (*Dioscorea praehensilis* Benth.) in Ghana. *Scientific African*, *12*, e00808. https://doi.org/10.1016/j.sciaf.2021.e00808

Afua, J., Haleegoah, S., Frimpong, B. N., Asante, B. O., Yeboah, H., Brobbey, L., Opoku, M., Ennin, S., & Osei, K. (2023). Gender dynamics awareness in seed yam production, implications on food security: The case of community action for improving farmer saved seeds (CAY-seed) project. *International Journal of Sociology and Anthropology*, *15*(3), 67–80. https://doi.org/10.5897/IJSA2023.0974

Aighewi, B., Maroya, N., Asiedu, R., Mignouna, D., Balogun, M., & Kumar, P. L. (2020). Eliminating hunger: Yam for improved income and food security in West Africa. In *Transitioning to zero hunger* (vol. 9, pp. 1–21). Basel, Switzerland: MDPI.

Anang, T. B., Alhassan, H., & Danso-Abbeam, G. (2020). Estimating technology adoption and technical efficiency in smallholder maize production: A double bootstrap DEA approach. *Cogent Food & Agriculture*, *6*(1), 1833421. https://doi.org/10.1080/23311932.2020.1833421

Andati, P., Majiwa, E., Ngigi, M., Mbeche, R., & Ateka, J. (2022). Determinants of adoption of climate smart agricultural technologies among potato farmers in Kenya: Does entrepreneurial orientation play a role? *Sustainable Technology and Entrepreneurship*, *1*(2), 100017. https://doi.org/10.1016/j.stae.2022.100017

Ankrah, D. A., Freeman, C. Y., & Afful, A. (2020). Gendered access to productive resources – evidence from small holder farmers in Awutu Senya West District of Ghana. *Scientific African*, *10*, e00604. https://doi.org/10.1016/j.sciaf.2020.e00604

Ansah, I. G. K., Appiah-Twumasi, M., & Tsiboe, F. (2023). Starchy staples production shortfalls in Ghana: Technical inefficiency effects outweigh technological differences across ecologies. *PLOS One*, *18*(4), e0284780. https://doi.org/10.1371/journal.pone.0284780

Ansah, I. G. K., Ehwi, J., & Donkoh, S. A. (2018). Effect of postharvest management practices on welfare of farmers and traders in Tamale metropolis and Zabzugu District, Ghana. *Cogent Food & Agriculture*, *4*(1), 1475916. https://doi.org/10.1080/23311932.2018.1475916

Asala, S. W., & Ebukiba, E. S. (2016). Profitability of yam production in Southern Guinea Savanna zone of Nigeria. *Net Journal of Agricultural Science*, *4*(1), 9–14.

Baffour-Ata, F., Awugyi, M., Ofori, N. S., Hayfron, E. N., Amekudzi, C. E., Ghansah, A., & Akorli, R. (2023). Determinants of yam farmers' adaptation practices to climate variability in the Ejura Sekyedumase municipality, Ghana. *Heliyon*, *9*(3), e14090. https://doi.org/10.1016/j.heliyon.2023.e14090

Balda, S., Sharma, A., Capalash, N., & Sharma, P. (2021). Banana fibre: A natural and sustainable bioresource for eco-friendly applications. *Clean Technologies and Environmental Policy*, *23*(5), 1389–1401. https://doi.org/10.1007/s10098-021-02041-y

Bolarin, O., Adebayo, S. A., & Komolafe, S. E., and (2022). Resilience building mechanism to mitigate effects of climate change by yam farmers in Benue State, Nigeria. *Sarhad Journal of Agriculture*, *38*(4), 1279–1288. https://doi.org/10.17582/journal.sja/2022/38.4.1279.1288

Brooker, R. W., Hawes, C., Iannetta, P. P. M., Karley, A. J., & Renard, D. (2023). Plant diversity and ecological intensification in crop production systems. *Journal of Plant Ecology*, *16*(6), 1–15. https://doi.org/10.1093/jpe/rtad015

Chavas, J. P., & Nauges, C. (2020). Uncertainty, learning, and technology adoption in agriculture. *Applied Economic Perspectives and Policy*, *42*(1), 42–53. https://doi.org/10.1002/aepp.13003

