UNIVERSITY OF CAPE COAST

IMPROVING PRODUCTION EFFICIENCIES, FOOD SECURITY, AND LIVELIHOOD NEXUS: STUDY OF SMALLHOLDER ARABLE CROP PRODUCERS IN BOTSWANA

TEBOGO MOKUMAKO

2023

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BY

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Thesis submitted to the Department of Agricultural Economics and Extension of the School of Agriculture and Natural Resources, University of Cape Coast, in partial fulfillment of the requirements for the award of Doctor of Philosophy degree in Agricultural Economics

SEPTEMBER 2023

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:.. Date:..........................

Name: Tebogo Mokumako

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

Low agricultural productivity aggravates the food insecurity situation in Botswana, resulting in the government rolling out subsidy programs to increase food production efficiency. How efficient a farmer is, determines his/her level of productivity and income and, subsequently, how food secure the family becomes. Thus, improvement in the production efficiency of arable crops is crucial for smallholder farmers' livelihood and food security. This study examines the effects of the timeliness of farmers receiving production inputs subsidy on the Botswana smallholder arable crop farmers' production efficiencies and, subsequently, evaluates how efficiencies impact farm households' livelihood and food security. A structured interview schedule was used to collect data from four hundred and seventy arable crop farmers who were selected using a multi-stage random sampling technique. For analysis, the study used the Stochastic Frontier Analysis (SFA), a Livelihood Assessment Index (LAI) and the Household Food Insecurity Access Scale (HFIAS). Furthermore, Seemingly Unrelated Regression (SUR) models were estimated to establish the empirical relationships between the farmers' livelihood on the one hand and production efficiencies and food security status on the other hand. The results revealed very low production efficiencies, high food security and livelihood status. The timeliness of receiving input subsidies by farmers negatively affected their efficiency highly. Therefore, policy should focus on improving the subsidy timeliness to increase farmers' efficiency, livelihoods and food security.

KEY WORDS

Arable crop

Efficiency

Food security

Input subsidy

Livelihoods

Productivity

Smallholders

ACKNOWLEDGEMENTS

Had it not been for the vital contribution of several individuals who have been acknowledged here, this work would not have been a success. First, I would like to thank my supervisory team; Professor Henry Nana De-Graft Acquah, Professor Samuel Kwesi Ndzebah Dadzie, and Dr Alexander Tetteh Kwasi Nuer, for all the guidance and support throughout the project from the day I started my studies. Professor Samuel Kwesi Ndzebah Dadzie, you have been a true mentor and the ideal supervisor I could ever ask for. I sincerely thank Professor Henry Nana De-Graft Acquah for all the valuable lessons and Dr Alexander Nuer for always being there when I needed to validate my ideas.

To my senior, Reverend Dr Emmanuel Wisgtos Inkoom, I want to say thank you for the data science skills you shared and imparted to me. Dr Michael Nkuba, thank you for the discussions we had that shed so much light always. The Ministry of Agricultural Development and Food Security in Botswana, especially Mr Richard Muyoba, selflessly assisted in revising the survey tool. Department of Crops Senior management and officers in the Central District, all extension officers that rendered assistance, and the farmers from whom I learnt a lot, I appreciate all your contribution to the success of this study. Thank you, to my research assistant, Ms Khumoetsile Octavia Sebotsa, and all the enumerators. Last but not least, a huge thank you to Botswana University of Agriculture (BUAN) and RUFORUM for the financial assistance. I appreciate you all for the support.

DEDICATION

To my family, for all the courage I gathered to get this far was through your motivation and inspiration.

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LIST OF ABBREVIATIONS

AE	Allocative efficiency
ALDEP	Arable Land Development Program
ARAP	Accelerated Rain-Fed Arable Program
BWP	Botswana Pula
CIA	Caloric intake assessment
COVID-19	Corona Virus Disease of 2019
DEA	Data Envelopment Approach
DFID	Department for International Development
DIA	Dietary intake assessment
DMU	Decision-making unit
EE	Economic efficiency
FANTA	Food and Nutrition Technical Assistance
FAO	Food and Agricultural Organization
FAP	Financial Assistance Programme
GDP	Gross Domestic Product
HFIAP	Household Food Insecurity Access Prevalence
HFIAS	Household Food Insecurity Access Scale
HFSSM	Household Food Security Survey Measure
ISPAAD	Integrated Support Program for Arable Agricultural Development
MLE	Maximum Likelihood Estimates
NAMPAAD	National Agriculture Master Plan for Arable Agriculture and Dairy Development

OLS	Ordinary Least Squares
SDG	Sustainable Development Goals
SFA	Stochastic Frontier Analysis
SFPF	Stochastic Frontier Production Function
SLF	Sustainable Livelihood Framework
SSA	Sub Saharan Africa
SUR	Seemingly Unrelated Regressions
TE	Technical efficiency
TFP	Total Factor Productivity
UNDP	United Nations Development Programme
USAID	United States Agency for International Development

CHAPTER ONE

INTRODUCTION

Background to the Study

Attainment of food security is a primary policy focus for many countries worldwide. FAO, IFAD, UNICEF, WFP, and WHO (2022) estimated the number of hungry people worldwide to have reached 828 million in 2021, with Africa having the highest percentage increase. The increase poses a global concern for achieving Sustainable Development Goal number two (SDG-2). Sustainable Development Goal 2 calls for achieving food security, ending hunger, and ensuring sustainable food production by 2030 (FAO, IFAD, UNICEF, WFP, & WHO, 2019). Africa has the largest population of people living under food insecurity, mainly in rural areas relying on Agriculture. Agriculture is the primary source of food security and livelihood through household farming for over 70 percent of the rural population in Sub-Saharan Africa (SSA) (Moyo, 2016). Low agricultural productivity aggravates the food insecurity situation in Africa. It is argued that increasing the productivity of cereal and starchy root crops is crucial for attaining sustainable household food security, as these crops provide two-thirds of the total energy intake and three-quarters for the poor (Muzari, 2013; Chandrasekara & Kumar, 2016).

In Botswana, agricultural productivity has been extremely low. Farmers realize dwindling and variable yields yearly, recording fewer kilograms harvested per hectare than other landlocked neighbouring countries like Zimbabwe and Zambia. Low productivity has affected the food security of

Botswana in such a way that the country relies mainly on food imports from neighbouring countries, especially South Africa. Food imports account for over 90% of the food in the market consumed by Batswana (Clapp & Moseley, 2020). Imports help the country achieve food security at the national level by reducing imbalances between local demand and supply. On the other hand, Botswana has parts of its population that are poor and food insecure because of high food prices and low earnings (Moseley, 2016; Mosha, 2016). The government provides food-based social safety net programs to help these groups of people.

Given recent experiences, the country has proven to be very vulnerable to shocks. First, the global economic recession of 2007/2008 resulted in domestic food prices rising sharply (Batisani, 2012). Tlhalefang and Galebotswe (2013) indicated that the government of Botswana increased expenditures during the global economic downturn to support its poor and vulnerable citizens. Furthermore, there was a balance-of-payments pressure due to food price shocks, which increased the import bill in response to higher food prices (Tlhalefang & Galebotswe, 2013). Consequently, foreign exchange constraints worsened, affecting food security directly (Kebakile, 2008).

In addition, recently, because of the novel Corona Virus Disease of 2019 (COVID-19), countries imposed national lockdowns and movement restrictions to control and contain the virus. Due to the measures for COVID-19 protocols, Botswana experienced delays in the trucking of food from South Africa and disruptions in the food import supply chain, resulting in food shortages within the country. This resulted in panic buying by those with higher incomes, leaving most people without food supplies. The government had to intervene and provided households with food hampers. Thus, food packages were distributed to almost all families nationwide during the lockdown. The national food hampers during the COVID-19 lockdown exerted financial pressure on the country's economy as government expenditure increased to provide for increased food needs while fighting the coronavirus. This was a wake-up call for Botswana to relook into its agricultural sector and find ways to increase local food production and security.

Numerous studies suggest that achieving food security requires increasing domestic food production and coming up with ways of increasing incomes of people living in rural areas (Dadi, Burton, & Ozanne, 2004; FAO, 2017; Magaña-lemus, Ishdorj, Rosson III, & Lara-álvarez, 2016). Increasing food production can be achieved through increased productivity (Danso-Abbeam, Ehiakpor, & Aidoo, 2018). Productivity refers to the efficiency of producers transforming production inputs into output in a production process (Coelli, Rao, O'Donnel, & Battesse, 2005). As a concept, efficiency describes how well inputs are turned into outputs using particular processes.

Based on Farrell (1957), efficiency is divided into two categories: (1) technical efficiency, which describes a firm's ability to maximize production from a set of inputs, and (2) allocative efficiency, which describes a firm's ability to use inputs in optimal proportions, given their specific prices.

Combining the two measures yields a full measure of economic efficiency (Coelli, 1995a). According to Coelli (1995b), productivity enhancement can be achieved through improved allocative, technical, and economic efficiency. Based on allocative efficiency, a farm can have technical efficiency and still be under or over-utilizing inputs relative to another, given their costs, thus, creating room for improvement (Kumbhakar, Parmeter, & Zelenyuk, 2020). Farrell showed that economic efficiency was equal to the product of technical and allocative efficiencies, therefore, a better measure of productivity. Increased productivity means more output produced from the same amount of inputs.

According to Mingsheng *et al*. (2012), China increased crop production by intensively increasing productivity and realized an almost threefold increase in yields of cereal crops without increasing the cultivated land. Iheke and Onyendi (2017) contended that productivity is determined by how efficient farmers are in their production; this ultimately determines their incomes and, subsequently, their food security. Iheke and Nwankwo (2016) asserted that efficiency is crucial in increasing productivity. They further stated that increasing agricultural production and improving farmers' food security and income depends on assessing the relative performance of the processes used to transform given inputs into outputs.

In consideration of the agricultural sector's declining productivity, the Botswana government has invested in input subsidies towards motivating the growth of the sector as an effort to improve food security and the welfare of the farmers (Motsatsi, 2015). According to Zhu and Lansink (2013), input subsidies can impact production by changing farms' technical and economic performance, particularly efficiency. The authors argued that subsidies give farmers the required capital and should boost technical efficiency. Conversely, if a subsidy is provided in cash, farmers treat it as some sort of income. In that case, they may be less motivated to produce and use it otherwise, resulting in declining technical efficiency. In Botswana, the arable crop sector productivity continues to decline despite government support. Therefore, an important research focus should be directed at improving the production efficiencies of arable producers, as this will provide policy insight into coming up with or modifying government support programs for farmers.

General Presentation of Botswana

With an estimated population of 2,346,179 (Statistics Botswana, 2022), Botswana is a semi-arid landlocked country in Southern Africa. Like most African countries, in Botswana, over 70% of the population dwells in rural areas, and their livelihoods depend on agriculture (Statistics Botswana, 2019). Agriculture is one of the main economic sectors, providing Batswana with food, income, and jobs, particularly the rural population (Bahta, Wanyoike, Katjiuongua, & Marumo, 2017). Despite playing a significant role in the livelihoods of Batswana, agriculture's contribution to the national GDP has been declining since its independence in 1966. The gradual decline followed the discovery of diamonds, which became the most important economic sector, earning foreign reserves for Botswana and moving the country from being one of the least developed to a middle-income economy.

Agriculture's declining role in Botswana's economy has been primarily linked to the discovery of diamonds. However, other causes of the declining performance trend are within the sector itself (Seleka, 1999). This forced the country to rely more on food imports while taking away the spirit of self-sufficiency from the nation. Initially, the agricultural sector was committed to a food self-sufficiency strategy before the early 1990s, which was revised in 1991. The Food Security Strategy was introduced at household and national levels (Lado, 2001). Lado and the previous agricultural economists argued that Botswana's food self-sufficiency policy strategy had severe environmental implications, and the physical and climatic conditions in most parts of the country showed that arable farming was best left as a marginal activity. The food security strategy was then adopted to enable the country to meet its national food requirements. Since then, the country has been importing most of its food needs, including sorghum and maize, the major staple cereals. Mosha (2016) reckons that the country also imported because the government had the resources to buy food from the neighbouring countries.

Although the discovery of diamonds earns foreign exchange for the country and allows the government to import food, mining provides little employment. Over seventy percent of the nation in rural areas still subsists on agriculture. The sector comprises two disparate farming systems: the commercial and traditional subsistence systems that produce crops and livestock. The two differ in the type of land ownership, technological usage, and marketing of produce (FAO & GoB, 2014). Most producers are smallholder farmers operating under the traditional sector through subsistence farming, dominated by farmers with small traditional holdings averaging five hectares. Over two-thirds of these subsistence farmers practice mixed farming, where they grow crops on their smallholdings and graze livestock communally (Motsatsi, 2015).

Smallholder farmers face many challenges in this traditional set-up, such as poor soil fertility, unfavourable climatic conditions, and their production depending entirely on rainfall. Nevertheless, these smallholder farmers collectively contribute most of the aggregate food produced in the country (Statistics Botswana, 2019). However, their yields are relatively low compared to the commercial sector (Bahta *et al*., 2017). For these reasons, through various subsidy programs, the government of Botswana decided to dedicate an amount of money to encourage farmers to expand production, increase productivity, and produce food for the country, particularly to achieve food security (National Planning Commission, 2017; Motsatsi, 2015).

These programs have overtime been changed and included: National Agriculture Master Plan for Arable Agriculture and Dairy Development (NAMPAAD); the Accelerated Rain-Fed Arable Program (ARAP); Arable Land Development Program (ALDEP); Financial Assistance Programme (FAP), which provided the financial funding for agricultural projects; and the current Integrated Support Program for Arable Agriculture Development (ISPAAD) (Motlhwa, Mgale, & Yan, 2019). These programs have changed over time but with similar set goals. Some of the programs were developed to provide farmers with financial assistance and later developed to provide freely accessible capital inputs in the arable sector, such as seeds and fertilizers. The most current initiative is ISPAAD, set up in 2008 to increase productivity in the arable sector and improve food security (Motlhwa, Mgale, & Yan, 2019).

ISPAAD was developed with the principal goal of improving food security on a national and household level, increasing grain production, enhancing extension outreach and commercializing agriculture by facilitating mechanization, access to agricultural inputs and credit (Seleka & Mmopelwa, 2018). The program encourages farmers to use improved production technologies, including row planting, harrowing their fields, and applying fertilizers and agrochemicals. According to the ISPAAD guidelines as MoA (2013) provided, the program provides farmers with a land cultivation subsidy to cover up to 16ha. Through ISPAAD packages, subsistence farmers receive a 100 per cent hybrid seed subsidy to cover up to 5ha (the remaining 11ha covered at a 50 per cent subsidy), but if using only open-pollinated varieties, a total subsidy to cover the maximum of 16ha is to be given.

ISPAAD provides seeds for the major grain crops sorghum, maize, millet, and cowpeas, subject to availability and suitability to the farming areas. The program engages private contractors to plough, harrow and row plant for farmers. Therefore, farmers use tractor-hire services for mechanization. The government fully pays up to a 5ha tractor-hire service for each farmer. However, the farmers identify the tractor service provider of their choice. The tractor-hire services must register with the extension service office to facilitate payments. The fertilizer application is offered for free to cover up to 5ha. Farmers are also eligible to receive herbicides to cover up to 5ha. If the farmer requires more, they are given free for 5ha and pay 50% of the price for the remaining supply, but this should not be for hectarage exceeding 16ha.

The subsidy pays tractor-service providers P800/ha for ploughing and row planting, while minimum tillage and harrowing are set at P500/ha and P360/ha, respectively. However, row planting and ploughing are paid for regardless of whether the farmer uses animal draft power or a tractor. Therefore, farmers who use animal draft power pocket the money themselves, serving as some form of income for the individual farmer. However, the seedbed preparation must be acceptable (MoA, 2013). All the other subsidy inputs are provided in physical quantities, and farmers must register at the end of each cropping season for access in the next season.

According to Seleka and Mmopelwa (2018), ISPAAD's success in reforming the agricultural sector to accomplish government goals has been dismal. Arable farmers continue to realise decreasing yields, and thus productivity is still very low. Sigwele and Orlowski (2014) mentioned that ISPAAD consumes about twenty million dollars ($20m) per annum, but the crop output does not match this expenditure. Some researchers point to unfavourable climatic conditions in explaining the sector's unimpressive performance (Irz & Thirtle, 2004; Kashe, Kolawole, Moroke, Mogobe, & Oarabile, 2019). Others allude to poor monitoring of the support programs (Motlhwa, Mgale, & Yan, 2019; Marumo, Tselaesele, Batlang, Nthoiwa, & Jasen, 2014). In addition, although farmers like the program, they complain about the timing of the input delivery, given that the country only gets a small amount of rain during the cropping season.

According to Laux, Jäckel, Munang, and Kunstmann (2009), the most crucial factor impacting crop growth and yields is rainfall, particularly in semi-arid or arid regions where rainfall is seasonal and occurs for a few months only. Therefore, the timing of the farmers receiving the inputs impacts the ploughing time. Reynold *et al.* (2015) added that the deficient performance is also worsened by poor farming practices that reduce productivity, resulting in lower production efficiencies, low crop yields, and decreased food security. In this case, the government needs to pay more attention to ways to improve agricultural productivity, such as efficient production, proper monitoring, and the proper use of government subsidies for inputs.

Statement of the Problem

Smallholder arable crop production in Botswana plays a significant role in livelihoods and ensuring the nation's food security. However, arable crop production is characterised by low productivity levels. Although the government supports smallholder arable crop farmers through subsidy programs such as ISPAAD, the sector's productivity continues to decline (Batlang & Nthoiwa, 2018; Motsatsi, 2015; Temoso, Villano, & Hardley, 2018). Little research has been conducted to investigate and understand the productivity of arable crop farming and the factors contributing to the low productivity. Finding studies conducted to examine the farm-level production efficiencies of the arable crop farmers in Botswana proved difficult when designing this study.

Moreover, considering the amount of government support to smallholder arable crop farmers and their significant role in ensuring household food security and providing for rural livelihoods, the arable crop sector has generally received minimal work on the effects of the subsidy programs such as the current ISPAAD on the performance and productivity of the farms, despite the policy target of improving food security through increased productivity in the sector. Although scholars, researchers and consultants (e.g., Motlhwa, Mgale, & Yan, 2019; Seleka & Mmopelwa, 2018; Marumo *et al*., 2014) have evaluated the program's performance, the evaluations revealed that the support succeeded in increasing the cultivated area. However, the findings are silent on how the subsidy program has contributed to smallholder farmers' productivity and food security. Furthermore, the previous studies have also not done much-assessing factors affecting farm-level efficiencies and also to include the time discrepancies in the smallholder farmers' receiving inputs from the subsidy program. Therefore, there is a knowledge gap on how with the subsidy program in Botswana, the efficiencies in farm production have contributed to food security and livelihoods of the farming households. Therefore, the study examines the effects of timeliness of the delivery, and the quality of ISPAAD program inputs and services on the efficiencies of the farmers and further how efficiencies contribute to improving farmers' food security and livelihoods.

Research Objectives

The study's general objective was to assess the effects of timeliness of the delivery, and the quality of ISPAAD program inputs and services on the efficiencies of the farmers and further determine how efficiencies contribute to improving farmers' food security and livelihoods of smallholder arable crop farmers in Botswana.

Specific Objectives

1. Analyze the technical, allocative, and economic efficiency of arable crop producers in Botswana.
2. Determine the socio-economic and institutional support factors influencing technical, allocative, and economic efficiencies among the smallholder arable farmers in Botswana.
3. Evaluate the household livelihood status of the arable crop farmers in Botswana.
4. Examine the household food security status of the arable crop farmers in Botswana.
5. Measure the effect of the production efficiencies on the livelihood status of the arable crop farmers in Botswana.
6. Measure the effect of the production efficiencies on the food security status of the arable crop farmers in Botswana.

Research Questions

With the guidance of the research supervisors, the student researcher formulated the following research questions to guide the study.

1. What are the technical, allocative, and economic efficiency levels of arable crop producers in Botswana?
2. What factors influence the production efficiency of arable crop producers in Botswana?

3. What is the household livelihood status of the arable crop producers in Botswana?
4. Are the arable crop farmers in Botswana food secure?

Research Hypotheses

The study set hypotheses were as follows.

1. Hypothesis 1:

H_0: Production efficiencies of the arable crop farmers in Botswana have no significant effect on their livelihood status.

H_a: Production efficiencies of the arable crop farmers in Botswana significantly affect their livelihood status.

2. Hypothesis 2:

H_0: Production efficiencies of the arable crop farmers in Botswana have no significant effect on their food security status.

H_a: Production efficiencies of the arable crop farmers in Botswana significantly affect their food security status.

Significance of the Study

This study contributes to the knowledge of efficiency through new insight on;

1. Time factor as a significant contributor to productivity hence impacting efficiency
2. Effects of government support/subsidy (ISPAAD program) on smallholder arable crop farmers' efficiency
3. Effects of improved efficiency on food security
4. Effects of improved efficiency on farming households' livelihoods

The results of the study are of great benefit to the following.

Farmers: the study shows the level of technical, allocative, and economic inefficiencies among the farmers revealing the potential to improve their productivity given government support.

Extension work and the Botswana Ministry of Agricultural Development and Food Security (MoA): the findings of the study highlight farm and farmer characteristics most likely to enhance productivity among the farmers; thus, extension work can focus on targeting those factors to improve arable farm productivity.

Policymakers: the study brings policy insight to policymakers and those responsible for reviewing or designing programs that contribute to measures needed to increase the productivity of the agricultural sector for increased food production in Botswana.

Future Researchers: the study approach and its findings can be used as a reference and a guide by other researchers who want to conduct similar or related studies on productivity and efficiency.