Cui, L., & Wang, W. (2023). Factors affecting the adoption of digital technology by farmers in China: A systematic literature review. *Sustainability*, *15*(20), 14824. https://doi.org/10.3390/su152014824]

Curry, G. N., Nake, S., Koczberski, G., Oswald, M., Rafflegeau, S., Lummani, J., Peter, E., & Nailina, R. (2021). Disruptive innovation in agriculture: Socio-cultural factors in technology adoption in the developing world. *Journal of Rural Studies*, *88*, 422–431. https://doi.org/10.1016/j.jrurstud.2021.07.022

Danquah, E. O., Danquah, F. O., Frimpong, F., Dankwa, K. O., Weebadde, C. K., Ennin, S. A., Asante, M. O. O., Brempong, M. B., Dwamena, H. A., Addo-Danso, A., Nyamekye, D. R., Akom, M., & Opoku, A. Y. (2022). Sustainable intensification and climate-smart yam production for improved food security in West Africa: A review. *Frontiers in Agronomy*, *4*, 1–13. https://doi.org/10.3389/fagro.2022.858114

Darkwa, K., Olasanmi, B., Asiedu, R., & Asfaw, A. (2020). Review of empirical and emerging breeding methods and tools for yam (Dioscorea spp.) improvement: Status and prospects. *Plant Breeding*, *139*(3), 474–497. https://doi.org/10.1111/pbr.12783

Dedehouanou, H., Affokpon, A., Badou, A., Guenther, R. H., Mathew, R., Sit, T. L., Byrd, M. V., Pirzada, T., Pal, L., Khan, S. A., & Opperman, C. H. (2022a). Comprehensive perception approach of adoption: Innovative wrap & plant technology for nematodes management on yam. *Advances in Social Sciences Research Journal*, *9*(4), 355–368. https://doi.org/10.14738/assrj.94.12225

Dedehouanou, H., Affokpon, A., Badou, A., Guenther, R. H., Mathew, R., Sit, T. L., Byrd, M. V., Pirzada, T., Pal, L., Khan, S. A., & Opperman, C. H. (2022b). Wrap & plant technology: An innovative and cost-effective method for seed yam treatment for nematode control in fields. *Advances in Social Sciences Research Journal*, *9*(5), 39–59. https://doi.org/10.14738/assrj.95.12240

Dessart, F. J., Barreiro-Hurlé, J., & Van Bavel, R. (2019). Behavioural factors affecting the adoption of sustainable farming practices: A policy-oriented review. *European Review of Agricultural Economics*, *46*(3), 417–471. https://doi.org/10.1093/erae/jbz019

Dissanayake, C. A. K., Jayathilake, W., Wickramasuriya, H. V. A., Dissanayake, U., Kopiyawattage, K. P. P., & Wasala, W. M. C. B. (2022). Theories and models of technology adoption in agricultural sector. *Human Behavior and Emerging Technologies*, *2022*, 1–15. https://doi.org/10.1155/2022/9258317

Easmin, F. (2022). A participatory approach: Climate change perceptions and adaptation strategies of small-holder farmers in Bangladesh. *International Journal of Environment and Climate Change*, *12*(11), 335–343. https://doi.org/10.9734/ijecc/2022/v12i1130979

Ema, E.-O. S., Obidiegwu, J. E., Chilaka, C. A., & Akpabio, E. M. (2023). Indigenous food yam cultivation and livelihood practices in cross river state, Nigeria. *World*, *4*(2), 314–332. https://doi.org/10.3390/world4020020

Emerick, K., & Dar, M. H. (2021). Farmer field days and demonstrator selection for increasing technology adoption. *The Review of Economics and Statistics*, *103*(4), 1–14. https://doi.org/10.1162/rest_a_00917

Gabriel, A., & Gandorfer, M. (2023). Adoption of digital technologies in agriculture—an inventory in a European small-scale farming region. *Precision Agriculture*, *24*(1), 68–91. https://doi.org/10.1007/s11119-022-09931-1

Ghana Export Promotion Authority (GEPA). (2019). *Potential markets–yam*. https://www.gepaghana.org/import/ghana-product/yams-from-ghana/.