Delimitations

The study focused on the smallholder arable crop farmers who benefited from the ISPAAD input subsidy program. The program helps everyone, regardless of their socio-economic status. It is all-encompassing and inclusive of marginalized groups, like, the elderly, women, the uneducated, and people with disabilities. Although ISPAAD is inclusive, the study focused only on the farmers who had received at least one of the subsidy benefits during the 2020–2021 cropping season. Observation from the field showed that a few farmers did not access the program benefits during the particular cropping season due to technical changes at the government agricultural offices that were communicated late, leaving some farmers out.

The study included major field crops that farmers in the study area produced despite the possibility of more or fewer other crops being grown by arable farmers in Botswana. Batswana grow various crops, including sorghum, maize, millet, cowpeas, sunflower, groundnuts, pumpkins, different melons, and fodder crops (e.g., lablab). Under the ISPAAD program, farmers get seeds for crops: sorghum, maize, millet, cowpeas, and half subsidy for lablab. These ISPAAD-selected crops are considered important cereal crops identified for food security purposes for Batswana. However, the study included the non-ISPAAD covering field crops (such as melons, sweet reed, sunflower, pumpkins, and pulses) as they added to the farmers' total output and were produced with the main crops mixed in the same fields.

The study was conducted in the Central District, one of the nine Botswana districts, with its rural community subsisting mainly on mixed agricultural production. However, the study focused on arable crop production and did not consider the livestock-rearing effect on efficiency estimation because the main focus of the study was the policy effect on arable production. Less focus was directed to livestock production as there are other several interventions for such. However, the effects of livestock rearing were considered in the factors influencing the efficiencies although aggregated as sources of livelihood which provided income to the farmers.

Limitations

Several limitations were encountered while conducting this study.

1. The study relied on farmers recalling the farm production information; however, not all could do so. Therefore, some farmers may have exaggerated or omitted some vital information.
2. There was difficulty in standardising units. Farmers reported their yields in various storage and measurement equipment pieces that were difficult to convert to standard units. In dealing with the measurement issue, the research assistants and enumerators requested that farmers show the equipment used, which in some instances was not readily available, leaving the researcher with a vague estimation from what the farmer described.
3. The COVID-19 pandemic delayed the starting of the fieldwork due to the student (principal) researcher contracting the virus. Some farmers also had some rejection, in fear of COVID-19. Enumerators called farmers before the visit to explain what would be done when the interviewer got to their homesteads to interview them.
4. The study used production data from the last cropping season, which had already ended. Some farmers had relocated from the ploughing fields to the villages, sometimes making it difficult to conduct the interviews as scheduled hence adding more time to the fieldwork exercise.
5. The data collection was conducted just at the end of the cropping season. This may have influenced the findings on food insecurity

because, at the data collection time, it is possible farmers still had fresh produce from the farms. Moreover, the analytical method used for food insecurity measurement only considered thirty days.

Definition of Terms

Arable crop production – the cultivation of field crops (mainly Botswana staple cereal crops; sorghum, millet, and maize) under rainfed conditions.

Batswana – the people of Botswana

Botswana Pula (BWP) – Botswana currency; one USD = P12.95 as of November 2022.

Efficiency – how well inputs are turned into outputs in production using the available resources and technologies.

Food security – the ability of people to access adequate nutritious food that meets their dietary requirements at all times, to sustain a healthy lifestyle and perform daily activities.

Input subsidy refers to government assistance given to farmers to enhance their production. It may include cash payments, supply of farm capital inputs such as seeds, fertilizers, agrochemicals and services such as tractors ploughing fields.

Ipelegeng – a cash-for-work government programme that was set to provide cheap labour for government development projects, such as road maintenance and other local government projects requiring manual labour.

Livelihoods – a way of life of the people that enhances their day-to-day sustenance.

Production efficiencies – the efficiency of production entailing technical, allocative and economic efficiencies.

Productivity – the efficiency of obtaining output from inputs in production.

Organization of the Study

The study is organized into six (6) main chapters.

Chapter one is an introductory chapter which consists of the background of the study, the problem statement, the study objectives, hypotheses, the significance of the study, scope and limitations and the definition of key terms used in the study.

Chapter Two, the Literature Review, presents the theoretical underpinnings of the study and provides the empirical review of literature related to the study.

Chapter Three presents the research methodology used in the study. It introduces the study area and includes the research philosophy, the research design, the population, sample and sampling techniques, instruments used, and data collection and analytical methods applied in the study.

Chapter Four presents the demographic results and discussion of the study's first objective on efficiency levels, results and discussion on the farmers' livelihood and food insecurity statuses.

Chapter Five presents the results and discussion of the relationships between production efficiencies and farmers' livelihoods; and production efficiencies and food insecurity.

Chapter Six presents the summary of the key findings of the study, conclusions, recommendations, and policy implications from the study findings.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter discusses the theories and empirical studies that provide a background and basis for the current study. The chapter presents the literature review according to the order of the study objectives. It begins with a review of arable crop production in Botswana, followed by the concepts and theories that guided the study and the empirical review. Specifically, the literature review discusses the theory of farm production, productivity and efficiencies, factors influencing production efficiencies. Literature was also reviewed on factors influencing production efficiencies, as well as sustainable livelihoods, food security concepts, and their respective empirical findings. The chapter ends with a conceptual framework demonstrating how the study's variables are related.

Arable crop production in Botswana

Botswana's smallholder arable crop production remains an essential livelihood source for the rural community, like in many sub-Saharan countries. However, crop production in Botswana has shown a continual decline, as highlighted by different agricultural statistics reports of the Central Statistics Office of the country. Although smallholder farmers prioritize feeding their families from their production, they also sell their little surplus in the market to generate income (World Bank, 2019).

Even though the productivity of this sub-sector has stagnated over the years, commercial producers tend to be doing much better than traditional smallholder farmers. Although variable at times, staple cereal crop yields have declined from 1979 to recent years (Statistics Botswana, 2018). For instance, the yields in the 2011 harvesting season for maize and sorghum were reported to be 19 237 kg/ha and 192 kg/ha of maize in the commercial and traditional sub-sectors, respectively, while sorghum was 4,106 kg/ha for commercial producers while traditional producers only realized 93 kg/ha (Statistics Botswana, 2014).

In recent years, the yields have been variable but reduced tremendously for commercial and traditional sectors. According to Statistics Botswana (2019), yields in the traditional sector were 251kg/ha for sorghum, which improved from the previously recorded 83kg/ha in 2015. Maize also increased in 2017 to 225kg/ha after recording 23kg/ha in 2015. In 2015, the commercial sector recorded a decline in the average of 1819kg/ha and 714kg/ha for sorghum and maize, respectively. There is no production data recorded for the commercial sector after that. The decline in the sector's performance is attributable to some factors discussed below.

Factors accounting for the deficient performance of the arable crop sector

The general agricultural sector in Botswana faces several challenges. The obvious challenge is that the country is predominantly arid to semi-arid, with low and erratic rainfalls. Botswana has a total area of 582,000 km2; however, crop farming is only limited to a small area of about 2,500 to 3,800 km^2 on the eastern and northern margins (Bahta *et al.*, 2017). Since the country's crop production relies on rain, yields are typically low due to low and unpredictable rainfall. Nthoiwa, Gombalume, and Nthoiwa (2013) found that another reason leading to low yields, specifically in subsistence farming, is the low adoption rate of enhanced farming technologies and practices by smallholder subsistence farmers in Botswana. They linked the underutilization of land to the possibility of economic constraints on the part of farmers with insufficient resources. The authors further cited reasons contributing to the low productivity of smallholder arable crop farmers. These reasons include the farmers' preference for one crop over the others, poor soils, outbreaks of diseases and pests, and a dysfunctional input-output market also worsened by poor farm-to-market roads and storage facilities and underutilization of land. However, the government assists farmers with the capital inputs such as seeds to incentivize them to keep producing.

Government Assistance to arable crop producers

Considering this poor performance, the government provided and continues to assist farmers through subsidy programs to promote local food production. Of these programs, the most prominent were the Accelerated Rainfed Arable Program (ARAP) and the now Integrated Support Program for Arable Agricultural Development (ISPAAD). Both these programs have provided funds for expanding cultivated land and free and subsidised inputs, including fertilizers and seeds, to farmers to promote output and productivity growth (Seleka & Mmopelwa, 2018). ARAP was implemented from 1985 to 1996 and was discontinued because the program was unsustainable. Seleka (1999) concluded from a review that ARAP achieved its objectives of increasing cultivated area for cereal crops, output and yields. The program, however, could not sustain its benefits after its lifespan due to its high implementation costs.

ISPAAD succeeded ARAP in 2008, which is currently in place. The main aim behind the inception of ISPAAD was to enhance grain production, improve national and household food security, enable mechanization and access to farm inputs, and improve extension services (Seleka & Mmopelwa, 2018). To achieve these objectives, ISPAAD provides subsistence farmers with free seeds, fertilizers, and ploughing subsidies, conditional on a set amount of hectares. When it started in 2008, the program provided smallholder farmers with a land cultivation subsidy to cover up to 16ha. Farmers received a total subsidy of P400/ha for the first 5ha and a P200/ha subsidy for the remaining 11ha. A farmer would be given P350/ha if the farmer practised minimum tillage. Farmers were encouraged to adopt row planting; therefore, those who used row planting were eligible to receive an additional P150/ha. Farmers received free fertilizers for the first 5ha. The remaining 11ha of the 16ha qualifying were fertilised at half the subsidy rate and was strictly applicable to farmers who had adopted row planting (Seleka & Mmopelwa, 2018). Furthermore, farmers were also receiving P150/ha for harrowing their fields.

During the 2013/2014 cropping season, ISPAAD packages were reviewed, and some adjustments were made (MoA, 2013). Subsistence farmers would now receive a 100 percent subsidy on hybrid seeds covering up to 5ha (the remaining 11ha covered at a 50 percent subsidy). If using only open-pollinated varieties, a total subsidy to cover the maximum of 16ha would be given. Seeds provided would be for the major grain crops; sorghum, maize, millet, and cowpeas, subject to availability and suitability to the farming areas. Fertilizer application would continue to be free fertilizer to cover up to 5ha, and also farmers would be eligible to receive herbicides to cover up to 5ha. Farmers would now be assisted with a total subsidy plough and plant in rows for up to 5 hectares. Ploughing and row planting subsidies were increased to P800/ha, while minimum tillage and harrowing subsidies were adjusted to P500/ha and P360/ha, respectively. The program would now pay private contractors to offer all the mechanization to farmers. As long as the land preparation is acceptable, ploughing and row planting would be paid for regardless of whether the farmer uses animal draft power or a tractor.

Review of theories and concepts

This section reviews the different theories that guided the study. The section is divided into subsections presenting the theories and concepts according to the study objectives.

Production theory in Economics

Theoretical Review

The study's first objective was guided by the theory of production in economics. The production theory was selected because it provides a basis for analyzing production efficiency. Production refers to transforming factors or inputs such as labour, capital, and land into products, services, or output (Chambers, 1988). The revenue, profit and cost frontiers and envelope features underlying the economic theory of production lead to profit-maximizing output supplies and input demands, input demands that minimize costs, and output supplies that maximize revenue (Fried, Lovell, & Schmidt, 2008). The production theory in economics is concerned with how efficiently firms or production units can attain the maximum output possible throughout a production process, hence optimization. Optimization implies production efficiency. According to Kumbhakar *et al.* (2020), production efficiency is a relative measure of productivity.

Efficiency and productivity tend to be used widely and interchangeably in economics. Although there are similarities and connections, they do not mean the same thing. Various factors influence productivity, including production technology, efficiency, and the environment (Lovell, 1993). Productivity is the ratio of outputs to inputs, thereby a natural way to measure performance. Calculating this ratio is straightforward if a firm or Decision-Making Unit (DMU) requires only one input and produces only one output. If the DMU uses many inputs to produce multiple outputs, as is more likely, then productivity is calculated by aggregating the inputs in the denominator and the outputs in the numerator to maintain the ratio of two scalars.

Conversely, efficiency compares the DMU's observed and optimal input and output values. The comparison can be between the observed output and the maximum possible output from the given input, or the observed input and the minimum possible input needed to produce the given output or a combination of the two. Efficiency is a technical concept, whereas the two comparisons define optimality in terms of production possibilities. Optimality can also be defined in terms of the production unit's behavioural objective. In this case, the production unit's economic efficiency is determined by comparing its optimal and observed revenue, profit, cost, or whatever it is pursuing, subject to the appropriate quantity and price constraints. To better understand the efficiency concept, it is essential to understand the concept of the production function, which relates output to input.

Concept of the Production function

A production function in economic theory, as defined by Battese and Coelli (1995), is the highest output a firm can produce from a set of inputs, given its current technology. The production function supports the theory of the firm and shows how inputs and outputs are related technologically. A production function describes the existing state of technology and how inputs can be transformed into outputs (Coelli *et al*., 2005) and can be expressed as;

$$Y = f(X) \tag{2.1}$$

Where Y is the output of a given product and X = (X_1, X_2, …, X_N,) is a N x 1 vector of factors used in the production process (e.g., land, labour, capital machinery, and raw materials) needed for producing a single output. Production functions are usually expected to fulfil some specific properties (Chambers, 1988); however, the current literature on production functions focuses mainly on empirically estimating efficiency.

The production function in microeconomic theory denotes the quantity of maximum output for a set of input quantities available. Therefore, all observations of the production data either lie on or below the production function. Hence, there can be no observation above the production function, and any observation below implies technical inefficiency. The main objective of every rational producer is to maximise output from available resources.

This aim can be satisfied by either maximising profit or cost minimisation in the production process, i.e., increasing the quantity of output (Y) to maximise profit or by reducing the cost of producing Y. Three possible ways are known to reduce the cost of producing Y; by i) improving management practices by the DMU; ii) cost reduction in inputs, or iii) development of cost-effective high yielding technologies (Bashir & Khan, 2005).

However, Bashir and Khan reasoned that producers have limited control over these ways of reducing costs in production. The authors pointed out that price increases for agricultural inputs are often much higher than for agricultural outputs. As far as developing new technologies is concerned, it can take several years and is a long-term process that is beyond the producers' control. Nonetheless, producers can reduce production costs by improving firm management practices. According to Bashir and Khan (2005.p. 643), "When economists talk about improvement in the management practices, they talk in terms of 'technical efficiency' and 'allocative efficiency'".

Agricultural production is typically associated with two most frequently used forms of production technology: single-outputs from multiple inputs and/or multiple-outputs from multiple inputs. Sometimes a lack of capital may prevent the producer from making short-term changes to the production function, forcing the producer to instead choose between other production functions, emphasizing how crucial decision-making is in agricultural production.

Concept of Efficiency in Production

Farrell (1957) popularised the measurement of efficiency after the work of Koopmans (1951) and Debreu (1951). In his empirical review, Farrell drew the various ways a productive unit may be technically or allocatively efficient. Therefore, efficiency comprises two main aspects: allocative (or price) efficiency (AE) and technical efficiency (TE), the product of which gives the overall efficiency that literature later termed economic efficiency (EE). In Farrell’s estimation, he explained technical efficiency (TE) as a firm’s ability to produce at an isoquant frontier. In his estimation, Farrell associated a firm’s technical efficiency (TE) with being able to produce on the isoquant frontier. He further considered the prices of the inputs and defined allocative efficiency (AE) as maintaining a given output level while minimizing input costs, i.e., producing a given output using the lowest cost combination of input prices. Economic efficiency (EE) combines technical and allocative efficiency and is defined as a firm's ability to maximize output while minimizing input costs.

Technical Efficiency

Technical efficiency estimation is commonly used for the assessment of farm productivity. Generally, a farm attains technical efficiency when it increases output using the existing technology without necessarily increasing the use or wasting of inputs (Alem, Lien, & Hardaker, 2018; Inkoom & Micah, 2017). Technical efficiency can be illustrated using a “best practice” production frontier which defines the association between output (Y) and input (X), reflecting the state of technology being employed. Firms operating along the production frontier are technically efficient. Others below the production frontier are inefficient and may increase their productivity as the deviations result from factors under the firm's control (Aigner, Lovell, & Shmidt, 1977). Therefore, technical efficiency estimation considers the equal proportionate use of input bundles to produce maximum output failing, resulting in overutilization of inputs, hence technical inefficiency.

Allocative Efficiency

Allocative efficiency estimation shows the use of productive inputs or the input mix that produces a set amount of output at a minimum cost given the input prices. This means the marginal value product of the input should be equal to the marginal cost of that input for allocative efficiency to be realized. If the condition is not met, then there is possible allocative inefficiency because firms are generally cost minimizers. If using the production function, the input usage choice is under the control of the firm manager. The thought behind allocative inefficiency is that firms can still improve, although being fully technically efficient, due to the over or underuse of inputs relative to another input regarding their prices (Kumbhakar *et al.*, 2020).

Economic Efficiency

Economic efficiency is the combination of allocative and technical efficiency. Technically inefficient firms operate below their stochastic production frontiers, and allocatively inefficient firms operate off their least-cost expansion paths. Farrell illustrated the concept of efficiency using two firms' examples that used two inputs (X_1 and X_2) in their production of output

(q), assuming constant returns to scale. Technical inefficiency is measured using a completely efficient firm isoquant, as shown in Figure 1 below.

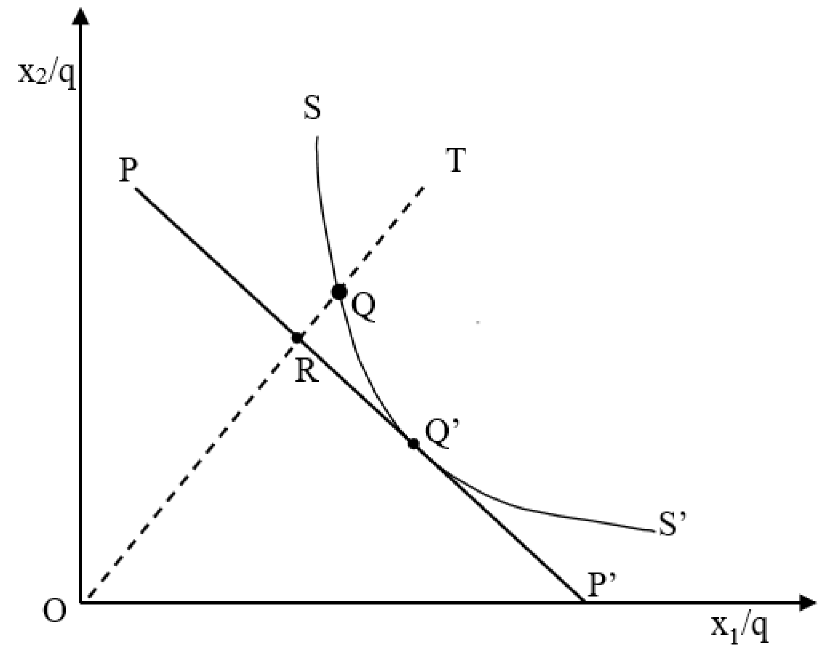


Figure 1: Allocative and Technical efficiencies

Source: Coelli, Rao, O'Donnel, & Battesse, (2005)

Point P in Figure 1 illustrates the quantities of inputs employed to produce one unit of output by the firm. Q represents the optimal combination given all the possible combinations along the isoquant (SS'). The distance QT shows technical inefficiency, which suggests the firm may proportionally use less input while still producing the same amount of output Q and attaining technical efficiency. The ratio of QT/OT is usually used to express inefficiency in percentage terms. Therefore, the ratio TE = OQ/OT, the difference between total efficiency and the inefficiency ratio (i.e., 1- QT/OT), is usually used to calculate the firm's technical efficiency.

It ranges between zero and one (or 0-100%), with one being the total efficiency and zero being the least amount of efficiency. PP' represents the isocost line or all possible combinations of input quantities x_1 and x_2 that would cost the same amount given their relative market prices (Coelli *et al*., 2005). A farm is allocatively efficient if its production uses the least cost combination of inputs, as shown in Figure 1, determined by the ratio AE = OR/OQ. The cost of production at point R is the same as at point Q', which is less than point Q, which is technically efficient but allocatively inefficient. Therefore, Q' is the cost point where the firm will have technical and allocative efficiency. With both technical and allocative efficiency achieved, at this point, the firm attains economic efficiency. OR/OT thus represents the measure of total economic efficiency EE, which is equal to both technical and allocative efficiencies combined, i.e., EE = TE x AE.

Measuring efficiency

Efficiency compares all the firms or Decision-Making Units (DMUs) with a benchmark of the best-performing firm or DMU (Coelli *et al*., 2005). By analyzing and comparing each farmer's performance, efficiency measurement enables the understanding of the factors contributing to any inefficiencies and variations in performance. With efficiency, farmers can raise their output without using more inputs by increasing production efficiency, and new production technology increases productivity (Mastewal & Wondaferahu, 2019). In other words, improved efficiency in production automatically translates into increased productivity (Abukari & Alemdar, 2019). Identifying inefficiency-causing variables can help stakeholders in productivity improvement recognize inefficiency-causing factors that can be managed and those that cannot be managed so that there is proper consideration when creating interventions.

The way to measure efficiency is to compare the actual performance to the best possible performance on the relevant frontier. However, because the true frontier cannot be determined, an empirical approximation is required and referred to as a "best-practice" frontier (Fried *et al*., 2008). Numerous measurement forms have been applied in evaluating the efficiency of firms following Farrell (1957). These methods are based on three assumptions of the data relating to "(a) the functional form of the best-practice frontier (a more restrictive parametric functional form vs. a less restrictive non-parametric form), (b) whether or not account is taken of random error that may temporarily give some production units high or low outputs, inputs, costs, or profits, and (c) if there is random error, the probability distribution assumed for the inefficiencies (e.g., half-normal, truncated normal) used to disentangle the inefficiencies from the random error" (Berger & Humphrey, 1997.p.177). This implies that approaches for efficiency measurement diverge in the assumptions of the distribution imposed on the random error and inefficiency and how much shape is assumed on the frontier (Ismail, 2010).

Farrel (1957) used linear programming techniques to estimate efficiency, which later influenced the work of Aigner and Chu (1968), Afriat (1972), and Richmond (1974), who used quadratic and linear programming techniques to estimate the frontier (Pitt & Lee, 1981). Their approach had a number of flaws, the most significant of which was that it did not account for random shocks in the production process that the firm has no control over.

Following the work of Farrel, literature on the analysis of efficiency increased with the development of new approaches which yield better efficiency estimates. Four methods of measuring efficiency are most commonly used, including (1) Stochastic Frontiers Analysis (SFA), (2) Data envelopment analysis (DEA), (3) Total factor productivity (TFP) indices, and (4) Least squares econometric production models. The TFP and Least squares are often applied to provide technical change measures and total factor productivity by aggregating time-series data (Birhanu, Tsehay, & Bimerew, 2022). For cross-sectional studies, the most widely used are the SFA and DEA. SFA is parametric and was proposed originally by Aigner and Chu (1968), while DEA, the non-parametric technique, was proposed by Charnes, Cooper, and Rhodes (1978) (Kumbakhar & Lovell, 2000). For the interest of the current study, the focus will be on the latter two methods i.e., DEA and SFA.

Data Envelopment Analysis (DEA)

DEA, a deterministic method, assumes that all output levels below optimal levels result from inefficiency rather than errors. Through linear programming methods, DEA creates non-parametric frontiers over a sample of data of relatively homogeneous firms, and then efficiency scores are calculated compared to the frontier. The best-performing Decision-Making Unit (DMU) is then used as the base reference for comparing with the rest of the DMUs (Coelli *et al*., 2005).

Stochastic Frontier Analysis (SFA)

SFA is a parametric approach proposed by Aigner *et al*. (1977), Battese and Corra (1977), and at the same time, Meeusen and van den Broeck (1977) conducted the same analysis. The parametric approach estimates efficiency by comparing it to a statistically estimated frontier production or cost function. While estimating the efficiency, the SFA model simultaneously accounts for the statistical noise for frontier production. When using the SFA, the researcher has to choose the frontier to use and subject the model to a functional form. The choice of the two models is not straightforward and lies with the researcher. One has to consider the availability and quality of data, the appropriateness of the functional form, and the relative appropriateness of SFA (Kumbhakar *et al*., 2020).

Determinants of the production efficiencies

Coelli *et al*. (2005) posit that independent variables affecting the environment in which production occurs often influence how well a farming household converts inputs into outputs given existing technology. The environmental variables may comprise factors specific to the farm, such as how it is managed, the constraints faced by the farm and measureless innovations. Observable characteristics, including age, farmer education, household size, experience, and involvement in agricultural development initiatives, can all partially represent the factors (Alem *et al*., 2018).

Therefore, when it comes to studying efficiency, it is not just about determining the efficiency level but also about determining the factors that contribute to it, usually the socio-economic and economic factors (Obi &

Ayodeji, 2020; Birhanu *et al*., 2022; Kehinde, Ademoyo, & Ogundeji, 2021). The methods used to determine these factors may differ depending on the methodology used to estimate the efficiency levels. Estimating the inefficiency factors can be done using one-stage or two-stage approaches. The inefficiency factors are estimated simultaneously with the efficiency levels in the same model with one stage approach. Contrary to the two-stage, the efficiency levels are estimated first, and then the scores are used in a second estimation as latent variables. However, the two-stage procedure is most commonly used for both the SFA and DEA approaches (Haji, 2008). First, the efficiency or inefficiency score is measured; secondly, the inefficiency or efficiency score is used as an outcome variable, which is then regressed against the other independent variables thought to influence efficiency levels.

Literature provides quite many determinants that have been empirically found to cause farms to be inefficient. These factors include the individual characteristics of the DMUs, the socio-economic and institutional factors such as gender, age, education, household size, income, farming experience, farm size, access to credit, and, where applicable, farm improvement initiatives and beneficiation from support programs such as input subsidies. These are applicable throughout many production industries and sectors, including the agricultural sector.

Empirical Review on production efficiencies

The theory of production and efficiency concept has been applied to various sectors measuring performance, such as private firms producing goods like factories, industries offering services like aviation and banks, and nonprofit-making organizations like hospitals and schools. Although this theory has been widely applied in Agriculture to measure the performance of different enterprises, much of the work concentrates on either one component of efficiency, i.e., technical efficiency, especially in the African context.

Review of empirical studies on technical efficiency (TE)

Although DMUs can be technically efficient without also being allocative and economically efficient in their productions, assessing technical efficiency and its determinants is insufficient. Despite much work on technical efficiency, most studies concentrate on estimating the efficiency and determining factors influencing technical efficiencies (e.g., Abate, Dessie, & Mekie, 2019; Beyene, Mulugeta, & Merra, 2020; Kodua, Onumah, & Bonsu, 2022). However, even technical efficiency literature in Botswana is typically scarce (e.g., Temoso *et al.*, 2018; Motsatsi, 2015; Thirtle *et al.*, 2003). All these studies regurgitated the same panel dataset updated from the same source (i.e. Botswana Agricultural Census Reports and Botswana Agricultural Statistics (CSO, 1979-1996) compiled by Irz and Thirtle, 2004) although employing different efficiency analytical methods.

For example, Temoso *et al.* (2018) examined Botswana's agricultural productivity trends using secondary data from 1979 to 2012. The authors used the Färe-Primont index to assess the total factor productivity (TFP) components of technical change, technical efficiency changes, scale efficiency, and mix efficiency changes. The findings of their study revealed a downward trend in technical efficiency, and a modest decrease in scale and mix efficiencies over the study period led to a decline in the yearly TFP. They concluded that farmers are slow to adopt new technologies because most lack the necessary skills or are unaware of the advantages of current initiatives in Botswana. To increase the agricultural sector productivity of the country, they suggested infrastructure development, institutional strengthening, capacity building, technology development and transfer, and changes and development of institutional policy. However, their research was limited to estimating the total factor productivity and its various components, not farm-level efficiencies. Farm-specific factors such as farmer's age, education, farm size, and extension services are important to evaluate as determinants of productivity. These factors can help improve the specific policy interventions formulated to target farmers' productivity, thus improving the overall sector productivity. Therefore the current study will bring this new insight.

In the neighbouring countries, Zambia, Zimbabwe, and South Africa, technical efficiency has been analyzed for different enterprises. These include the work of Bahta *et al*. (2020) in Zimbabwe, who evaluated the technical efficiency of the Tokwane-Ngundu Smallholder Irrigation Scheme for Masvingo province's smallholder maize farmers, determined the variables influencing productivity and identified the better management practices that the farmers have adopted. The majority of the province depends on irrigation because it is in the low veld region of Zimbabwe, which receives little and variable rainfall and is prone to drought. In a Principal Component Regression (PCR), the authors used Data Envelopment Analysis and the Double Bootstrap Approach. The study findings revealed that the farmers' average technical efficiency was 77%, suggesting a 23% improvement in efficiency potential.

The results further identified extension contacts, human capital, and adherence to best management practices to increase technical efficiency.

Mujuru *et al*. (2022) conducted similar work in South Africa. Using the STATA software, they employed the SFA using a normalized translog profit function fitted with a one-step technical efficiency estimation and its determinants. The study collected data from a random 158 smallholder farmers who cultivated maize using the irrigation schemes of the Tyefu and Qamata in the province and the nearby areas. Their study showed that 65% of the respondents were males; although they concluded that the number of men on farms surpasses that of women, most of the time, women do more work than men. Their study also showed that over 50% of their respondents were aged above 61years. Thus, they concluded that older adults practice farming while the youth migrate to cities. Although these studies were conducted in the same region, they were limited to farmers who irrigate their production; therefore, they can not be compared with the current study, where farmers rely solely on rainfed crop production.

Given similar semi-arid production conditions similar to Botswana, Pangapanga-Phiri and Mungatana (2021) examined the factors influencing the practices of Climate Smart Agriculture (CSA) adoption and their impact on the technical efficiency of maize production among households affected by extreme drought episodes in rural farming communities in Malawi. The Cobb-Douglas Stochastic Frontier Analysis was used in the study, and the findings indicated that maize farming households were 63% technically efficient, suggesting a 37% increase in production potential. They found that drought episodes significantly increased the adoption of organic manure by 76% and soil and water conservation by 29% using a conditional logit model. The study also employed a two-stage Tobit model, which demonstrated that the simultaneous application of organic manure and inorganic fertilizers on the same farm significantly increased the productivity of maize production by 18%, and the effect was more pronounced amongst households affected by drought. The study also found that education and marital status significantly impacted how technically efficient maize production is. The study under review primarily focused on farming regions affected by drought, even though it contributed to knowledge on how to increase agricultural productivity under various weather conditions. It focused on farmers' coping mechanisms, whereas the current study identifies the impact of timely ploughing on effectiveness as one crucial factor that can raise farmers' productivity in a semi-arid environment.

In other parts of Africa, much literature is available on technical efficiency, although primarily concentrated on the specific crops produced as staples for particular countries. Considering field crops similar to those produced in Botswana, technical efficiency literature shows that generally, farmers are above 50% efficient in their production. Kodua *et al*. (2022), for instance, examined the technical efficiency levels of smallholder maize farms in Ghana's Brong-Ahafo region. The study accounted for the differences in maize seed types used by various farmers, measuring the levels of productivity of the seed varieties, i.e., improved maize seed varieties and native maize seed varieties. The study estimated the TE and the technology gap ratios and determined the causes of inefficiencies. The authors estimated the technical efficiency levels of regional farms producing enhanced maize seed varieties using the stochastic frontier approach and the Translog specification. Their findings demonstrated the inefficiency in their production with high gamma values of 0.97 and 0.91 for the local and improved maize farms, respectively, from the models. The results also showed that for the improved local maize seed variety farms, technical efficiency was 72%. In comparison, the pooled data technical efficiency scores mean technical efficiency relative to the meta-frontier was 44% and 50%, respectively. The study also found from their inefficiency model that the technical efficiency of maize farmers in Ghana was statistically significantly influenced by factors such as years of farmers attending formal education, labour source, the frequency of extension contacts, credit, and farmgate purchases.

In East Africa, Birhanu *et al*. (2022) conducted a study in Ethiopia to examine the effects of research-based suggested cereal production practices on the technical efficiency of farming households. Focus groups, key informant interviews, and questionnaire surveys were employed to collect household-level data for the study. The stochastic meta-frontier approach was used to estimate the technical efficiency scores, considering the anticipated variations in production technologies. The authors used the Tobit regression framework to determine the causes of farm inefficiency. According to the results, the households had a mean technical efficiency of 58%, indicating that they could increase cereal output by roughly 42% using the current input mix and technology level. The results showed that farm households who used high-yielding varieties with advised production methods based on research were more technically efficient than those who did not. The econometric model results also showed that the technical efficiency of farm households was positively and significantly impacted by the use of high-yielding varieties and research-based recommended seed rates. Gender, age, ownership of a cell phone, membership in a cooperative, access to the input market, and crop damage were additional factors influencing farm efficiency.

Mastewal and Wondaferahu (2019) estimated used stochastic frontier analysis (SFA) and the Translog function by likelihood ratio (LR) test to assess the level and factors impacting the TE of smallholder teff producers in Ethiopia. Their results showed that TE of smallholder teff farmers in Ethiopia ranges between 13% and 92%, with mean productivity of 73%. According to the Maximum Likelihood Estimate (MLE) results, land fragmentation, area, and fertilizer use are the main factors that affect production. The study also discovered that agroecology zones, seed type, extension, age, and incomes other than farm profits are the primary socio-economic determinants affecting efficiency.

Considering the different climatic conditions in the Sub-Saharan African region, Ntwiga (2021) examined the impact of climatic factors on the technical efficiency of agricultural production in Sub-Saharan Africa, including Botswana, using time series data for 25 years from 1991 to 2015 selected from nine countries. The countries included in the study were Botswana, Ghana, Kenya, Ethiopia, Cameroon, Benin, Burkina Faso, Nigeria, and Mali. With agricultural land as the input variable and agricultural value-added as the output variable, the study evaluated TE using DEA. For the determinants of the inefficiency model, TE scores were the response variable, while the predictor variables were rainfall, temperature, forest cover, population, and greenhouse emissions. The study findings showed that the temperature, forest area, and greenhouse gases as predictor variables significantly impacted the technical efficiency of agricultural production. Their results ranking the countries by the efficiencies showed Botswana having the least technical efficiency at as low as 4.7% compared to the other countries. In comparison, Ethiopia had the highest at 97.1%, and the margin in TE of agricultural production between Botswana and Ethiopia was approximately 92%, which was a significant difference between the two countries.

Review of empirical studies on allocative efficiency (AE) and economic efficiency (EE)

Although much work concentrates on technical efficiency, allocative and economic efficiencies are also important because a firm can be technically efficient but fail to be allocatively efficient hence economic inefficiency. However, there is a growing literature on allocative and economic efficiencies in East and West Africa, particularly Ethiopia and Nigeria. For example, Ahmed *et al*. (2018) used the stochastic production function, fitted with the Cobb-Douglas production function, to assess the production efficiency of maize production in eastern Ethiopia. They collected cross-sectional data from 480 maize farms. The authors applied the stochastic decomposition approach using the self-dual structure of the production and cost function to decompose

TE, AE, and EE using the Cobb-Douglas function. The results indicated that maize production was determined by land, the amount of seed, and diammonium phosphate (DAP), which had highly significant estimates. The study used the one-stage approach to identify socio-economic and institutional factors that affect TE in the study area. The mean efficiencies obtained from the study were 82.24% for the TE, 37.07% and 28.97% for AE and EE, respectively. The study findings also showed that allocative efficiency, rather than technical efficiency, is more likely to increase the economic efficiency of maize production in the study area. The inefficiency model showed that adoption of improved seed, participation in off/ nonfarm income, membership in agricultural cooperatives, number of extension contact, and distance to the nearest market were all significant in determining TE of maize production.

Tesema (2021) analyzed the allocative and economic efficiency of mixed crop-livestock production smallholder farmers in Horo District, Ethiopia. The author collected cross-sectional data from 152 households and used the deterministic non-parametric DEA method to analyze the efficiencies. The study used the household's output, an aggregate output of crops (wheat, teff, maize, barley, beans and others) and livestock (poultry and milk), as the dependent variable measured in currency, the Ethiopian birr. The predictor variables used for the study's estimation of efficiencies were land, labour and material inputs like seeds, fertilizers and agrochemicals, feed, forage, and urea.

Furthermore, the study used the two-stage approach employing a Tobit regression model to determine factors explaining the efficiencies. The latent variables representing the AE and EE were regressed against several factors affecting efficiencies, such as the age of the household head, sex of the household head, years of formal education, family size, precisely the number of adults in the household, livestock ownership, credit use, terrace contraction, distance to markets, frequency of extension contact, partaking in off/non-farm activities, and others. The results showed mean efficiency scores of 57% for allocative efficiency and 38.4% for economic efficiency. Furthermore, Tobit regression model results showed that the household head's education level, extension, and off-non-farm income positively affected allocative efficiency, while extension service credit use and terrace positively affected economic efficiency.

Still in Ethiopia, Gela, Haji, Ketema, and Abate (2019) used the stochastic production and cost frontier functions to estimate the technical, allocative, and economic efficiency of the small-scale sesame growers in the Godar Zone. They examined how institutional, socio-economic, and demographic factors affected the production efficiency of sesame in their study using OLS regression. The results revealed that sesame output in production was determined by most capital inputs (seeds, fertilizers and pesticides, and labour except land, which had a significant but negative coefficient). The study also determined the factors affecting the farmers' production efficiencies. Their study showed that mean technical efficiency was 71.8%, allocative efficiency was 49%, and economic efficiency was 35%. The results revealed that factors affecting sesame production efficiency were: the household head's age, education level, cellphone ownership, number of livestock, association membership, off/non-farm income, credit access, extension contact, and participation in training, which were significant and positive/negative. The positive coefficients were for education, extension contact, training, and off/non-farm income, implying that these factors improve yield and raise the household's observed output level. On the other hand, they discovered that efficiency was inversely correlated with age, access to finance, and ownership of a mobile phone, showing the effects of yield reduction on the observed output level of households.

In Nigeria, Hassan, Jonathan and Idris (2022) examined the allocative efficiency of rainfed rice farmers in the Ardo-kola and Jalingo local government districts of Taraba State using the stochastic frontier approach. The study area has relatively high annual rainfall and humidity, ideal for crop production. Their study results revealed that farmers had a mean allocative efficiency of 89%. The study showed a significant and positive correlation between the cost of seed, the cost of fertilizer, the cost of family labour and the cost of agrochemicals showing that the cost of production increases when increasing these inputs. The study also revealed that socio-economic factors, age, gender, education, and extension contact increase the allocative efficiency of rice farmers in the study area.

It is pretty apparent from the aforementioned studies that while farmers may be technically efficient, their economic and allocative efficiencies can be low, thus, necessitating research on all the production efficiencies. Nevertheless, the above studies were conducted in areas of differing climatic conditions and/or for crops unknown to the Botswana farmers; therefore, their findings may not be relevant in Botswana. In Kenya, the semi-arid Kajiado County of Kenya, Mibei, Macharia, and Mwenjeri *et al*. (2021) examined the small-scale tomato farmers' economic, technical, and allocative efficiency. Agro-pastoralism is practised on a relatively smaller scale in this county which depends mainly on pastoralism as the primary source of income. 150 tomato farmers were sampled for the study to estimate the productive efficiencies. The authors employed the SFA using the Cobb-Douglas Production function. Their results revealed that the farmers' average technical, allocative, and economic efficiencies were 47.2%, 75.8%, and 35.8%, respectively. They concluded that since the mean allocative efficiency score was higher than the mean technical efficiency, the primary source of inefficiency was tomato growers' failure to optimize output rather than the failure to reduce production costs. However, they ended at estimating the efficiencies without analyzing the determinants of the efficiencies.

In Southern Africa, empirical work is conducted mainly in South Africa but scanty in the other SADC countries, notably Botswana. In the Eastern Cape of South Africa Obi and Ayodeji (2020) applied the Translog stochastic frontier using the one-stage approach to estimate the technical efficiency and determinants of the technical efficiency in maize production. The authors used the output elasticity in relation to each of the applied inputs, particularly the economic farm size of the maize farmers. Their study also measured the overall cost elasticity in relation to the average cost of each input and the determined cause factors. Their study showed that maize is significantly determined by the seeds and labour used as inputs in production.

The results revealed the mean technical efficiency to be 70%, with a minimum score of 22% and a maximum of 99.8%. From their inefficiency model, education, experience, credit, and farm size were among the factors that significantly and directly influenced technical efficiency. This finding meant that TE increased as these factors increased. On the other hand, the authors found that marital status and access to credit were negatively correlated with cost efficiency. Farm size was a negative determinant of economic efficiency; thus, an increase in farm size decreased economic efficiency. However, these factors had different effects on maize producers' technical, cost, and economic efficiencies across the board.

In Botswana, only Moikgofe (2020) evaluated the effects of input subsidy on the sorghum production economic efficiency in Botswana. She used secondary data (spanning from 1998-2017) to estimate the Cobb-Douglas production function using the SFA to compute the technical efficiency and the cost function for the allocative efficiency computation. In the efficiency models, the author used sorghum output as the dependent variable measured in tonnes per year. However, it is not clear how the secondary data predictor variables were measured and employed in the study. The study had severe data limitations in estimating the economic efficiency of producers. Also, the study focused on sorghum, although it was unclear whether it was for smallholders or commercial farmers. Given this lack of knowledge about the production efficiencies of producers in Botswana, the current study provides the needed insight for formulating and amending policies necessary for improving farmers' productivity, livelihoods and food security.

The concept of livelihoods

Chambers and Conway (1992) defined livelihood as making a living, including income, food and assets. Several researchers and development organizations have been credited with providing the theoretical foundation for the term livelihood. Some of these conceptual underpinnings are discussed in this section.

Sustainable livelihoods

The literature presents two commonly used concepts for sustainable livelihoods; environmental and social sustainability. When a livelihood has net positive effects on other ways of life and preserves or enhances the local and global resources on which it depends, it is considered environmentally sustainable hence the notion of sustainable livelihoods. It is socially sustainable when it can withstand stress, recover from shocks, and provide for future generations. Chambers and Conway (1992) posited that sustainable livelihoods are normatively grounded in capacities, equity and sustainability. Each of these concepts serves as both an end and a means in sustainable livelihoods. The ability to earn a living supports the development and application of capabilities (an end), and capabilities (a means) enable the ability to do so. Equitable assets and equal access are preconditions (means) for achieving equity, which must entail adequate and decent livelihoods for all (a goal). Sustainable resource management acts as a goal in and of itself and creates the framework required to sustain future generations' livelihoods (Chambers & Conway, 1992).

Frankenberger and McCaston (1998) defined livelihood status as determined by the ability to access sufficient and sustainable income and resources to meet basic needs, including clean water, food, housing, health care, educational opportunities, and time for community involvement and social integration. Livelihoods may consist of on-farm, off-farm, or a combination of both, including various food and income-generating strategies. Hence, each household may have a few potential entitlement sources that make up its livelihood. These benefits are determined by the household's resources and position within society's social, political, and legal systems (Frankenberger & McCaston, 1998). Therefore, livelihoods are sustainable when resources and activities crucial to a person's ability to gain income are well-secured (Chambers, 1988). "The risk of livelihood failure determines the level of vulnerability of a household to income, food, health, and nutritional insecurity" (Ahmed & Mustapha, 2020.p.119).

The Brundtland Commission coined the concept of sustainability in 1987, focusing mainly on human development (Solesbury, 2003). Chambers and Conway (1992) then brought about the concept of sustainable livelihoods defining livelihoods as how people can make a living based on assets, capacity, and activities. According to Solesbury, the Brundtland Commission Report defined sustainable development as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". Following the Brundtland Commission's work, the United Nations Development Programme (UNDP) shared subsequent reports on the Human Development Report, which drew attention to development regarding health, education for individuals and households, and well-being. The Brundtland Commission and UNDP's concerns were mainly on the emphasis on self-reliance and sustainability, the importance of citizen participation, poor people and their needs, and the ecological constraint (Solesbury, 2003). Department for International Development (DFID) adopted the definition from Chambers and Conway (1992), which has since been the commonly used definition.