Ghana Export Promotion Authority (GEPA). (2022). Annual non-traditional export statistics report 2022. https://drive.google.com/file/d/132gOYOLl_oTB-rwWflG8Zt8bUtdIAYq0/view

Kiba, D. I., Hgaza, V. K., Aighewi, B., Aké, S., Barjolle, D., Bernet, T., Diby, L. N., Ilboudo, L. J., Nicolay, G., Oka, E., Ouattara, F. Y., Pouya, N., Six, J., & Frossard, E. (2020). A transdisciplinary approach for the development of sustainable yam (Dioscorea sp.) production in West Africa. *Sustainability*, *12*(10), 4016. https://doi.org/10.3390/su12104016

Liu, L., Danquah, E. O., Weebadde, C., Bessah, E., & Basso, B. (2021). Modeling soil organic carbon and yam yield under different agronomic management across spatial scales in Ghana. *Field Crops Research*, *263*(October 2020), 108018. https://doi.org/10.1016/j.fcr.2020.108018

Masere, T. P., & Worth, S. H., University of KwaZulu-Natal. (2022). Factors influencing adoption, innovation of new technology and decision-making by small-scale resource constrained farmers: The perspective of farmers in lower Gweru, Zimbabwe. *African Journal of Food, Agriculture, Nutrition and Development*, *22*(3), 19994–20016. https://doi.org/10.18697/ajfand.108.20960

Montes de Oca Munguia, O., Pannell, D. J., & Llewellyn, R. (2021). Understanding the adoption of innovations in agriculture: A review of selected conceptual models. *Agronomy*, *11*(1), 139. https://doi.org/10.3390/agronomy11010139

Morse, S. (2022). The role of plant health in the sustainable production of seed yams in Nigeria: A challenging nexus between plant health, human food security, and culture. *Plant Pathology*, *71*(1), 43–54. https://doi.org/10.1111/ppa.13409

Mukaila, R., Falola, A., Awoyelu, F. E., Akanbi, S.-U. O., Chiemela, C. J., Ukwuaba, I. C., Ileka, C. M., & Erim, P. A. (2022). Profitability of Cocoyam production and its determinants in cross river state, Nigeria. *Jordan Journal of Agricultural Sciences*, *18*(4), 279–292. https://doi.org/10.35516/jjas.v18i4.788

Mumah, E., Chen, Y., Hong, Y., & Okello, D. (2024). Machinery adoption and its effect on maize productivity among smallholder farmers in Western Kenya: Evidence from the chisel harrow tillage practice. *Research on World Agricultural Economy*, *5*(1), 1–18. https://doi.org/10.36956/rwae.v5i1.983

Naazie, G. K., Dakyaga, F., & Derbile, E. K. (2023). Agro-ecological intensification for climate change adaptation: Tales on soil and water management practices of smallholder farmers in rural Ghana. *Discover Sustainability*, *4*(1), 4–27. https://doi.org/10.1007/s43621-023-00142-w

Neina, D. (2021). Ecological and edaphic drivers of yam production in West Africa. *Applied and Environmental Soil Science*, *2021*, 1–13. https://doi.org/10.1155/2021/5019481

Neina, D., & Agyarko-Mintah, E. (2023). The Terra Preta Model soil for sustainable sedentary yam production in West Africa. *Heliyon*, *9*(5), e15896. https://doi.org/10.1016/j.heliyon.2023.e15896

Nugroho, H. Y. S. H., Sallata, M. K., Allo, M. K., Wahyuningrum, N., Supangat, A. B., Setiawan, O., Njurumana, G. N., Isnan, W., Auliyani, D., Ansari, F., Hanindityasari, L., & Najib, N. N. (2023). Incorporating traditional knowledge into science-based sociotechnical measures in upper watershed management: Theoretical framework, existing practices and the way forward. *Sustainability*, *15*(4), 3502. https://doi.org/10.3390/su15043502

Okeoghene, E. S., John, E., & Ose, O. O. (2013). Profitability analysis of yam production in Ika south local government area of delta state, Nigeria. *Journal of Biology, Agriculture and Healthcare*, *3*(2), 118–130.