Sustainable livelihood approach

A sustainable livelihood is vital as most of the population is rural and subsists in agriculture. The livelihood notion originates from the sustainable livelihood approach, which has been widely defined as a way of life that is resilient to shocks and pressures and does not negatively impact the environment (Tanle, 2013). When people can adapt to changing environments, bounce back from external shocks, and retain or improve their capacities and assets for the benefit of future generations without harming natural resources, they are said to have sustainable livelihoods (DFID, 2000). DFID proposed a people-centred sustainable livelihoods framework (SLF) to help understand and analyze the livelihoods of farming households. The framework provides an approach to help understand the intricate connections between various elements that affect the livelihoods of farming households.

According to the DFID SLF, multiple factors determine livelihoods. Livelihoods can be understood by gathering different types of information depending on the scope of the study. This information includes livelihood resources and assets, the vulnerability context; policies, institutions, processes; livelihood strategies; and livelihood goals and outcomes. All these make the components of the DFID livelihood framework, as explained in the next session.

Components of the Livelihood Framework

Vulnerability context: refers to factors that people have little to no control over that can impact their livelihoods and expose them to the risk of becoming food insecure. These factors include examples of unforeseen natural disasters such as droughts, floods, pest attacks, and outbreaks of diseases that will impact livelihoods, market collapse, and long-term trends like population pressures on land, land degradation, climate change, and price inflation (Córdova, Hogarth, & Kanninen, 2018). Vulnerability is more concerned with how people can cope with the shocks and their options in response to a shock. The ability to cope with shocks depends on resources or assets, including social networks. The concept of vulnerability is conceptualized in many different ways by intellectual communities, for instance, food security and poverty analysts and those who study natural hazards (Adu, Kuwornu, Anim-Somuah, & Sasaki, 2018).

Livelihood assets: According to the SLF, livelihoods are based on livelihood assets which DFID categorized into five, namely, natural capital, human capital, physical capital, social capital, and financial capital. Livelihood assets are the natural and human resources necessary for people to make a living. They can be used to produce income streams or other advantages by being stored, traded, or exchanged (Liu, Chen, & Xie, 2018). These livelihood assets determine farming households' livelihood strategies, resulting in various livelihood outcomes. These five asset categories are interconnected; therefore, no one independent category can yield all the various and numerous livelihood outcomes that people need.

These five asset categories are interlinked, and no single category on its own is sufficient to yield all the many and varied livelihood outcomes that people seek.

Assets reflect the resource stock households can utilize to meet their basic needs, manage risk, make an income, and withstand stress and shocks. Where there is a more broad base of extensive assets, it generally results in better security of livelihoods. According to Liu *et al*. (2018), the more assets base farm households have, the more options and opportunities they have to adjust their livelihood strategies to safeguard their livelihoods flexibly. These livelihood assets are named as follows and their respective indicators.

Human assets: include the respective competencies possessed by individuals that define how their skills and capabilities can be applied toward livelihood activities. The indicators for the human asset include the head of household’s level of education, training attended, experience in farming and labour availability for the household farm, and off-farm employment.

Natural assets: Take into account the household’s control over the physical environment and the natural resource stocks used to increase or improve livelihoods. Natural assets indicators may include ownership of land, size of land, and access to water for irrigation where possible.

Physical assets include the households’ various possessions, including the physical assets and resources that enable the household to pursue its livelihoods. Physical resources such as road proximity, access to electricity and other infrastructures, tap water, farm machinery, tools, and draft animals are examples of physical asset indicators. The indicators may include moveable assets used in production, such as trucks, bicycles, radios, and other productive small assets.

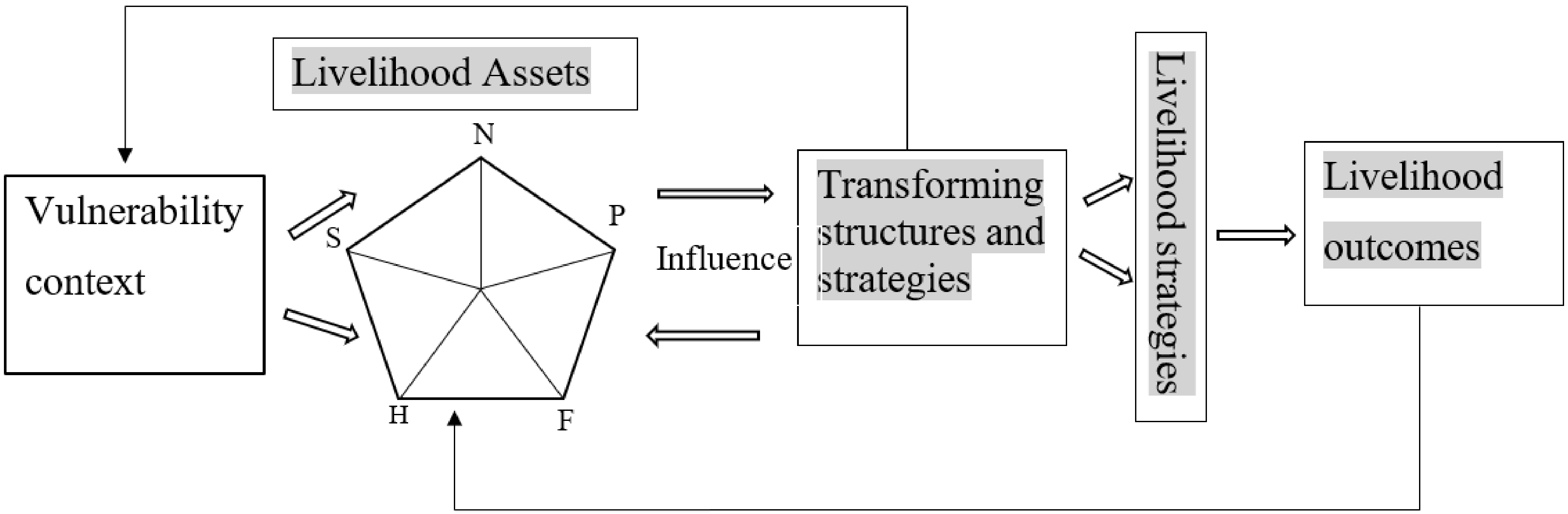
Social assets: consist of shared norms, values and understandings among the networks that facilitate cooperation within or among groups. Social capital is created by the relations of the household in a social network and the characteristics of resource sharing, trust, and reciprocity of those connections. Indicators include the frequency of extension visits from the relevant officers, access to the market, and participation in social organisations such as village development committees and farmers' groups.

Financial assets: refer to the available financial resources to the household. Indicators include cash savings, access to credit, insurance, remittances, pensions, cash transfers from social welfare programs, and livestock ownership. According to Liu *et al*. (2018), the circumstances and the nature of a household's livelihood assets are the basis for understanding the household or individual's options, livelihood strategies, and the risk environment. Therefore, people must possess several livelihood assets to achieve positive livelihood outcomes.

Policies, institutions, and processes: These are essential man-made external factors that influence people's choices for accomplishing their livelihood objectives. They influence who has access to resources and is vulnerable to shocks. Policies may include agricultural subsidies, land tenure or land-use policies which help reduce vulnerability to disasters. According to Manlosa, Hanspach, Schultner, Dorresteijn, and Fischer (2019), livelihood strategies in agricultural landscapes are changing in developing countries all over the world due to global developments. Smallholder farming households are transitioning from crop production focused on subsistence to crop production focused on commercial benefits. Livelihood strategies comprise the range and combination of activities and choices household members make/undertake to achieve their livelihood goals.

Livelihood strategies: refer to measures taken and decisions made, including production practices and investment strategies to achieve livelihood objectives (Liu, Chen, & Xie, 2018). Livelihood strategies comprise household members' various activities and decisions to pursue their livelihood goals.

Livelihood outcomes: the accomplishments or results of livelihood strategies are known as livelihood outcomes. Livelihood outcomes are categorized into three subheadings, namely, economic, social, and biological (WWF, 2008). Economic outcomes include food, and income security, i.e., people having access to enough food and income to meet their basic needs. Social outcomes include dignity, an all-encompassing term that includes notions like choice, relations and control over one's future, and a sense of self-worth and status. Examples of biological measures of livelihood outcomes include malnutrition rates and mortality. Livelihood strategies produce livelihood outcomes that subsequently bring about changes in the assets. DFID devised the following diagram in Figure 2 to understand the SLF better. Although food security is also an economic outcome under the SLF, the study assessed it independently, not as a livelihood outcome. This allowed getting an in-depth measure of food security.



N=Natural Asset P=Physical Asset F=Financial Asset H=Human Asset S=Social Asset

Figure 2: DFID Sustainable Framework

Source: DFID (2000)

Empirical Review on the livelihoods of farmers

Research on sustainable livelihoods is broad but extensively focuses on the relationship between climate and agriculture and its consequences on food security and poverty. For instance, In Bangladesh, researchers Ahmed, Saha, Hossain, Khan, and Prodhan (2021) evaluated the food and livelihood security of fishermen who spend their entire lives on fishing boats and whose only source of income is fishing. The capital asset framework-based livelihood evaluation index was employed in the study. The findings showed that the livelihood capitals of floating fisherman households were lower than the country average. The majority lacked skills in ways to make money, and the literacy rate was minimal. Floating fishermen made far less money on average than the general population. The fishing boat, which they also used as their home, was their most valuable physical possession. It was further found that the fishermen had trustworthy relationships with members of their communities and shared knowledge among their communities.

Ninety percent of floating fishermen's households were far more than the national average impoverished. Because of their disjunction from the social structure and lack of affiliation with local institutions, they had a low social status outside their communities. As a result, it was discovered that this community's livelihood assessment index was extremely low, with the financial capital index being the lowest. The study recommended that for the government to improve living conditions and lessen poverty in the floating fishermen communities, it is necessary to increase education participation, arrange permanent residence, train people in various income-generating activities, and provide financial support.

Although there are quite several studies on livelihoods, one limitation in main of these studies is to focus on the vulnerability of the interest groups such as farmers to climate risks such as drought. For example, using socio-economic data, Nyairo, Machimura, and Matsui (2020) examined the livelihood vulnerability of households in two communities in Burundi, where one site is climate analogous to the other under anticipated future climate change. The authors analyzed to comprehend variability in community vulnerability and how to address them to advance plans for the rural adaptation. The study linked the human subsystem with existing biophysical vulnerability studies by identifying sources of household livelihood risk by examining human and social capital. Factor Analysis on Mixed Data (FAMD) was performed to analyze a subset of pertinent variables, with the first eight dimensions of FAMD accounting for the majority of the variance in the data. Five clusters containing a mixture of households from the two communities were produced after clustering based on eight dimensions.

Their findings showed that one cluster (Cluster 3) was least vulnerable since a higher percentage of households in that particular cluster had implemented farming techniques that provided access to food and water. To lessen their exposure, households in the other clusters must make the necessary improvements. Results indicated that social issues should be examined when studying rural vulnerability rather than regional variations in climatic conditions and agricultural management since they substantially impact policy.

The sustainable livelihood framework is often used to evaluate livelihood in farming communities. For instance, Mahama and Maharjan (2019) conducted a study in Ghana, modifying the sustainable livelihood framework to assess the nature of the asset pentagon as well as the assets' temporal-spatial changes. The authors determined by modifying the SFL how the assets affected livelihood opportunities. The authors constructed an asset index to measure the livelihood assets status and then examined the relationship between household assets and livelihood opportunities. Their study used a test for the mean to compare rural and urban households. Their findings demonstrated that Ghana's human and financial assets were below average, particularly in rural areas, while the overall social, natural, and physical assets scores were above average. Their research showed that rural households scored better in social, physical, and natural assets, while urban households scored higher in financial and human assets. Their study revealed that the agricultural-based household had lower financial asset scores than others, except for higher social and natural assets scores. The SLF allows the researchers to modify it to fit the different needs of their particular studies. Therefore, like Mahama and Maharjan, the current study applies the SLF to assess how the farmers' livelihood status improved attributable to the ISPAAD program beneficiation.

Concept of food security

The notion of food security first appeared in the middle of the 1970s. Over the years, the food security concept has evolved and had over two hundred definitions (Maxwell, 1996). In a broad sense, food security refers to a person's ability to acquire enough food in a continuous supply shortage; otherwise, the person is termed food insecure. The World Bank defined food security as "access by all people to enough food at all times for an active and healthy life", and FAO later expanded this definition to include food preferences and nutritional value. FAO defines food security as "*when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO, 2009). FAO derived the definition from the 1996 World Food Summit Plan of Action. The FAO definition has since been widely accepted and used to define food security. Bestowing to the FAO definition, food security is founded on four pillars: food availability, accessibility, stability, and utilization.

Food availability: refers to the physical existence of food in sufficient amounts of the right and necessary types. Food availability addresses the "supply side". Supply can be ensured from domestic production (subsistence production for household consumption and commercial farms), domestic food production, net food reserves, commercial food imports, or food aid. Agriculture is the primary food source and ensures food security, which relies on the agricultural industry and domestic and international distribution networks (Sassi, 2018). FAO (2009) asserts that the food on the market must be of acceptable quality to satisfy consumer preferences and cultural values.

Food access is the second pillar of food security which addresses people's physical and financial ability to acquire food. A sufficient national or international food supply does not ensure individual households' food security. Therefore, food access considers the ability to have sufficient food of a particular amount and quality to meet all household members' nutritional needs and preferences. One critical determinant of accessibility is the income available to the household. Economic access to food requires households and individuals to have sources of income needed to buy food. Kuwornu, Suleyman, and Amegashie (2013) posit that people should have both physical and financial resources under allowing social and political factors to have food access. Adjimoti and Kwadzo (2018) explained accessibility as having enough resources and entitlements to acquire sufficient food.

Stability means having enough food accessible whenever needed throughout the year, without fear of shortages, even during shocks. Unfavourable weather, economic factors (increasing food prices, unemployment) or political instability may affect food security status. One may have adequate food intake at the current time but still be classified as food insecure if they occasionally have poor access to food.

Utilization implies proper intake and digestion of quality, safe-to-consume food in adequate amounts containing sufficient energy and essential nutrients. Therefore, food preparation and storage should be sufficient to avoid food-related illnesses caused by inadequate or disproportional nutrient amounts. Food safety relates to health and is concerned with issues of food-borne biological pathogens, chemical toxicants, and other hazards (FAO, 2014). Safety and utilization are concerned with whether individuals can convert their food to the essential nutrients required to lead a healthy, active life (Adjimoti and Kwadzo 2018). Kuwornu *et al.* (2013) maintained that food safety and utilization concerns are issues of consumers in developed countries as consumers expect food to be tasty, meet their dietary needs, and be produced ethically, which in developing countries is not a significant priority. Food shortages and lower incomes affect dietary choices. Therefore, significant concerns in developing countries are accessing and availability of a nutritious food at lower costs throughout the year.

Measuring Food security

Food security is multi-dimensional; therefore, accurate intervention and policies become complex and challenging for policymakers (Abdullah *et al*., 2019). According to Barret (2010), each pillar is necessary but deficient in ensuring the achievement of food security alone. The earlier focus of food security concentrated mainly on availability, with many governments directing assistance to the supply side to achieve sufficiency. However, in recent years there has been a gradual change in thinking. Access and entitlements were focal points in the early 1980s, but by the late 1990s, the attention had shifted to the individual levels (Sassi, 2018). According to Sassi, although food availability is necessary, it is insufficient for access.

On the other hand, access is necessary but insufficient for utilization, which means that all four pillars of food security must be satisfied simultaneously to achieve food security. Food security has been measured using several methods. However, because food security is multi-dimensional, it is not easy to assess it, simultaneously capturing all the food security indicators. Therefore, it is best first to define the intended scope of the study. For this study, possible food security gains are evaluated considering the possible improvements in the productivity of farming households. The expectation is that with increased productivity, the subsistence farming households will have food supplies for the members of the household as well as have a surplus to sell or release some of the resources used in production to engage in other economic activities that can get some income for the households.

In 2003, FAO grouped the food security measuring methods into five according to the indicators. The first measure is the undernourishment measure generally associated with the Food and Agricultural Organization (FAO) of the United Nations (Bushara & Ibrahim, 2017). The FAO method relies on aggregate food supply data to estimate the per capita dietary food energy supply. The second group uses household expenditure surveys to assess food insecurity. The household expenditure method estimates the average calories consumed by each household member daily and requires data on food bought and consumed, whether from within or outside the house.

The third method is the individual food intake survey which measures the total food consumed by the individual or household referring to a period, e.g., 24 hours, seven days. This method relies mainly on the respondent's memory to recall all the food consumed and uses the food frequency questionnaire. The fourth group is the anthropometric measures based on the assessment of dietary deficiencies to measure food utilization through nutritional status. The last group is the qualitative measures of food insecurity and hunger using experience-based measurement scales. This method determines the food security status of the respondent using a cut-off point to say whether one is food secured or not as per their experience.

FAO devised different food security indicators for the distinct levels of assessment based on the pillars. Availability best addresses food security status at a national level; access addresses mainly the household level, while stability and utilization are expected at all levels (FAO, IFAD, & WFP, 2013). Although the literature suggests that own production enhances food security by making food available, farming households may produce food that does not make up their consumed food baskets. Therefore, their consumed food baskets are filled with food items they are not producing; hence, they sell their produce to buy the household preferences. Therefore, this study considered this aspect by also bringing the concept of sustainable livelihoods to establish the linkages between food security and the livelihoods of farming households.

Empirical review on food security

The notion of food security has been well-researched with different scopes. Some researchers try to capture all the pillars of food security in their assessments by using measurements that allow for capturing all dimensions. For instance, Adjimoti and Kwadzo (2018) conducted a study to establish the effects of crop diversification on the food security status of rural households in the Collines Region of Benin. The study used principal component analysis (PCA) and constructed a composite food security index to assess food security.

The PCA incorporates several indicators for the four food security pillars to capture the different dimensions. In doing so, they employed the factorial methods. They included factor analysis: a geometrical approach that automatically converts a large data table into synthetic pictures from which the primary structures will develop, the principal component analysis, and correspondence analysis. PCA also tries to examine the linear relationships between factors to find similar clusters of people from the correlation matrix or covariance by extracting the maximum amount of information. However, with this method, they reported difficulty in interpreting the results obtained from the analysis. To establish the effects of crop diversification on food security status, the authors used a linear regression model where the constructed food security index was then used as a continuous variable to regress against a vector of explanatory variables. Their results revealed that the more diverse the crops the household planted, the more likely it was to be food secure. The study also showed that the household head’s education, access to credit, and the number of livestock units positively affected the households’ food security status.

In a different study, Ngema, Sibanda, and Musemwa (2018) compared the beneficiaries of the “One Home One Garden” (OHOG) programme to non-beneficiaries and evaluated the factors that influence household food security status in Maphumulo, South Africa. Their study used a Household

Dietary Diversity Score (HDDS) and Household Food Consumption Score (HFCS) instrument to measure programme recipients' household food security status versus non-beneficiaries. They used a binary logistic regression model to determine the variables affecting a household's level of food security. The findings showed that infrastructure support (irrigation), education, and OHOG programme participation positively impacted household food security. However, there was an inverse relationship between household income and access to credit.

Similarly, Tuholske, Andam, Blekking, Evans, and Caylor (2020) used three measures of food security; the Household Food Insecurity Access Scale (HFIAS); the Household Food Insecurity Access Prevalence (HFIAP); and the Food Consumption Score (FCS) to characterize and compare the predictors of household-level food security of the low- and middle-income residents of Accra, Ghana. Only 2% of studied homes fell below FCS acceptable threshold, even though HFIAP reported that 70% were food insecure. The study results indicated that low and middle-income households in Accra reported anxiety and experiences associated with food insecurity on a frequent yet low basis when using the HFIAP. In contrast, the FCS results showed that a small proportion of the survey-sampled homes were either food insecure or at-risk of becoming so. The study also used a suite of general linear models to determine factors affecting food security and found that smaller households were likely to be more food secure than larger households. Higher education, a greater household asset index, and receiving remittances were some factors that significantly increased household food security.

However, capturing all dimensions of food security can be very complex and require expertise from different fields of practice. For this purpose, experience-based measurement scales are commonly used for assessing farming communities' food security. For example, Mota, Lachore, and Handiso (2019) used the Household Food Insecurity Access Scale to assess the level of food insecurity of the farmers in Ethiopia. They used logistic regression to analyse the determinants of food insecurity by regressing the categorical dependent variables on the food security status. Their study showed that 71.6% of the households were food insecure. The logistic regression results showed that food insecurity increased with household size. Although the increase provides labour for farming households, it exerts more pressure on consumption. They also found that an increase in household heads' age and credit from non-formal rural lenders negatively affects the family food security status. Low household head education, low cropping land size and household lacking livestock were associated with food insecurity.

In another study in the rural Oyo State of Nigeria, Otekunrin, Otekunrin, Sawicka, and Pszczółkowski (2021) evaluated farming households' food insecurity status using the HFIAS module. It examined factors affecting food insecurity using the ordered logit model (OLM). The findings showed that 87.2% of the households experienced food insecurity of some level, while only 12.8% were food secure. The OLM results showed that substantial differences in food insecurity among farming households were associated with gender, age, household head's education level, experience, farm size, non-farm income, food spending, and access to extension services. The latter studies are similar to the food security analysis of the current study as they use a similar method of analysis for the food security measurement.

Linkages between production efficiencies and livelihoods or efficiencies and food security

The linkages between farmers' productivity and livelihoods/ food security are comprehensively researched. However, one limitation in most of the research conducted is the influence that special/government support programs have on these linkages. African agriculture is characterised by many challenges and underdevelopment, resulting in farmers requiring government assistance through subsidies. However, many often criticise these subsidy programs, arguing their sustainability and that their cost may outweigh the benefits over the long term (Kansiime, van Asten, & Sneyers, 2018; Sigwele & Orlowski, 2014; Jayne, Mather, Mason, & Ricker-Gilbert, 2013). Notwithstanding the critiques, input subsidies have been implemented in other African countries and found to raise food production (Jayne & Rashid, 2013). In Botswana, subsidies have increased the cultivated area but have failed to increase productivity as crop yields continue to fall (Seleka & Mmopelwa, 2018). According to Kashe *et al.* (2019), agricultural input subsidies will continue in the foreseeable future. These arguments suggest that input subsidies should be explicitly evaluated in their specific components and implementation to establish benefits and disbenefits (Minviel & Latruffe, 2017).

Minviel and Latruffe (2017) conducted a meta-analysis of existing empirical studies on the relationship between public subsidies and farm technical efficiency. The authors discovered that the existing literature does not widely cover emerging and developing countries. Therefore, the literature reviewed in this sub-section is on input subsidies and their effects on productivity and efficiency. Jambor and Szerletics (2022) used quantitative regression-analysis models to evaluate the impact of the Common Agricultural Policies (CAP) on farm productivity in the case of the New Member States (NMS) in Europe. Their results showed that direct subsidies negatively affect labour and productivity in agriculture.

Similarly, using the Agricultural Accountancy Data Network, Alexendri, Saman, and Pauna (2021) investigated the effects of CAP subsidies on farm productivity. The authors used multilevel mixed-effects models that contained fixed and random effects to describe the data's heterogeneity and the significance of group effects. In almost all of the countries they looked at, subsidies negatively impacted agricultural productivity, according to their research.

Much of the literature on the topic is from Europe (Rizov, Pokrivcak, & Ciaian, 2013; Staniszewski & Borychowski, 2020; Zhu & Lansink, 2013) evaluating the impacts of the CAP subsidies on productivity and efficiency. Most of these studies have concluded that subsidies negatively affect farm productivity. However, the European subsidy literature can not be applicable in Africa because most studies are conducted in developed countries, and the literature does not cover developing countries (Minviel and Latruffe, 2017). Africa comprises a mainly agrarian population made up of resource-poor rural people. Therefore, the African input subsidies cannot be compared to the European subsidies but instead be seen as "some social protection" for the farmers.

Malawi is one African country that has been seen as a "model" other countries look up to when designing their subsidy policy (Jayne *et al.*, 2013). Malawi Farm Input Subsidy Program (FISP) has been evaluated for its benefits against costs (Jayne & Rashid, 2013; Jayne *et al*., 2013), but little has been done to evaluate its effects on farm efficiency. Using Malawian maize farmers as a case study, Darko and Ricker-Gilbert (2013) investigated production efficiency and how agricultural input subsidy schemes affected it. The study findings demonstrated that farm input subsidies increased farmer productivity efficiency, yet farmers were only 47% productively efficient even with the subsidy.

Sibande, Bailey and Davidova (2015) analyzed the effects of a fertilizer subsidy program in Malawi on household food security and the overall yearly per capita consumption expenditure. According to the authors, the fertilizer subsidy program significantly influenced household food security and annual per capita consumption expenditures. The study used fixed and correlated random effect quantile regression models to estimate the subsidized fertilizer's conditional mean and heterogeneous effects. The findings revealed that the availability of kilocalories per person per day, the number of months that a household experienced food security, and the possibility that a home would experience year-round food security were all positively impacted by subsidized fertilizer. The study findings indicated that agricultural input subsidy programs might improve food security, especially for larger or commercial food crop producers. The study suggested that the input subsidies are less beneficial when the primary policy goal is to reduce poverty. Although this reviewed study showed that subsidy was less effective in reducing poverty and that subsidy inputs could benefit larger food crop producers, most subsidies in Sub-Saharan Africa are set to assist smallholder farmers. These farmers collectively produce most of the food in the markets; thus, the current study focuses on smallholder farmers.

An essential and appealing finding from the literature is that most input subsidy programs focus on providing seeds and fertilizers to the farmers. However, none mention the mechanization aspect for the farmers. Nonetheless, the Botswana input subsidy has gone the extra mile to provide farmers with seeds, fertilizers, and tractor services (farm mechanization). However, the benefits or demerits of this subsidy aspect have not been fully explored in the literature hence the knowledge gap that the current study seeks to address.

In Botswana, the subsidy programs have been evaluated for achieving their specific set objectives (Marumo *et al*., 2014; Motlhwa *et al*., 2019; Seleka, 1999; Seleka & Mmopelwa, 2018), but little empirical work has been conducted to evaluate the programs of their effects on the crop farmers' efficiency. These studies have pointed out that the subsidy programs have not improved farmers' yields but have failed to evaluate the components of the subsidy program to find out the exact cause of the failure to increase the yields. Hence this study assesses the effects of the timeliness of farmers receiving the inputs on the productivity and efficiency of the crop farmers. Only (Moikgofe, 2020) conducted a similar study in Botswana, but the study had severe data limitations.

Empirical review on effects of production efficiencies on food security and livelihoods

Literature extensively explores the linkages between farmers' productivity, food security, and income. Most studies on farmers' efficiencies tend to estimate and determine factors influencing the efficiencies. However, only a few of these reviewed studies analysed the effects of the efficiencies on the farmers' livelihood and food security. Most consider the effects of farm productivity on food security and farmer incomes but seldom analyse the farmers' efficiencies in improving their livelihoods and food security status simultaneously.

Kehinde, Ademoyo and Ogundeji (2021) used the simultaneous equation model to analyse the two-way causal relationship between farm productivity, social capital, and food security of cocoa-based farming households in Southwestern Nigeria that depend on cocoa farming. The study used Calorie consumption as a proxy for measuring food security and constructed a capital asset index. The study results revealed that the household size, household heads' age, and education level significantly affected the farming households' cocoa farm productivity. However, an increase in household size and the household head's age decreased the food security status. The study concluded that improved social capital improves the productivity of cocoa farmers, thus improving incomes and household food security.

Danso-Abbeam and Baiyegunhi (2020) used the DEA method and Conditional Mixed-process (CMP) to evaluate the bi-directional effects of technical efficiency and welfare of the cocoa farmers in Ghana. Their study estimated mean technical efficiency was 76% and scale efficiencies estimated at 58%. The results showed that household welfare and efficiency significantly complement each other. An increase in technical efficiency was found to improve the farmers' welfare, and farmers with better welfare had increased efficiency scores. The study further indicated that if increased, policies aimed at farm-level use, such as input subsidy programs and farmer training on proper agrochemical use, can improve agricultural efficiency because efficiency influences household welfare.

Empirical review on the effects of production efficiencies on food security

Oyetunde-Usman and Olagunju (2019) analyzed Nigeria's agricultural households' technical efficiency. They categorized the households into food secure and food insecure and tested for the significance of the technical efficiency mean. The authors used the stochastic frontier to estimate the efficiencies employing the one-stage approach to assess the determinants of technical efficiency. They determined food security using a subjective measure based on the household's access to healthy and nutritious food the household presented as its food basket. A standard probit model was then employed to determine the factors influencing the household food security status. The study estimated the mean technical efficiency of the households at 52%. The results showed that households classified as food-secure were more technically efficient than those classified as food insecure. The study also found that household size was a significant determinant of technical efficiency, showing that technical inefficiency decreased as household size increased; however, food insecurity increased as the household size increased. Technical inefficiency was negatively associated with food insecurity, showing that the more technically efficient households were, the less likely they are to be food insecure.

Again in Nigeria, Iheke and Onyendi (2017) used the Stochastic Frontier Profit function to examine farm households' economic efficiency and food security status in the Abia State of Nigeria. Their study showed that farmers' age, education, farming experience, primary occupation, farm size, extension contact, credit, and association membership were significant factors influencing the economic efficiency of the farm households. The study showed that 31.25% of the farmers were food secure, while 68.75% had food insecurity.

Other studies showed similar results as the above-reviewed studies, and most show similar findings regarding the relationships between production efficiencies, livelihoods and food security. The studies point out similar determinants of these variables but none; however, all these studies have not considered the farmer subsidy timeliness provided by governments and how receiving the subsidy inputs on time possibly impacts the productivity and efficiency of farmers, which is the novelty of the current study.

Conceptual Framework

The study's conceptual framework illustrates the diagrammatic representation of how the critical variables of the study relate. From Figure 3, the study used the production, institutional, and socio-economic factors to measure the levels of efficiency. As Chambers (1988) defined production, the farmer combines the labour, land, and capital under their management to produce output. The farmers' management decisions in production are influenced by the farmer's characters and the institutional and policy factors. The institutional and policy factors are represented by capital inputs used in production, such as seeds and farm mechanization. Institutional and policy factors include access to credit, extension agent contacts with the farmer, farmers' access to the capital seeds provided by the government subsidy program (ISPAAD), and membership in social groups. Socioeconomic factors include information on the farmers and their households. When combined, all these factors determine a farmer's production efficiency in their operations.

The farmers' production efficiency is divided into economic, allocative, and technical. The factors are expected to influence the farm production and efficiency levels of the farmer as they influence the farmers' decisions on their production and livelihoods. It should be noted that there can be direct relationships between food security and livelihoods. However, the analysis did not further establish the relationship between the two variables for this study.

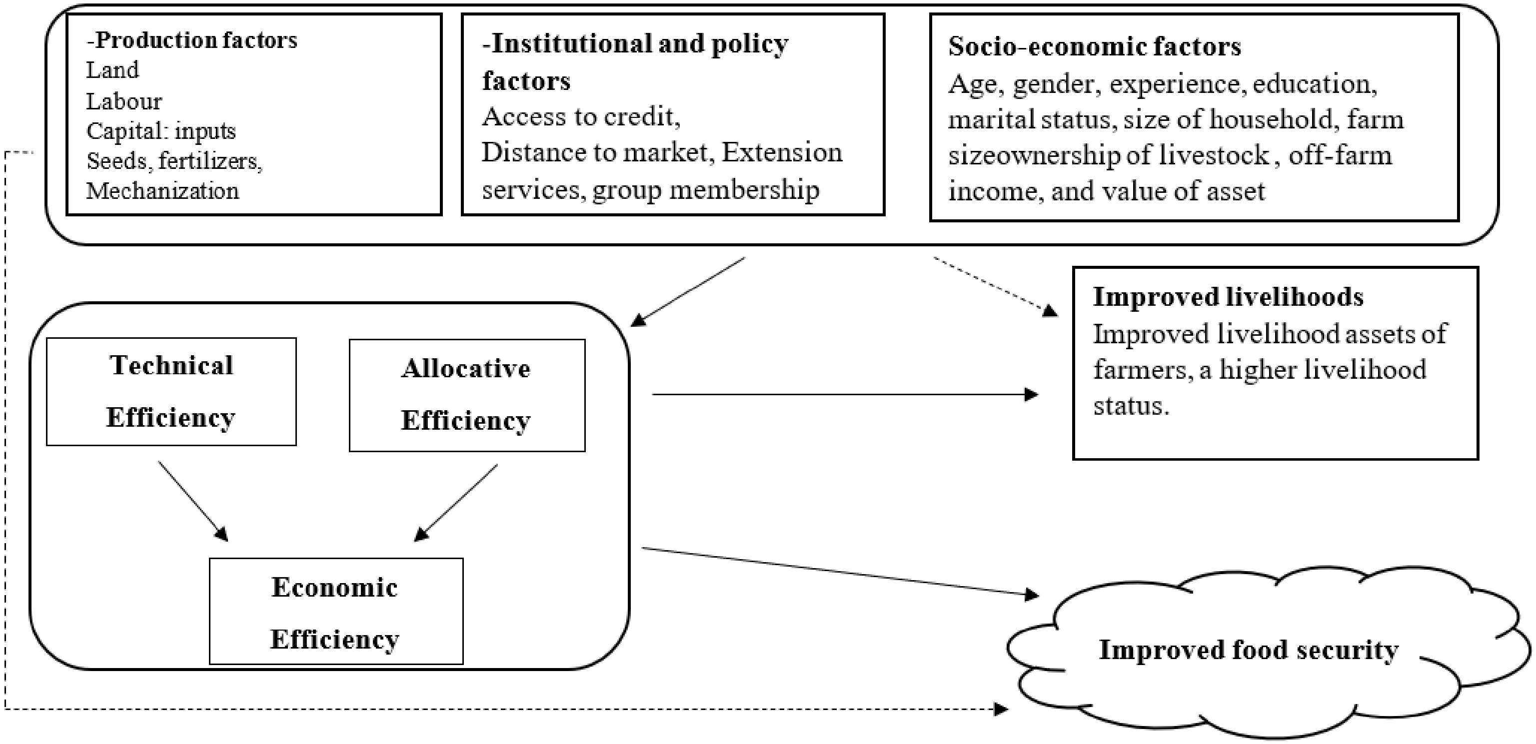


Figure 3: Conceptual framework of the study

Source: Author's construct

CHAPTER THREE

RESEARCH METHODOLOGY

Introduction

The study aimed to measure the arable crop farmers' efficiencies and further examined how the production efficiencies affect farmers' livelihoods and food security in Botswana. This chapter explains the methods used for the study data collection and analysis. It starts by explaining the research philosophy and discusses the study area, research design, study population, sampling method, sample size determination, research instrument, data collection procedure, data processing, and analysis techniques.

Research Philosophy

Research philosophy is a set of beliefs about how data on a phenomenon should be collected, analyzed, and utilized (Collis & Hussey, 2014). Two major research philosophies used in research are positivism and interpretivism. Under positivism, the phenomenon is explained and predicted based on theories. The explanations establish relationships between variables by evaluating their influence on the outcomes and linking them to a deductive theory. According to Collis and Hussey, positivists posit that an assertion should be justifiable and that knowledge is derived from 'positive' information that can be verified scientifically. In other words, providing mathematical or logical proof for every rationally justifiable assertion is possible. Therefore, positivists employ logical reasoning to ensure accuracy. Rigour and objectivity underpin positivists' approach rather than subjectivity and intuitive understanding (Collis & Hussey, 2014). Positivists believe that reality exists independently of the people and that investigating social reality has no effect on it (Creswell, 2014). Positivists use statistical methods of analysis for quantitative research data.

On the contrary, for interpretivism to gain interpretive understanding, it explores the complexity of social phenomena. Interpretivism believes in society not being objective but highly subjective, as people's perceptions shape it. According to Creswell (2014), the researcher interacts with the subject of the study, making it impossible to differentiate between what occurs in the social environment and what exists in the researcher's head. Interpretivism uses several methods to describe, interpret and explain a phenomenon rather than statistical analysis of quantitative data like positivists. Therefore, the research under interpretivism uses an inductive approach. This study followed the positivist philosophy to allow the researcher to dissociate from and acquire knowledge unrelated to personal values and moral content.

In this study, the positivist philosophy was followed due to the quantitative nature of the research. The study also intends to portray the behavioural patterns of farmers by looking at cause and effect. When these cause and effect are established, the research philosophy allows for a generalisation of the findings from the sample to the population. Additionally, the philosophy creates the framework for the selection of the research design of the study.

Research Design

Leavy (2017) defined research design as the process of building a structure or plan for conducting research. Research design provides a clear plan for action that includes techniques employed in executing the research (Blanche, Blanche, Durrheim & Painter, 2006). The execution of research involves the data collection procedures and data analysis. According to Blanche *et al*., a research design should provide a plan that specifies how the research will be executed so that it answers the research questions. The design choice lies with the researcher considering the type of research problem being investigated. This study is quantitative research using a descriptive correlational survey design. In a descriptive correlational study, the researcher identifies the variables in the study to explain better the causal relations between the variables (Collis & Hussey, 2014).

In this study, production efficiencies, farmers' livelihoods, and food security were studied, and then their relationships were explored; hence the descriptive correlational design was chosen. This study tested the relationships between two dependent variables (food security and livelihood) and production efficiencies to make inferences for the entire arable farming community.

Study Area

The study was conducted in the Central District of Botswana, which is one of the government's ten (10) administrative districts. Most of the arable production activities occur in this district, and it has the highest number of smallholder farms planted than any other district (Statistics Botswana, 2019). Statistics Botswana (2019) and Motsatsi (2015) reported that the soil and climate conditions are more conducive in the Northeast and Central Districts of the country; hence most arable production occurs, which contributed to its selection for the study.

The Central District is located in the Eastern region of the country. It borders the Chobe District on the north, Ghanzi on the western side and Kweneng and Kgatleng Districts on the southwest and south, respectively. It extends to the country's borders with Zimbabwe in the northeast and the Republic of South Africa in the south and east. The weather is predominantly semi-arid, with vast areas devoid of surface water and extremely high temperatures (Lemenkova, 2022). The region experiences variable rainfall, with January and February receiving the highest amounts in the rainy season, which begins in October and lasts through April (Batisani, 2012). The amount of rain is frequently in the form of heavy downpours that contribute little to the soil's ability to store water and cause quick run-off and erosion. This precipitation mode predisposes croplands to land degradation (Mashame & Akinyemi, 2016). Soft penetrating continuous rain that lasts for extended periods is relatively rare (Siderious, 1978).

The Central District is home to most mines (diamond, sodium carbonate (soda ash), copper, nickel, and coal). Although the mines play a significant economic role for the entire nation, they provide only small employment opportunities for people in the Central District. Therefore, most rural village households depend on agriculture for their livelihood. The Central District comprises nine sub-districts: Serowe, Palapye, Mahalapye, Machaneng, Bobonong, Selibe-Phikwe, Tonota, Tutume and Letlhakane-Boteti. These subdistricts comprise a total of 97 extension areas. Figure 4 below shows the Central District in the map of Botswana and the four (4) subdistricts selected for the study.

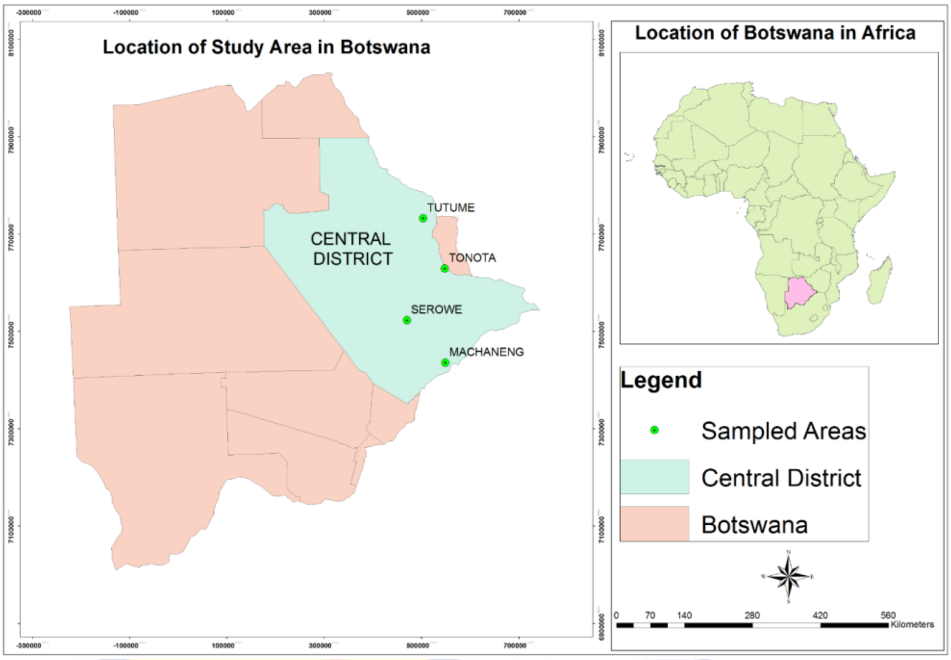


Figure 4: Study area map

Source: Author's construct, (2021)

Study Population

A population is a precisely defined group of people considered for statistical purposes. The target population for the study consisted of all smallholder arable farmers in the Central District of Botswana who benefited from the ISPAAD program during the 2020/2021 cropping season. The total number of smallholder arable farmers in the Central District was estimated at around 30 000 (Statistics Botswana, 2019). However, the accessible population in the selected four sub-districts was 18513, according to the lists of farmers provided by the extension officers from the 2019/2020 farmers registered for ISPAAD beneficiation. A smallholder producer is a traditional farmer who produces in less than 16 hectares according to the ISPAAD criteria for the beneficiaries. The farmers typically use hired tractor services covered by the subsidy program to plough their fields. They use small equipment in their production of arable crops. These farmers' production depends primarily on family members to provide labour on the farm and mainly produce for family consumption while selling their surplus to the market (Motlhalamme, 2019). The study participants were farmers who benefited from the ISPAAD program by accessing at least one of the subsidized inputs: seeds, fertilizers, agrochemicals, and/ or tractor services to plough in the 2020/2021 cropping season.

Sampling Procedure and Sample Size Determination

Sampling is the procedure followed in selecting participants for the study from a population. Sampling is concerned mainly with representativeness. The objective is to select a sample representative of the population and draw conclusions from the sample for the population. A multistage sampling technique involving four stages was employed in this study. The first stage involved a purposive selection of the Central District for having the highest number of smallholder farmers, and most arable production activities occur in this district. Using the lottery method, the second stage randomly selected four subdistricts out of the nine in the Central District hence the study's selection of Machaneng, Serowe, Tonota, and Tutume subdistricts.

The four sub districts were selected because most of the arable production activities occur in these sub-districts, and they have the highest numbers of smallholder farms planted than other subdistricts in the Central District (Statistics Botswana, 2019). Statistics Botswana (2019) and Motsatsi

(2015) reported that the soil and climate conditions are more conducive in the Northeast and Central Districts of the country which is mainly made up of these four subdistricts; hence most arable production occur, which contributed to the selection of these subdistricts for the study.