Onwuka, S. (2020). Effect of adoption of improved agricultural technologies on the productivity of yam farmers in Ghana. *Nigerian Agricultural Journal*, *51*(2), 538–544.

Osei-Adu, J., Aidoo, R., Fialor, S. C., Ennin, S. A., Osei, K., & Asante, B. O. (2022). Profitability of positive selection technique for seed yam production in Ghana and Nigeria. *Cogent Economics & Finance*, *10*(1), 2034281. https://doi.org/10.1080/23322039.2022.2034281

Owusu Danquah, E., Dissanayake, H. G., Danquah, F. O., Weebadde, C., Acheampong, P. P., & Ennin, S. A. (2023). Financial analysis of pigeonpea-yam cropping system options and implications on profitability of smallholder farmers in Ghana. *Agroforestry Systems*, *97*(1), 69–79. https://doi.org/10.1007/s10457-022-00788-x

Pirzada, T., Affokpon, A., Guenther, R. H., Mathew, R., Agate, S., Blevins, A., Byrd, M. V., Sit, T. L., Koenning, S. R., Davis, E. L., Pal, L., Opperman, C. H., & Khan, S. A. (2023). Plant-biomass-based hybrid seed wraps mitigate yield and post-harvest losses among smallholder farmers in sub-Saharan Africa. *Nature Food*, *4*(2), 148–159. https://doi.org/10.1038/s43016-023-00695-z

Raimi, A., Adeleke, R., & Roopnarain, A. (2017). Soil fertility challenges and Biofertiliser as a viable alternative for increasing smallholder farmer crop productivity in sub-Saharan Africa. *Cogent Food & Agriculture*, *3*(1), 1400933. https://doi.org/10.1080/23311932.2017.1400933

Rangsiwanichpong, P., & Melesse, A. M. (2022). Analyzing the benefit-cost ratio of sediment resources by remote sensing data in the Ping River Basin, Thailand. *Water*, *14*(13), 2071. https://doi.org/10.3390/w14132071

Rizzo, G., Migliore, G., Schifani, G., & Vecchio, R. (2024). Key factors influencing farmers' adoption of sustainable innovations: a systematic literature review and research agenda. *Organic Agriculture*, *14*(1), 57–84. https://doi.org/10.1007/s13165-023-00440-7

Siva, R., Kesavaram, B., Jones Martin, J., Mathiselvan, G., Navas, K. B., & Sangeetha, M. (2021). Mechanical behavior of sisal and banana fiber reinforced hybrid epoxy composites. *Materials Today: Proceedings*, *44*, 3692–3696. https://doi.org/10.1016/j.matpr.2020.10.805

Tanko, M., & Alidu, A. F. (2017). Profit efficiency of small scale yam production in Northern Ghana. *International Journal of Development and Economic Sustainability*, *5*(1), 69–82.

Thakur, N., Nigam, M., Mann, N. A., Gupta, S., Hussain, C. M., Shukla, S. K., Shah, A. A., Casini, R., Elansary, H. O., & Khan, S. A. (2023). Host-mediated gene engineering and microbiome-based technology optimization for sustainable agriculture and environment. *Functional & Integrative Genomics*, *23*(1), 57. https://doi.org/10.1007/s10142-023-00982-9

Tolessa, A., Louw, T. M., & Goosen, N. J. (2022). Probabilistic techno-economic assessment of anaerobic digestion predicts economic benefits to smallholder farmers with quantifiable certainty. *Waste Management*, *138*(July 2021), 8–18. https://doi.org/10.1016/j.wasman.2021.11.004

Wumbei, A., Kengni Nerlus Gautier, S., Kwowura Kwodaga, J., Fovo Joseph, D., & Joseph Hubert Galani, Y. (2023). State of the art of yam production. In Prashant Kaushik (Ed.), *Advances in Root Vegetables Research* (pp. 1–26). London: Intech Open. https://doi.org/10.5772/intechopen.106504

Xie, H., Perez, N., Anderson, W., Ringler, C., & You, L. (2018). Can Sub-Saharan Africa feed itself? The role of irrigation development in the region's drylands for food security. *Water International*, *43*(6), 796–814. https://doi.org/10.1080/02508060.2018.1516080