The third stage involved sampling the extension areas under the selected four (4) subdistricts. The four subdistricts comprised forty-four (44) extension areas that the study intended to cover all. However, some areas were not reachable due to unforeseen circumstances beyond the researcher's control upon reaching the field. Therefore, thirty-eight (38) extension areas were purposively sampled. The final stage involved randomly selecting the farmers from the list the extension area officers provided using the RANDARRAY function in Microsoft excel.

Sample size determination was achieved by employing the Yamane (1967) formula, which gave a sample size of 392, as calculated below.

$$n = \frac{N}{1+Ne^2} \qquad (3.1)$$

Where;

- n = the sample size needed
- N = population size
- e = margin of error

A margin of error (e) of 5% for this study, and the sample frame was 18513. The sample size was then calculated as follows:

$n = 18513 / [1+18513(0.05)^2] =$ **392**

Raosoft (2004), a sample size calculator, was used alongside the Cochran method for verification purposes. The Raosoft helped to substantiate the calculated statistically acceptable sample size for the population using a 95 per cent confidence level and a margin of error of five per cent. However, to allow for replacement in the sample of respondents who might drop out of the study, cater for the incomplete entries, and avoid missingness of data, the sample size was increased by 20%, giving a total of 470 farmers who were interviewed. A proportionate sampling method was used to determine the number of respondents per subdistrict to ensure equal representativeness from the subdistricts. When using proportionate sampling, the number of respondents from each subgroup depends on how many belong to that group overall (Etikan & Bala, 2017). The following formula was employed for proportionate sampling;

$$n\ sub = \frac{total\ persubdistrict}{total\ study\ area\ accessible\ population} * calculated\ n \qquad (3.2)$$

Where *n sub* represents the sample to be selected per subdistrict and *calculated n* is the study calculated sample size. This method was ideal because the subdistricts differed in the number of farmers. Table 1 shows the determined sample sizes per subdistrict.

Table 1: Study sample size

Subdistrict	**Serowe**	**Tutume**	**Tonota**	**Machaneng**	**Total**
Number of EAs	11	14	8	11	44
Sampled EAs	9	11	8	10	38
Sampling frame	4344	6044	4173	3952	18513
Sampled (n_{sub})	**109**	**146**	**113**	**102**	**470**

Source: Field survey, Mokumako (2022)

Data Collection Instrument

Primary data for the 2020/2021 cropping season was collected from the study area using the Structured Interview Schedule (Appendix A). The student researcher developed the instrument, and the study supervisors validated it at the Department of Agriculture Economics and Extension, University of Cape Coast, to ensure that the content was consistent with the study objectives. The primary purpose of validating the survey tool is to ensure it “measures what is intended to be measured” (Taherdoost, 2020). The instrument was divided into four subsections. Section A captured the demographics and farmer information; section B captured the farm production data; section C captured the livelihood asset improvement Likert-type scale questions; and finally, D captured the HFIAS questions.

The study adopted a structured interview schedule to capture data from respondents who could not read and write. Also, the interview schedules were ideal for language differences (Cresswell & Cresswell, 2018) because some respondents could only understand their local language, hence needed translation.

Pilot Test

The pilot exercise was conducted to pre-test the interview schedule survey instrument. The pretesting exercise was necessary to ensure the reliability of the survey tool and observe the length of time required to interview the respondents in the study area. Twenty-four farmers were interviewed in one Extension area in the Serowe Subdistrict for pre-testing the interview schedule survey instrument. A pre-test is a critical examination of the survey tool to determine if it will function adequately as a reliable and valid research tool (Converse & Presser, 1986; Taherdoost, 2020). Pretesting reduces measurement errors, reduces respondent burdens, determines whether respondents understand and answer the questions correctly, and ensures that the order of the questions does not influence how the respondents answer the questions. In the pretesting process, problems with the survey tool were identified. The necessary changes were made, and the language corrections were noted to ease administering. Final changes to the survey tool were implemented before the final data collection process.

Reliability analysis was conducted from the pre-testing exercise on Statistical Package for Social Sciences (SPSS) software version 25. Reliability refers to the consistency among a survey instrument's components; hence testing for reliability is crucial (Taherdoost, 2020). According to Yurdugül (2008), a Cronbach's alpha requires a sample of at least thirty (30). However, due to some respondents not being available, the current study used a sample size of 24 to estimate the Cronbach Alpha's reliability coefficients to examine consistencies in the farmers' responses to determine how reliable the research instrument items were. Table 2presents Cronbach's alpha results for reliability using the Household Food Insecurity Access Scale (HFIAS), factors hindering productivity, and livelihood asset improvement scale. According to Tavakol and Dennick (2011), a Cronbach Alpha between 0.7 and 0.9 renders the instrument reliable, thus showing that the survey tool used for this study was reliable.

Table 2: Reliability Analysis of the survey tool using Cronbach's Alpha

Construct	No. of items	Reliability Statistics
HFIAS	18	0.900
Factors hindering productivity	20	0.76
Level of livelihood asset improvement	29	0.905

Source: Field survey, Mokumako (2022)

Data Collection Procedures

Before the data collection procedure, an introductory meeting was held with the District Arable Agriculture Principal Officer (DAAPO) to explain the research objectives and expected benefits, introduce the student researcher, and get consent to conduct the data collection exercise. Due to the size of the sample and, in some areas, the language barrier between the student researcher and the respondents, before the data collection process, six field assistants were recruited and trained to help collect data from the study area. These research assistants were university graduates with an agricultural background and knowledge of the local language (and specific dialects per subdistrict). Using the validated and pretested structured interview schedules, the field assistants and principal researcher performed face-to-face interviews for data collection. The student researcher facilitated a day of training for the field assistants to explain the various parts of the instruments. The instrument was discussed in the local language with the research assistants helping translate the keywords into the local dialects. Upon understanding the tool, field assistants and the student researcher would call the sampled farmers on mobile phones (list and numbers of farmers obtained from the extension area officers' registry) to set an appointment for the interview, explain the interview expectations, and the COVID-19 protocols to be followed. The data collection started in mid-July and continued until mid-October 2021.

Problems Encountered in Collecting the Data

Data collection was carried out during the movement restriction times due to the novel COVID-19 outbreak. Movement permits were to be acquired before moving from one region to the other, and this presented challenges to the student researcher. Sometimes the movement permits would delay or even were denied for the enumerators, and time for data collection was lost. This challenge was addressed by recruiting research assistants at each subdistrict to avoid any delays. Due to the COVID-19 scare, some farmers would not agree to be interviewed. Some would have contacted COVID-19-infected individuals, therefore required to quarantine and could not be interviewed. In one particularly extreme case, fifteen of the twenty farmers called to be interviewed were in quarantine and could not be interviewed at the set time though some insisted. The farmers were later revisited for interviews after their quarantine was over. The student researcher also contracted COVID-19, and data collection had to stop for fourteen days of isolation.

Ethical Issues

It is required to obtain a research permit before conducting research in Botswana. Therefore, the principal researcher applied for a permit from the Ministry of Agricultural Development and Food Security while still preparing the proposal for the study. Following the grant of the permit, the researcher applied for ethical clearance from the Institutional Review Board (IRB) at the University of Cape Coast, which reviewed the proposal and ensured ethical considerations were adhered to (see Appendix B for the ethical clearance from the UCC IRB). Ethical procedures were taken seriously and adhered to in the data collection exercise. Ethical issues such as consent, confidentiality, autonomy, and anonymity were adhered to during the data collection process. The candidate also avoided plagiarism when preparing the study reports by ensuring that the word similarity index was below 20 per cent, as stipulated by the University of Cape Coast. The final reports for the study were subjected to Turnitin Software for plagiarism checks.

Data Processing and Management

According to Coelli *et al*. (2005), data editing is essential in efficiency and productivity measurement. They noted that the researcher needs to correct errors in the data and drop real outliers and invalid observations or modify them. Data from the survey was entered and cleaned using SPSS version 25 and then exported to Microsoft Excel. The unit of analysis for the study was the farmer. Therefore, data from 470 smallholder farmers was processed for the study. Farmer households were then used for the assessment of food security and livelihoods and the household in the context of the current study referred to the farmer's dependents (specifically the spouse, children if any living with the farmer).

Ten units were dropped from the sample size of 470 when estimating the efficiencies. These extreme outliers were identified by running a simple regression to estimate the basic production function and examined the residuals to check for outliers and observations that exerted much influence on the regression equation (see appendix C). Microsoft Excel was used to compute the necessary calculations, and the data was then imported into the R software for further analysis. Different R-software packages were used for analysis. Some of the data was analyzed using Microsoft Excel.

Definition of Study Variables

Explanatory variables for this study were chosen based on theory, empirical research, data accessibility, and the researcher's understanding of the surrounding context. The variables used in the study (as discussed below), are subdivided into different themes as explained in the conceptual framework. The analytical framework presented below provides the study's variables according to the study objectives. After a thorough review of the literature, the supervisors' guidance, and the student researcher's experience, the variables were summarized as presented in the analytical framework.

Farm and household socio-economic characteristics

- **SEX** = sex of farmer measured as a binary variable (1 for male and 0 for female). Most studies tend to report the sex of household heads as the household heads are the decision markers. However, the current study omitted data collection on the household head but focused on the farmer as the decision-maker in production. Studies show mixed results about the role played by gender in productive efficiency.

- **AGE** = age of farmer measured in years.
- **MARITALS** = Marital status of farmer measured as a binary variable (1 married, 0 otherwise)
- **EDUCATION =** Education level of farmer measured by the number of years in formal school.
- **EXPERIENCE** = farmer's farming experience measured in the number of years of arable crop production.
- **HHSIZE** = household size measured as the number of individuals in a household who are dependent on the farmer. The household size determines the amount of labour available in agricultural setups. The expectation is that the larger households would have more hands available to participate in farm management activities (Mota *et al*., 2019; Oyetunde-Usman & Olagunju, 2019). However, this is subject to the age categories of the household members. It is also an important determinant of food security in that, as the household size increases, the more mouths to feed hence a burden on the household (Nkomoki, Bavorová, & Banout, 2019). The household size was measured as the number of persons sharing meals from the same pot and dwelling in the same homestead. This excluded relatives in the diaspora but focused on the members who resided in the household dwellings

continuously for atleast a month. A positive relationship was expected between household size, production efficiencies, and food insecurity.

- **INCOME** = household income measured in BWP as the average monthly income for a household summed from all the farmer's sources (including farming, off-farm employment, cash for work, remittances and pension). The ability of a household to acquire farm inputs and food largely relies on household income. Income was postulated to increase the farmer's efficiency and positively influence the livelihood while improving the farmer's food insecurity status.
- **SOURCE_LIVELIHOOD** = farmer's household primary livelihood source measured as a dummy variable (1 for agricultural sources and 0 for otherwise).

Institutional factors

- **EXT_VISITS** = Number of times the farmer interacted with the extension area officer. The visits included the farmer going to the extension office (for registry and access to the ISPAAD inputs) or the extension officer going to the farm. However, the practice in the study area was that farmers collect the seeds from the extension office, register their output after harvest, and register for beneficiation for the next cropping season. Agricultural extension transfers new technologies, better management alternatives, and farming techniques to farmers (Rahman & Connor, 2022). Empirical studies have shown that farmers who accessed extension more frequently benefit positively from the benefits through guidance and motivation, translating to better or higher yields and productivity (Danso-Abbeam, Ehiakpor, & Aidoo, 2018).

- **CREDIT =** whether the farmer has access to credit (1 for having access and 0 for otherwise). Access to credit included any means, not only the formal borrowing setup.
- **TIMEseeds** = perception of timeliness of receiving seeds from the extension officer by the farmer (1 = on time and 0 = otherwise). Late was defined in reference to the starting of the ploughing season, generally after the onset of rains.
- **TIMEtractor** = perception of timeliness of receiving hired tractor service by the farmer (1 = on time and 0 = otherwise). Late was defined in reference to the starting of the ploughing season, generally after the onset of rains.
- **QLT_TS** = perception of the quality of tractor service received by the farmer (1 = satisfactory and 0 = otherwise)

Production factors

- **LAND** = cultivated land measured in hectares.
- **SEEDS** = amount of total seeds used measured by total cost for the seeds
- **TRACTOR** = hired tractor service to represent all the mechanization used in the farm measured by the amount paid for service
- **LABOUR** = total labour employed in the farm during production, including family and hired labour measured in BWP per hour worked.
- **Time_plough** = perception of the timeliness of ploughing by the farmer (1 for on time and 0 for otherwise). Late was defined in

reference to the starting of the ploughing season, which is generally after the onset of rains.

- **I(TRACTOR*SEEDS)** = the computation of the interaction of the TRACTOR and SEED variables, defined above, to capture the effects of the ISPAAD subsidy program.

Latent Variables

- **TE** = technical efficiency score estimated for each farmer from the productivity analysis
- **AE** = allocative efficiency score
- **EE** = economic efficiency score for each farmer
- **LH_SCORE** = the computed livelihood assessment score for each farmer
- **FIS_SCORE** = the calculated food insecurity score for each farmer from the HFIAS computations.

The ISPAAD subsidy program plays a vital role in arable production, and its effects were captured in the models. A variable showing the interaction between the program components (i.e., seeds and tractor services) computed to represent the subsidy effect hence the I(SEED * TRACTOR) variable. Furthermore, the subsidy components' timeliness were included in the determinants models disintegrated into two items: TIMEseeds and TIMEtractor, representing the timeliness of the farmers receiving the subsidy inputs. The study variables are summarized in Table 3 below.

Table 3: Description of the variables used in the study for analysis

Variables	Description	How they were measured
I(SEED * TRACTOR)	Interaction between tractor and seed costs from ISPAAD	(Subsidy effect)
EXPERIENCE	Farmer's experience in crop farming	Ratio
HHSIZE	Number of individuals in a household	Ratio
SOURCE_LIVELIHOOD	Whether farmers subsist on agriculture or otherwise	dummy 0= agricultural, 1= otherwise
INCOME	Average income for a household	Ratio
EXT_VISITS	Number of visits to the extension officer	Number of times
SEX	Sex of farmer	Dummy 0 = female 1= male
EDUCATION	Number of years in school	Years
AGE	Age of farmer in years	Years
MARITALS	Marital status	dummy 0= otherwise, 1= married
TIMEseeds	Time of acquiring seeds	dummy 0 = ontime 1= otherwise
TIMEtractor	Time of getting tractor service	dummy 0 = otherwise 1= ontime
QLT_TS	Quality of tractor service rendered	dummy 0 = good 1= poor
Credit	Access to credit	dummy: 0 = not a concern 1 = it is a concern
LH_SCORE	Livelihood score	Livelihood scrore ranging between 0-100%
FIS_SCORE	Food insecurity score	Food insecurity score ranging between 0-27
TE	Technical efficiency score	Technical efficiency score, ranges between 0-1
AE	Allocative efficiency score	Allocarive efficiency score, ranges

		between 0-1
EE	Economic efficiency score	Economic efficiency score, censored between 0-1

Data Analysis

According to the ordinary least squares (OLS) assumptions, the estimators should be Best Linear Unbiased Estimators (BLUE), hence very close to reality. Violating these assumptions leads to various consequences for the model estimation and inference. Although most productivity and efficiency studies avoid testing for the assumptions, some of the analyses cause a statistical error in the regression estimates and correlation (Khanal, Lohani, & Khanal, 2022). Therefore, it is essential to test for the violation of these assumptions and apply the appropriate remedial measures if applicable.

Test for Heteroscedasticity

Heteroscedasticity refers to a case where the error term is not constant for all observations or values of the independent variable. Heteroscedasticity leads to unbiased but inefficient estimates of the coefficients, biased standard errors, and biased test statistics (Acquah, 2013). Heteroscedasticity is one violation of the OLS that can cause the variances to be too small or too large, resulting in Type I or II error results of hypothesis testing. Heteroscedasticity is common when using cross-sectional data (Gujarati & Porter, 2003), which this study employed. Therefore, it is necessary to test for heteroscedasticity in a stochastic frontier model to correct for it if present. Heteroscedasticity can be corrected by weighting every term of the regression and logarithmic transformation of the variables to use when estimating the regression. In this study, the Breusch-Pagan test was used to test for heteroscedasticity, where a null hypothesis of homoscedasticity against the alternative of heteroscedasticity was set. The null hypothesis of the Breusch-Pagan test follows a Chi-square distribution. Where the p-value is less than the critical value, we reject the null hypothesis and conclude that there is heteroscedasticity (Wongnaa, 2016). However, where the p-value is greater than the critical value, the test confirms the validity of the constant variance.

Test for Multicollinearity

Multicollinearity occurs when two or more explanatory variables in the regression models are highly correlated, thus making it difficult to isolate their individual effects on the response variable. Multicollinearity only affects computations with unit predictors, not necessarily the model's predictive power. The implication is that a multiple regression model with correlated predictors can be used to determine how well a group of predictors as a whole predicts the dependent variable; however, obtaining reliable information about individual predictors may not be possible. The presence of multicollinearity results in high R square and regression coefficients that are statistically insignificant. According to Gujarati and Porter (2003), sometimes, when multicollinearity is detected, there is nothing one can do. One can use more observations to correct multicollinearity by increasing the sample size or dropping the highly collinear variables. The variance inflation factor (VIF), which assesses the degree of correlation between predictor variables in a regression model, was used to test for multicollinearity in the current study. The threshold usually established for the VIF to consider high collinearity is 10 (VIF=>10). Therefore, values greater than 10 indicate significant concern for multicollinearity (Salmerón, García, & García, 2018).

The Methodological Framework of Production Efficiencies

There are two methodologies commonly used by researchers to estimate the levels of efficiency of farm enterprises. These methods fall under the categories of mathematical programming approach (Data Envelopment Analysis [DEA]) and econometric approach (Stochastic Frontier Analysis [SFA]). The SFA uses statistical approaches to estimate the function's parameters, assuming that outputs and inputs have a functional relationship (Ahmed *et al*., 2018). It incorporates an error term made up of two additive components: a non-negative component reflecting production inefficiency and a symmetric component representing statistical noise caused by data measurement errors. The asymptotic efficiency attribute makes SFA a better method for predicting efficiency (Ngango & Seung, 2019). However, to use the SFA, one has to assume a functional relationship between the inputs and outputs and then estimate the function's parameters using econometric methods (Ahmed *et al*., 2018).

DEA is non-parametric and uses linear programming techniques to build a piecewise frontier of data. DEA is deterministic, meaning all frontier deviations are attributed to inefficiency (Watkins, Hristovska, Mazzanti, Wilson, & Schmidt, 2014). The fact that all the deviations are attributed to inefficiency subjects DEA to statistical noises resulting from data measurement errors (Coelli, 1995). However, the advantage DEA has is that, because it is non-parametric, there are no functional or distributional assumptions to be made (Tesema, 2021). The author added that DEA does not require assumptions about the underlying production technology.

The results from the two approaches may be slightly different depending on the type of data (Ngango & Seung, 2019). However, most studies measuring production efficiency use the SFA, while a few use the DEA. According to Coelli *et al*. (2005), SFA is probably the most appropriate model for measuring efficiency levels in research related to the agriculture sector, particularly in developing countries, because it can handle the effect of statistical noise. When using the stochastic production function, there are two methods of estimating efficiencies: one-stage and two-stage estimation. With one-stage estimation, the frontier production function parameters are estimated along with those of an inefficiency model, which specifies the effects of technical inefficiency as a function of other factors (Shiferaw *et al*., 2021). Shiferaw *et al*. further added that this method has drawn criticism because of the failure to estimate the factors determining allocative and economic efficiencies, as it can only estimate the determinants of technical efficiency. The two-stage approach allows for estimating the economic and allocative efficiencies using the dual cost frontier of the production function. For this reason, this study uses the SFA model to estimate the three components of efficiency using the stochastic production frontier function and its self-dual, the cost frontier.

Analytical Framework for Efficiency Estimation

Stochastic Frontier Production Function for Technical Efficiency

Aigner, Lovell, and Schmidt (1977), specified the stochastic frontier production function as;

$$Y_i = f(X_i\beta)\exp(v_i - u_i) \qquad i = 1, 2, 3, \ldots n \qquad (3.3)$$

Where Y_i represents the output of the i^{th} firm, X_i is a vector of inputs , β is a vector of parameters to be estimated that are unknown, v_i is a random variable that is assumed to be $N(0,\sigma_{v_i}^2)$ and independent of the u_i a non-negative random variable that is assumed to account for technical inefficiency in production (Coelli *et al.*, 2005). Conditional on the firm's input level, the technical efficiency of each firm is determined in terms of the ratio of observed production output to the corresponding frontier output. Hence the technical efficiency (TE) of the i^{th} firm is specified as follows;

$$TE_i = \frac{Observed\ output\ of\ the\ ith\ firm}{Frontier\ output\ of\ all\ firms}$$

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{F(X_i\beta)\exp(v_i - u_i)}{F(X_i\beta)\exp(v_i)} = \exp(-u_i) \qquad (3.4)$$

Technical efficiency depends on the value of the unobservable u_i being predicted. When u=0, it means TE = 1, and the firm is said to be producing on the frontier hence technically efficient (Inkoom & Micah, 2017). If u > 0, production lies below the frontier, and the firm is technically inefficient. Therefore, the value of technical efficiency lies between zero and one. The most efficient firm will have one value, whereas the less efficient firm will have efficiencies between zero and one. According to Coelli *et al.* (2005), to predict the technical efficiency as shown, one needs to estimate first the parameters of the stochastic production frontier model in equation (3.3).

Estimating the Parameters

To estimate the parameters, the random variable v_i is assumed to be independently distributed of each u_i and both terms are non-correlated with the explanatory variables X_i. Furthermore, the noise component v_i, is assumed to have identical properties to the error term in the classical linear regression model, i.e., independently and identically distributed (*iid*). The inefficiency component u_i, also has the same properties except for the non-zero mean. Although with these assumptions, OLS can be used to estimate the slope coefficients, the OLS estimator of the intercept coefficient is biased downward, making it unsuitable for use to compute the efficiency measures (Coelli *et al*., 2005). To address this problem, some distributional assumptions about v_i and u_i are made to estimate the model using the traditional maximum likelihood estimator (MLE) method (Kumbhakar, *et al*., 2020).

The distributional assumption that can be made when estimating the stochastic frontier production function (SFPF) using the MLE include the half-normal distribution, exponential distribution, the truncated normal distribution for u_i and normal distribution for v_i. In their work, Aigner *et al.* (1997) and Meeusen and van den Broeck (1977) assumed a normal distribution for *v*. However, Aigner *et al.* (1997) assumed a half-normal distribution and Meeusen and van den Broeck (1977) assumed an exponential distribution for *u*. Aigner *et al.* (1997) suggested that the parameters could also be estimated using a method of corrected least squares (COLS). However, estimating the SFA using the MLE method can be asymptotically efficient if the correct distributional specifications are made for the error term (Kumbhakar *et al.*, 2020).

The original SFPF has been altered and extended in several directions, like the stochastic cost frontier (Coelli, 1995a). The stochastic frontier production model used to measure technical efficiency does not involve input prices, but the stochastic cost frontier can then be analysed where prices are available. The assumption is that firms are cost minimizers. A cost function explains the firm's total cost as a function of input prices and output quantities, showing the minimum cost of producing the output combination *y* when the input prices *w* are given. Unlike the production function, the cost function can easily handle more than one output, and the cost function is also able to answer all questions that a production function can answer.

Stochastic Cost Frontier Function for Economic and Allocative Efficiency

In estimating allocative and economic efficiencies, the cost efficiency function is specified by changing the error from the $\varepsilon_i = V_i - U_i$ to $\varepsilon_i = V_i + U_i$. Transforming the production function gives the cost function in a general form as:

$$C_i = f(Y_i;\ P_i; \beta)\exp(U_i + V_i) \qquad (3.5)$$

Where C_i is the total cost of production by the i^{th} farmer with a corresponding output, Y_i and P_i are the vectors of observed output and input prices for the i^{th} farm, and β is the vector of unknown parameters to be estimated. v_i are random variables assumed to be independent and identically distributed with 0 mean, and a variance of δ^2, i.e., iid N(0, δ_v^2), and independent of the U_i are non-negative variables which are assumed to be iid N(0, δ_u^2) and responsible for cost inefficiency by determining how far the firm operates above the cost frontier. Firm-specific economic efficiency is then obtained as the ratio of minimum total production cost (C^*) to the actual observed total production of cost (C) as follows:

$$EE = \frac{C_i^*}{C_i} = \frac{f(Y_i; P_i;\beta)\exp(U_i+V_i)}{f(Y_i; P_i;\beta)\exp(V_i)} = U_i \qquad (3.6)$$

where C^* is the production cost under the ideal condition where efficiency is attained, and C represents the actual cost observed from the individual firm sampled. Economic efficiency ranges between 0 and 1, 0 representing an economically inefficient farm while 1 is the maximum economic efficiency. A firm is economically efficient if U=0 and thus $C^*= C$. If $C>C^*$, there is economic inefficiency (EI).

As Farrell (1957) stated, allocative efficiency (AE) can be obtained from EE values, given that $EE= TE_i$ x $AE_{i.}$ Giving allocative efficiency as follows;

$$AE = EE/TE \qquad (3.7)$$

However, Ahmed *et al*. (2018) argued that there is little to no input price variation across farms. Therefore, any econometric estimation of a cost function is very difficult. Hence, the self-dual structure of the production and cost function is applied to offer the computational advantage of decomposing the cost efficiency into AE and EE.

Choosing the functional form

One must choose a functional form when estimating the production or cost frontiers. The two commonly chosen functional forms in literature are the Cobb-Douglas and the Translog. The Cobb-Douglas is more restrictive but preferred for its advantages in specifying and estimating different efficiencies and decomposing cost efficiency into different components of efficiencies (Kumbhakar, 1991). The Translog function is flexible, but there is no self-dual for the translog production frontier, meaning that the allocative efficiency measure cannot be worked out (Kalirajan, 1990).

However, choosing the appropriate functional form is not straightforward, as no functional form dominates under all circumstances (Giannakas, Tran, & Tzouvelekas, 2003). The authors further argued that functional forms are both data and model specific and differ in their convergence properties, making the choice of the appropriate function case specific. Despite its well-known limitations, the Cobb-Douglas functional form has been employed in several studies to analyse agricultural efficiency. However, it is necessary to test for the adequate representation of the production data collected to represent the data. The generalised likelihood ratio test is used diagnostically to establish which of the functional forms best fits the collected data. The test enables the comparison of the models, and the statistic associated with the test is defined below (Kodua, *et al*., 2022).

$$\lambda = -2\left[In\frac{L(H_o)}{L(H_1)}\right] = -2[InL(H_o) - InL(H_1)\,] \qquad (3.8)$$

Where $L(H_o)$ is the log-likelihood value of the model under the null hypothesis, while $L(H_1)$ is the value of the function under the alternative hypothesis. The test statistic follows a Chi-square distribution, with the number of degrees of freedom equal to the number of parameters assumed to be zero in the null hypothesis. When the test statistic is greater than the critical value, the null hypothesis is rejected in favour of the alternative at the given significance level.

Therefore, for choosing the functional form, the study set the following hypothesis;

H_0 : Cobb Douglas adequately represents the production frontier function and is a statistically valid model appropriate for the dataset

H_1 : Cobb Douglas does not adequately represent the production frontier function and is not a statistically valid model appropriate for the dataset

Method of Analysis of the Efficiencies

Following the work of Ahmad *et al*. (2018), the study adopted the self-dual structure of the production and cost functions. The linear form of the Cobb–Douglas production function is given specified as;

$$In\, Y_i = \beta_0 + \beta_i InX_{ij} + v_i - u_i \qquad i=1,2,3,\ldots n \qquad (3.9)$$

Where *In* represents the natural log, Y_i is the output of the i^{th} firm, X_i is a vector of inputs, j is the number of inputs, and β is a vector of unknown parameters to be estimated, v_i is a random variable that is assumed to be *N*-$(0,\sigma_{v_i}^2)$ and independent of the u_i a non-negative random variable assumed to account for technical inefficiency in production. By solving the problem given under equation (3.10), the dual cost function is derived from the production frontier (Ahmed *et al*., 2018);

$$\text{Subject to}\begin{cases} \underset{x}{\text{Min}}\, C = \sum_{n} \omega_n x_n \\ Y_k^{i*} = \hat{A}\prod_{n} x_n{}^{\hat{\beta}_n} \end{cases} \tag{3.10}$$

Where A = exp (β_0); ω_n = input prices; β = the parameter estimates of the production function given under Equation (3.9); x_n= inputs used in production and Y_k^{i*}= input-oriented adjusted output level. When the cost-minimizing levels of input are substituted into equation (3.10), the dual cost function is obtained as;

$$C(Y_k^{i*}, w) = HY_k^{i*\mu} \prod_{n} \omega_n^{\alpha_n} \tag{3.11}$$

where $\alpha_n = \mu\hat{\beta}_n$, $\mu = \left(\sum_n \hat{\beta}_n\right)^{-1}$ and

$$H = (1/\mu)\left(\hat{A}\prod_{n} \hat{\beta}_n{}^{\hat{\beta}_n}\right)^{-\mu} \tag{3.12}$$

Specification of the empirical model: Stochastic Frontier Production Function (SFPF)

In formulating the production function model, a set of production input factors was hypothesized to affect the farmers' production output significantly. These factors were used as the explanatory variables for the productivity model. Thus, the empirical model for the Cobb-Douglas production function was;

$$In\ OUTPUT = \beta_0 + \beta_1 InLAND + \beta_2 InSEEDS + \beta_3 InTRACTOR + \beta_4 InLABOUR + \beta_5 TIME_{plough} + v_i - u_i \quad (3.13)$$

Where;

- β_i = a vector of parameters to be estimated
- In = natural log to the base e
- OUTPUT = the total value of output from arable crops of the *i*th farm measured in BWP
- Land = cultivated land in hectares
- Seeds = total seeds used in production measured in BWP
- Tractor = mechanization used in production measured in BWP
- Labour = total employed labour measured in BWP
- Time_plough = the timeliness of ploughing; (dummy) 1= on time, 0=otherwise (dummy).

Following the productivity analysis using the Cobb-Douglas stochastic production function (SPF), the cost function was then estimated to be decoupled to obtain the allocative and economic efficiencies.

Model Diagnostics

In order to detect the inefficiency, following equation (3.13), the parameter estimation for the SFA model was accomplished by Maximum Likelihood Estimates (MLE). The likelihood function estimates indicate gamma (γ) and sigma squared (δ^2). The two variance parameters are computed below (see Chandio *et al*., 2019; Mwalupaso *et al*., 2019).

$$\gamma = \frac{\delta^2}{\delta_v^2+\delta_u^2};\ \delta^2 = (\delta_v^2 + \delta_u^2)$$

(3.14)

Gamma (γ) shows the validity of the random disturbances (v_i,u_i) proportion of the model, and it ranges between zero and one ($0 \leq \gamma \leq 1$). If the value is zero, then the variance of the inefficiency effects is zero, meaning that the variation between actual output and the maximum possible output results from other uncontrolled pure random factors, which makes the use of the stochastic frontier model meaningless. If the γ value is closer to one, it shows that the variation comes mainly from the effects of one or more exogenous (independent) variables that are used in the model" (Chandio *et al*., 2019). The frontier package by Coelli and Henningsen (2013) in the R-software was used to estimate these parameters and efficiencies.

Determining factors influencing technical, allocative, and economic efficiencies

Several studies have analyzed the factors determining the different efficiency components using one-step and two-step approaches. The one-stage approach allows for the simultaneous estimation of the production frontier and inefficiency model (Ngango and Seung, 2019; Mujuru *et al*., 2022, Ahmed *et al*., 2018). The one-stage technique is limited to the estimation of determinants of technical efficiency and does not allow for allocative and economic efficiencies. The two-stage technique estimates the production frontier first, and then the obtained efficiency scores are regressed on a vector of predictor variables believed to influence efficiency. The Logit and Tobit regressions are commonly used for the two-step approach

(Pangapanga-Phiri & Mungatana, 2021; Birhanu *et al*., 2022; Tesema, 2021). This study followed the two-stage technique of estimating the efficiencies first and using the obtained scores as the latent variables to regress them against a set of predictor variables assumed to influence the efficiencies. The determinants were established using the Seemingly Unrelated Regression models explained in the last part of the methodology.

Evaluating the livelihood status of the farming households

Many organizations and scholarly researchers have extensively used the DFID Sustainable Livelihood Framework (SLF) to assess livelihood vulnerability and status (Manlosa *et al*., 2019; Adu *et al*., 2018; Ahmed & Mustapha, 2020; (Gichure, Njeru, & Mathi, 2020)Ahmed *et al*., 2021). The analytical framework on Sustainable Livelihoods (SLF) of the DFID provides approaches that can be employed to assess livelihood depending on the scope of the study. The SLF has multidimensional aspects, including livelihood assets, livelihood strategies, livelihood outcomes, institutional involvement, and vulnerability context. Therefore, it is crucial to select parameters that are representative indicators of all the sectors of human life.

This study aimed to assess the livelihood status improvement attributed to the Integrated Support Program for Arable Agriculture Development (ISPAAD) subsidy program. ISPAAD is a government subsidy program that plays a pivotal role in the arable cropping livelihoods of farmers. The study used the livelihood assets and determined how the improvement in household livelihood status was associated with accessing and using the ISPAAD inputs and services. Likert scale questions were asked to gather farmers' responses about improving their livelihood assets following benefiting from the ISPAAD program. The aim of using the livelihood assets was to obtain a livelihood status score for the arable crop farming community in Botswana. At the time of designing this study, it was hard to come across any study in literature that has used this approach to assess the livelihood status of farm households in Botswana.

Following the work of Hahn, Riederer, and Foster (2009), the study adopted the Livelihood Vulnerability Index(LVI) method and constructed a Livelihood Assessment Index (LAI) and assessed the farmers' livelihood status improvement following their benefiting from ISPAAD. The Livelihood Vulnerability Index is a method for determining how well-prepared households are for shocks like epidemics, natural disasters, and civil conflicts (Sallu *et al*., 2010). It uses various indicators to evaluate household economic and social characteristics that influence their ability to adapt to change and current health, as well as characteristics of food and water resources that determine their sensitivity to the effects of climate change (Hahn *et al*., 2009). According to Hahn *et al*., the LVI construct can be adapted to assess community development projects.

Therefore, using the LAI, the study used the livelihood assets and their respective indicators to estimate the livelihood status. The LAI was calculated using a composite index approach. The composite index was calculated using the DFID Sustainable Livelihood Framework (SLF) as the SLF assets' major components. Each component comprised several indicators that were treated as sub-components. The indicators were developed guided by the literature review on the examples of the livelihood indicators, and the appropriate indicators were sort applicable in the study area.

The livelihood index for each livelihood asset was constructed using a balanced weighted average approach by averaging the indicators. Since the major components consisted of different numbers of indicators, the averaging approach allowed the sub-component to each contribute to the overall index equally. To ensure that the weighted averages were equal, each sub-component was first standardized as an index since the sub-components were individually measured on varying scales. The conversion of sub-components to index was computed using each indicator's minimum and maximum values as in the equation below.

$$I_i index = \frac{I_u - I_{min}}{I_{max} - I_{min}} \quad (3.15)$$

Where I_i was the original indicator or subcomponent in the asset used to construct the index, I_u was the mean score from the responses for the particular indicator, and I_{min} and I_{max} were the minimum and maximum values, respectively. After standardizing each sub-component, the sub-components were averaged using the equation below;

$$A_i = \frac{\sum_{i=1}^{n} I_i index}{n} \quad (3.16)$$

Where A_i was one of the five major components, i.e. the livelihood assets for the district [Natural Assets (NA), Physical Assets (PA), Financial Assets (FA), Human Assets (HA), and Social Assets (SA)]. *Ii* represented the sub-components that make up each major component, and *n* was the number of sub-components in each major component. After computing the mean scores for each asset, then the composite overall livelihood vulnerability index for the households was constructed using the following formula as follows:

$$LAI_i = \frac{\sum_{i=1}^{n} w_i M_i}{\sum_{i=1}^{n} w_i} \tag{3.17}$$

Which can also be expressed as;

$$LAI_i = \frac{(w_{NA}NA + w_{PA}PA + w_{FA}FA + w_{HA}HA + w_{SA}SA)}{(w_{NA} + w_{PA} + w_{FA} + w_{HA} + w_{SA})} \tag{3.18}$$

Where LAI_i was the calculated livelihood assessment index, w_i are the weights of the components determined by the number of indicators used to construct each major component and were included to ensure that all sub-components contributed equally to the overall LAI_i (Hahn *et al*., 2009). Individual farmer LAI*i* scores were determined as a continuous measure of the degree of farmers' livelihood improvement. The scores were computed by taking an average of each farmer's livelihood asset indicator. For this study, the LAI*i* is scaled from 0 (low improvement) to 1.00 (high improvement) as an improvement attributed to the ISPAAD program.

Critiques of the sustainable livelihood framework

Researchers have criticised the dominant use of the SLF five assets (see Natarajan *et al*., 2022) because it places too much emphasis on the micro-level while ignoring higher levels of governance, the political climate, and regional and global economic growth (Hussein, 2002). These concerns are addressed in the broader SLF, particularly in the context of vulnerability and the changing structures and processes. However, in practice, many people have focused on the five assets rather than their connections and the larger environment in which people live. The concept of sustainable livelihoods has been criticized for failing to include power dynamics, such as those relating to gender. Nonetheless, it is particularly applicable to the objective of the current research as it is applied to the micro level, and the main concern is the improvement of the livelihood assets rather than the vulnerability context.

Measuring food security

Multiple methods have been used to measure food security, depending on the scope of the study. Among these methods, the food intake measures and the experience-based food insecurity scale methods are the most used for individuals and households. The food intake measures are based on the dietary intake assessment (DIA) or caloric intake assessment (CIA) method of individuals or household members and require the respondent to recall the food consumed from all sources in the last 24 hours and the food frequency questionnaire (Ahmed, Ying, Bashir, Abid, & Zulfiqar, 2017). According to Ahmed *et al*., this method can assess the respondent’s short, medium and long-term food intake with reference to a defined period such as seven days or a month. It requires weighted values used for food before and after consumption to determine the food security score of the household. They further noted that this method is limited to the respondent’s memory and is costly to apply. The dietary intake method requires high-quality food composition tables to apply the food frequency questionnaire. Although this method is the most commonly used, it is subject to memory recall bias and measurement error. It needs highly trained and experienced researchers for data collection (Ahmed *et al*., 2017).

The second commonly used method is the experience-based food insecurity scale, which measures household food insecurity using scales based on the perspective or experience provided by the respondent. This method uses more self-assessment indicators and was pioneered by the United States through the Household Food Security Survey Measure (US HFSSM) based on a score derived from 18 questions on food-related behaviours and conditions associated with food deprivation (Bushara & Ibrahim, 2017).

However, though unchanged, the US HFSSM 18 question module has been modified to have less burden on respondents. Therefore a 10-question (the adult module) and 6-questions modules have been developed. Experience-based food insecurity scales present a simple, less costly, and timely method for assessing food insecurity based on data collected at the individual or household level (Cafiero, Melgar-Qui˜nonez, Ballard, & Kepple, 2014; FAO, 2013). Based on cut-off point scales, a summative score is calculated for each household to categorize them as either food secure or in one of three levels of food insecurity. The scale considers factors like worrying about running out of food, having a limited variety of food, borrowing food, and not having enough food at home. Scales, however, do not fully reflect all aspects of food security, such as the utilization component (Bertelli, 2019). However, Bertelli maintains that the experience-based food insecurity scales method can cover a few food security dimensions in the same indicator, making it a potentially useful indicator of food security status.

USAID's Food and Nutrition Technical Assistance (FANTA) project adapted the US HFSSM approach and produced a Household Food Insecurity

Access Scale (HFIAS) to estimate the prevalence of food insecurity. The method is built on the hypothesis that those who experience food insecurity react predictably and have quantifiable reactions that can be measured using surveys (Coates, Swindale, & Bilinsky, 2007). The HFIAS module provides information on household food insecurity (access) using four calculated indicators to evaluate food insecurity in the surveyed population. These indicators offer an overview of the conditions, domains, scale scores, and prevalence of household food insecurity. Therefore, on this basis, the study examined the food security status of the farmers in Botswana using USAID's HFIAS.

Following the HFIAS published guidelines, food security was rather measured by determining the insecurity categories. HFIAS 18 questions were asked, where there were two categories of questions, i.e., nine occurrence questions and the corresponding frequency of occurrence questions. Where a farmer responded with a "no" to the occurrence question, then the frequency of occurrence question would be skipped. The scores were calculated on a continuous measure of the household's degree of food insecurity (access) in the past four weeks (i.e., 30 days).

Calculation of the Household Food Insecurity Access Scale Score

HFIAS score was calculated for each household by summing the codes for each frequency-of-occurrence question. The frequency-of-occurrence was coded as 0 for all cases where the answer to the corresponding occurrence question was "no" (i.e., if Q1=0, then Q1a=0, if Q2=0, then Q2a =0, and so forth). The maximum a household could score was 27. The minimum score was 0, indicating that it had answered "no" to each occurrence question. Higher scores indicated more food insecurity (access) the household experienced. While the lower score indicated food insecurity (access), a household experienced. The average HFIAS score was then calculated as in the equation below. Sum of HFIAS Scores in the sample Number of HFIAS Scores (i.e., households).

$$Average\ HFIAS = Sum\ of\ HFIAS\ Scores/n \qquad (3.19)$$

Where n was the total number of respondents. The prevalence indicator was derived from the score to categorize households into four food insecurity (access) levels: food secure, mild, moderate, and severely insecure. As farmers' households responded positively to more severe conditions and/or experienced those conditions more frequently, they were classified as having an increased level of food insecurity.

Categorization of farmers' households into Household Food Insecurity Access Prevalence (HFIAP)

Using the IF and the AND functions in Microsoft Excel, farmer households were categorized into four levels of food security status. First, an HFIAS category variable was calculated by assigning a code to the food insecurity (access) category that the household falls under. Prior to assigning the food insecurity (access) category codes using the HFIAP, the frequency-of-occurrence was coded as 0 for all instances when the response to the related occurrence question was "no". To guarantee that households were categorised following their most severe response, the four food security categories were sequentially created as follows:

Food secure: does not experience any of the food insecurity (access) conditions or just experiences worry, but rarely.

Mildly food-insecure household (access): The household is concerned about not having enough food occasionally or frequently. The household may complain about not being able to eat certain meals they prefer, eating a more repetitious diet than they would want, or occasionally eating foods they think are not ideal for them. However, it neither decreases the amount nor exhibits any of the three most serious conditions (running out of food, going to bed hungry, or going a whole day and night without eating).

Moderately food-insecure household (access): Frequently compromises quality by consuming repetitious foods or undesirable foods, and/or has started reducing quantity by reducing meal sizes or meal frequencies, rarely or occasionally. However, it does not have any of the three most serious conditions.

Severely food insecure household (access): household has progressed to reducing meal size or the number of meals regularly and/or has experienced any of the three most severe conditions (running out of food, going to bed hungry, or going a full day and night without eating), even if only seldomly. In other words, a household is regarded as extremely food insecure if only one of these three circumstances occurred within the last four weeks (30 days).

It is crucial to emphasize that the HFIAS and HFIAP are used to measure food access as a component of food security. However, they are not meant to evaluate the reasons for food insecurity, comprehension of coping mechanisms, cultural appropriateness, or awareness or uptake of nutritional information.

Establishing the linkages between the efficiencies and the livelihood and food insecurity scores of the farmers

Most studies (e.g., Oyetunde-Usman & Olagunju, 2019; Pangapanga-Phiri & Mungatana, 2021; Birhanu *et al*., 2022) have shown that researchers commonly use generalized linear models such as logit and probit to establish the relationship between key variables such as efficiencies, food security and livelihoods. Many of the reviewed studies (e.g., Birhanu *et al*., 2022; Kodua, *et al*., 2022; Tesema, 2021) applied the Logit, Probit or Tobit models in determining the factors influencing the current study's key variables . Logit models are used where the dependent variable is categorical. This can be for binary outcomes (0 and 1) or for three or more outcomes (multinomial logit) for instance, where food security status is divided into four categories. Probit models are generally similar, especially when expressed in binary form (0 and 1). However, Probit functions are different when there are three or more outcomes (in this case, ranking or ordering). It uses a single regression equation, which limits the application of marginal effects to the extreme (higher and lower rankings).

Tobit models are different from the above but are a form of linear regressions. The Tobit model has nothing to do with binary or discrete outcomes. It is explicitly used if a continuous dependent variable that needs to be regressed is skewed in one direction. The Tobit model permits regression of such a variable while it is censored to allow for regression of a continuous dependent variable. While maintaining the linear assumptions required for linear regression, the Tobit model enables the analyst to select a lower (or upper) threshold to censor the regression. The efficiency scores are typically skewed in one direction, so scholars tend to use the Tobit model. Despite these models being widely and appropriately used, they do not offer the opportunity for two-way modelling relationships between the response variables. Another way of establishing whether farmers with high efficiencies have improved livelihood or food security could be through a simplified OLS model where the food insecurity and livelihood scores are now the dependent variables and the efficiency scores as explanatory variables. However, the latent variables (efficiency scores, food insecurity scores and livelihood scores) are also used as part of the explanatory variables and assumed to be exogenous while potentially endogenous. Thus, while variation in the efficiencies explains livelihood and food security status, they are also explained by other variables. Hence, estimating without considering this endogeneity results in biased and inconsistent estimations. Therefore, for this purpose, the current study employed the Seemingly Unrelated Regression (SUR) models to analyse the relationships between the latent variables.

SUR models generalize linear regression models by considering multiple regression equations linked by simultaneously correlated disturbances (Peremans & Stefan, 2018). Zellner (1962) introduced the SUR model of $p>1$ correlated dependent linear regression equations called blocks. The p regression equations seem unrelated because the error terms would follow standard linear OLS model form, taken separately (Beasley, 2008).

When calculating separate OLS solutions, any correlation among the errors between the equations is`` ignored. Nevertheless, the dependent variables may be correlated, and the design matrix may contain some of the same independent variables, so there may be a "contemporaneous" correlation among the errors across the equations. Therefore, as noted by Beasly (2008.p.1), "…SUR models are often applied when there may be several equations, which appear to be unrelated; however, they may be related by the fact that: 1) some coefficients are assumed to be the same or zero; 2) the disturbances are correlated across equations; and/or 3) a subset of right-hand side variables are the same. *This third condition is of particular interest because it allows each of the p dependent variables to have a different design matrix with some of the predictor variables being the same* [emphasis added]."

SUR models estimate the parameters of all equations so that each equation considers the information provided by the other equations (Zellner, 1962). As a result, the parameter estimates are more accurate because the system is described using more information (Cadavez & Henningsen, 2012). "These efficiency gains increase with increasing correlation among error terms of different equations, larger sample size, and higher multicollinearity between independent variables" (Heidari, Keshavarz, & Mirahmadizadeh, 2017, p.181).

Theoretical specification of the SUR model

The SUR framework is essentially stacked general linear models, constrained by the linear relationships between response variables and covariates and the stochastic specification (Taylor & McGuire, 2005). In Zellner's SUR framework, the model specification forms a system of $m > 1$ equations, also called blocks, each containing T observations (Baltagi, 2008; Peremans & Stefan, 2018). Denoting the *i*th block in matrix form by

$$y_i = X_i\beta_i + \varepsilon_i \qquad i = 1, \dots, m \tag{3.20}$$

Where y_i and ε_i are T-dimensional vectors, X_i is $T \times K_i$ and βi is a K_i-dimensional vector. Stacking all m equations gives:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \cdots & 0 \\ 0 & X_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & X_m \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_m \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_m \end{bmatrix}$$

Which compact to be written as;

$$y = X\beta + \varepsilon \tag{3.20}$$

where ;

- y = a vector of the observed values of the response variable
- X = a vector of predictor variables
- β = a K-dimensional vector of the regression parameters
- and $K = \sum_{i=1}^{m} K_i$.
- ε = constitutes its error term

For the mT X 1 vector of stacked disturbances, the assumptions are that $E(\varepsilon_j) = 0$, and cov $E(\varepsilon_i\varepsilon_j) = \sigma_{ij}I_T$ where T represents T X T an identity matrix. These assumptions imply that, in each m equations, the T disturbances are uncorrelated and have a zero mean, equal variance (Baltagi, 2008). It is important to note that the blocks do not necessarily contain the same number of predictors (Peremans & Stefan, 2018). Peremans and Stefan further cautioned that each regression equation in a SUR model is a linear regression model in its own right. Therefore, the different blocks are related through their error terms but may seem to be unrelated at first sight.

According to Kehinde *et al.* (2021), farm productivity and food security are statistically and structurally related through the jointness of the error terms and the non-diagonal covariance matrix. This implies that the random error components correlate, making the SUR model ideal for this analysis. Therefore, this study used the SUR models to establish the bi-directional relationships between the estimated efficiencies and the livelihood and food insecurity scores as latent variables. The R package systemfit (Henningsen & Hamann, 2007) was used for this analysis section. Certain variables were omitted in the first level equations for the relationship between livelihoods and the efficiencies and food insecurity and the efficiencies.

Empirical models for the bidirectional relationships between livelihood and the efficiencies

The SUR model for the bidirectional relationships between livelihood and the different efficiency components was specified as follows.

Equation 1:

$$\begin{aligned} LH\_SCORE \; = \; & Efficieny + I(SEEDS * TRACTOR) + EXPERIENCE \\ & + HHSIZE + SOURCE\_LIVELIHOOD + INCOME \\ & + EXT\_VISITS + SEX + EDUCATION + AGE \\ & + MARITALS + Credit \end{aligned}$$

Equation 2:

$$
\begin{aligned}
Efficiency = {} & LH\_SCORE + I(SEEDS * TRACTOR) + EXPERIENCE \\
& + HHSIZE + SOURCE\_LIVELIHOOD + INCOME \\
& + EXT\_VISITS + SEX + EDUCATION + AGE \\
& + MARITALS + TIMEseeds + TIMEtractor + QLT\_TS \\
& + Credit
\end{aligned}
\tag{3.21}
$$

Where:

- LH_SCORE was the livelihood score determined from the livelihood status analysis
- Efficiency was the specific efficiency scores from objective one analysis (i.e., TE, AE and AE).
- I(TSEEDS * TRACTOR) was the integration of the tractor and seeds from the ISPAAD program to represent the subsidy effect.
- HHSIZE = household size
- SOURCE_LIVELIHOOD = a dummy variable to represent the source of livelihood for the household, i.e., 1= agricultural-based, 0= otherwise
- INCOME = household average income
- EXT_VISITS = the number of extension visits/ farmer interactions with the extension area officer.
- SEX = farmer's gender
- EDUCATION = total years in school by farmer
- AGE = farmer's age
- MARITALS = marital status of the farmer

- TIMEseeds = dummy variable representing the timeliness of farmer receiving the seeds, i.e., on time or late
- TIMEtractor = dummy variable representing the timeliness of farmer accessing the tractor service, i.e. on time or late
- QLT_TS = dummy variable to represent the quality of tractor service received by the farmer during ploughing, whether good or poor
- Credit = dummy variable showing whether the farmer's access to credit is a concern or not.

The above model was repeated and run for all the efficiency components. The same process and analysis were repeated. FIS, the food insecurity score determined earlier, replaced the LH_SCORE to establish the bidirectional relationship between food insecurity and efficiency scores, as shown in the equation below.

Equation 1:

$$\begin{aligned} FIS = Efficieny &+ I(SEEDS * TRACTOR) + EXPERIENCE \\ &+ HHSIZE + SOURCE\_LIVELIHOOD + INCOME \\ &+ EXT\_VISITS + SEX + EDUCATION + AGE \\ &+ MARITALS + Credit \end{aligned}$$

Equation 2:

$$\begin{aligned} Efficiency = {} & FIS + I(SEEDS * TRACTOR) + EXPERIENCE \\ & + HHSIZE + SOURCE\_LIVELIHOOD + INCOME \\ & + EXT\_VISITS + SEX + EDUCATION + AGE \\ & + MARITALS + TIMEseeds + TIMEtractor + QLT\_TS \\ & + Credit \end{aligned} \quad (3.22)$$

Chapter Summary

The chapter presented the study's detailed methodology. The chapter showed that a multistage sampling procedure was used to select the sample, and at each stage, a simple random sampling method was applied.

Objective one of the study was addressed by estimating the production efficiencies using the Stochastic Frontier Approach (SFA), using the Cobb-Douglas functional form. The software used was R-software, the frontier package.

Objective two analysed the determinants of the production efficiencies using the SFA Cost Function dual approach. Analysis was conducted in R-software using the frontier package.

Objective three: The livelihood assessment index (LAI) was adopted to establish the livelihood improvement attributable to the subsidy program on how farmers perceived it to have benefited their livelihood assets (following the DFID Sustainable Livelihood Framework).

Objective four: measured the farmers' food security status using the USAID FANTA Household Food Insecurity Access Scale (HFIAS). Objectives three and four were analysed in Microsoft Excel (Office 365).

Objectives five and six established the linkages between the efficiency scores and the livelihood scores, as well as the efficiency score and the food insecurity status of the farmers. The Seemingly Unrelated Regressions (SUR) were estimated for these objectives. The systemfit package in R-software was used for the last two specific objectives.

CHAPTER FOUR

PRODUCTION EFFICIENCIES, LIVELIHOODS AND FOOD SECURITY STATUS: EMPIRICAL ACCOUNT

This chapter presents the study findings on productivity and production efficiencies, livelihood and food security statuses of the farmers in Botswana. The chapter starts with a presentation of the descriptive characteristics of the farmers. These farmer characteristics are used in chapter five as predictor variables to explain the linkages between the farmers' efficiencies, livelihood and food security status. The chapter is divided into four sections, namely, (1) socio-economic characteristics, (2) Estimation of Production efficiencies, (3) Assessment of livelihood status, and finally, (4) Measurement of food security status.

Socio-economic Characteristics of Farmers

It is imperative to take heed of the farmers' characteristics as they influence their productivity levels and aid in their management of the farms. This section provides a brief discussion of the study findings on the socio-economic characteristics of the farmers as follows.

Results of the study indicate that there are more females than males in smallholder arable crop farming in Botswana. Table 4 shows that 82.13% of the respondents were females, while 17.87% were males. Most empirical studies (see Mujuru *et al*., 2022, Myeni *et al*., 2019, Pangapanga-Phiri & Mungatana, 2021) show that males dominate smallholding crop production farming in Southern Africa.

Table 4: Farmers' socio-demographics characteristics

Variable	**Number of respondents**	**Percent (%)**
Sex of farmer: Male	84	17.87
Female	386	82.13
Marital status: Married	207	44.04
Otherwise	263	55.95
Education level: None	94	20.00
Primary	258	54.90
Above Primary	118	25.10

Variable	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
Age	62.12	11.037	26	90
Education (years)	6	4.17	0	16
Crop farming experience	27.76	17.099	1	71
Household size	5.06	2.85	1	18
Land cultivated (ha)	3.832	2.061	0.5	15.1

Source: Field Survey, Mokumako (2022)

From their study, Mujuru *et al*. (2022) contended that although their results showed men predominate on farms in terms of numbers, on average, women work more hours on the farm than men. However, contrary to the above, the current study established that women dominated smallholder arable crop production in the study area. The findings of the current study are consistent with the work of Marumo *et al.* (2014) in Botswana, who also reported a gender distribution of 60% females in the arable crop farming ISPAAD beneficiation. This finding is not surprising because, in the Botswana cultural setup, a family would have three different dwellings: (1) a family home in the village, (2) a ploughing field (*masimo*) and (3) the cattle post (*moraka*). Most of the time, the women spend more time ploughing fields while their male counterparts rear cattle in the cattle posts. Again 44% of the farmers reported being married, which could mean that, although men are household heads, women do the fieldwork in the crop farming households as noted by Mujuru *et al*. (2022), hence the current study results revealed a higher percentage of females.

The mean age of the respondents was 62years, with the most appearing age being 65 years. The youngest farmer respondent was 26 years old, while the oldest was 90. Even though studies report different age distributions of crop farmers in different parts of Africa (see Pangapanga-Phiri and Mungatana, 2021; Mujuru *et al*., 2022), the current study showed age skewed towards the elderly. However, the age distribution analysis in the study area is consistent with Marumo *et al*. (2014). There is low youth participation in the arable sector, which is a concern for the sector's productivity. This may create an age vacuum as the already ageing naturally move out of production in the long run. Crop farming experience ranges between a year and 71 years. Farmer years of experience are essential for knowledge that can improve the farmer's efficiency. In some instances, experience may hinder the farmer from adopting new technologies, reducing productivity and efficiency.

Farmers' low levels of education are often considered a significant hindrance to knowledge, skills and technology transfer in agriculture. Table 4 shows that 54.9% of the farmers attained primary education, while 20% reported no formal education. Only a quarter of the farmer respondents had formal education exceeding the primary school level. This finding shows that smallholder arable crop production is carried out as a means of self-sustenance by vulnerable people, i.e., the ageing and the less educated.

Household Size and Total Cultivated Land

Household labour plays a vital role in the success of smallholder production in that the farmers produce primarily to feed the household (Mota *et al*., 2019; Oyetunde-Usman & Olagunju, 2019; Yusuf, 2018). Arable production in Botswana is seasonal. Some farm management practices require more labour, such as weeding and harvesting, especially where more land is cultivated. Study results revealed that the average family size was five persons per household. These were people (count per head, including children) who resided in one homestead and ate together from the same pot daily for at least one month. According to Statistics Botswana (2018), the average household size in the study area is 3.6 persons per household. The land cultivated ranged from 0.5 hectares to 15 hectares. However, the average cultivated land was 3.867 hectares, as presented in Table 3. In the 2020/2021 cropping season, the ISPAAD program only provided seeds and tractor services to cover four hectares instead of the normal five hectares hence the average cultivated land of 3.867 hectares for the 2020/2021 cropping season.

Farmer's Employment Status and Source of Livelihood

Given the nature of arable production in Botswana, having one cropping season forces some people to seek non-farm employment during the dry season and plough during the rainy season. Hence more than 20% of the respondents reported being employed outside the farm. However, because most respondents were above age 65years, about 50% were either retired or unemployed. Retired farmers are those who have held non-farm formal employment before concentrating on arable crop production. Table 5 shows 25.96% of the respondents reported being engaged in other jobs. Other jobs included doing odd jobs, piece jobs like washing, and being a housemaid. However, most of the respondents recorded under others mentioned that they worked for "*Ipelegeng*".

Ipelegeng is a poverty eradication program to help people in peri-urban and rural areas with temporary employment. Ipelegeng employs people regardless of age; hence even the elderly (above 65years) are eligible to work there. With the Ipelegeng program, people do odd jobs for the government under the local government management, such as bush clearing and covering ditches in the roads. The program is four hours of work daily from 0800am till noon, and the workers are provided with a working snack of bread and drinking squash. Therefore, some people opt to do Ipelegeng, knowing they will get paid and be fed while they only work in their fields in the afternoons.

The results on sources of livelihood indicate that only 16.6% (Table 5) of the respondents subsist entirely on arable farming. 31.28% of the respondents reported that their livelihoods depend on agriculture through mixed farming. Therefore, it is worth noting that the male counterparts focus more on pastoral farming while the females perform most of the roles in crop production hence the female domination in crop production. However, agriculture is the majority's primary livelihood source. Farmers practise mixed farming, and arable crop production supports livestock production for farming households.

Table 5: Employment status and source of livelihood

VARIABLE	**Frequency** (n=470)	**Percentage (%)**
Employment status of farmers		
Employed by the government	20	4.26
Employed by a private company	5	1.06
Self-employed	80	17.02
Retired	65	13.83
Unemployed	177	37.66
Others	122	25.96
Main source of livelihood		
Arable farming	78	16.60
Pastoral farming	22	4.68
Mixed farming	147	31.28
Non-farm employment	46	9.79
Transfer payments	38	8.09
Others	139	29.57

Source: Field Survey, Mokumako (2022)

Multicollinearity and heteroscedasticity tests

Prior to the regression analysis, tests for the model assumptions were conducted. Multiple linear regression was estimated using the variables used in the efficiency estimation regressions. The variables used in the model were tested for multicollinearity using the Variance Inflation Factor (VIF). The results indicated the absence of multicollinearity in the Cobb-Douglas PF model, as all VIFs were small and all less than 10 (see Appendix D). In addition, a heteroscedasticity test was conducted using the Breusch-Pagan test. The null hypothesis of homoscedasticity was tested against the alternative hypothesis of heteroscedasticity. The results showed a high *p*-value of (0.1242) that confirmed the validity of the constant variance and that there was no heteroscedasticity for the Cobb-Douglas PF (see Appendix D).

Estimation of production efficiencies

This section presents the findings of the study on production efficiencies. The section starts by describing the variables used to analyse production efficiencies. The chapter provides the empirical results to answer study question one; What are the technical, allocative, and economic efficiency levels of arable crop producers in Botswana?

Descriptive results of the quantitative data used for the stochastic production frontier model estimation

Table 6 summarizes the variables used in the stochastic frontier production function model. The variables include the farm output, variable input factors namely, labour, seeds and tractor and land as a fixed production factor. The land cultivated ranged from 0.5 hectares to 15 hectares. However, the average cultivated land was 3.75 hectares, as presented in Table 6. In the 2020/2021 cropping season, the ISPAAD program only provided seeds and tractor services to cover four hectares instead of the usual five hectares hence the average cultivated land of 3.75 hectares for the 2020/2021 cropping season.

The mean farm output measured in Botswana Pula (BWP) was 9659.61 with a standard deviation of 9934.42, which is very high, indicating the output data points were varying by a high margin, with some points being highly above and some below the mean. Farmers had a standard cost for tractor services per hectare as the charge for tractor services is borne by the government, and where a farmer decides to pay for tractor services to avoid delays in ploughing, the prices remained the same hence a mean of 4001.92 (Table 6). TIME_plough was included in the estimation of the Cobb-Douglas Stochastic Frontier Production Function ploughing as a dummy variable to capture the timeliness of ploughing (with one (1) being on time and zero (0) being otherwise) and the results showed that 115 farmers responded Yes to ploughing on time while 345 responded otherwise as shown in Table 6.

Table 6: Summary statistics of the variables used for the Stochastic Frontier Models

Variables	Mean	Std. Deviation	Minimum	Maximum
OUTPUT (BWP)	9659.61	9934.42	200	75700
LAND (ha)	3.75	1.91	0.5	15.1
SEEDS (BWP)	783.33	423.67	130	4023
TRACTOR (BWP)	4001.92	2054.29	500	17400
LABOUR (BWP)	3577.24	2182.15	350	19600
TIME_plough	0 = 345		1 = 115	

Source: Field data, (2022)
NB: USD1 = BWP12.80

Functional form selection is crucial in stochastic frontier analysis, depending on the nature of the available data. Therefore, a log-likelihood test was conducted to choose the functional form that adequately represented the data collected for this study. The log-likelihood test provided a statistic of (-600.727) distributed with Chi-square comparing the OLS model to the surveyed data's error component frontier model. These results showed that Cobb Douglas better represented the data. The corresponding p-value value was significant at a one per cent significance level, thus rejecting the adequacy of the OLS model in representing the data. The test was also performed between the Cobb Douglas and the translog functions. The results showed that the translog function had a higher log-likelihood ratio of (-591.45) (see appendix E), making it a statistically valid model appropriate for the dataset. However, the translog PF had high multicollinearity (see appendix E) problem. Dropping the highly collinear variables would result in model misspecification. In addition, the attempt to use a translog form approach failed because of its self-dual; the cost function estimation was impossible (Kalirajan, 1990; Kumbhakar, 1991), making it difficult for the student researcher to estimate the allocative and economic efficiencies. Therefore, the study employed the Cobb-Douglas functional form.

Results of the Stochastic Frontier Production Function

Cobb-Douglas production was used to estimate the efficiencies with its self-dual, the cost function. Table 7 presents the Maximum Likelihood results of the production function. The results show the model diagnostics confirming the goodness of fit for the model and the correct distributional assumption compared to the ordinary least squares model. The estimated variance shows that sigma squared (δ^2) of 1.7377 and gamma (γ) of 0.8180, which are the diagnostic statistics for the model, were significant at a one per cent level of significance.

These results suggest the model's goodness of fit and the correctness of the specified distributional assumptions. The estimated gamma (γ) value measures the amount of variation in the observed output resulting from inefficiency in production. Computed gamma is significantly different from zero, implying that 81.8% of the total variation in output is a result of inefficiency in production. These results are similar to results from other efficiency studies by other previous researchers who also reported goodness of fit with a highly significant gamma (see Kodua *et al*., 2021, Mwalupaso *et al*., 2019, Chandio *et al*., 2019, Inkoom and Micah, 2017).

Table 7: Maximum Likelihood Estimates of the Cobb-Douglas Stochastic Frontier Production Function

Variables	Parameters	Coefficients	Std Error	Z-value
Intercept	β_0	4.6504***	1.4112	3.2954
In(LAND)	β_1	0.3381	0.1883	1.7950
In(SEEDS)	β_2	0.4430***	0.1019	4.3457
In(TRACTOR)	β_3	0.0268	0.1667	0.1605
In(LABOUR)	β_4	0.1939**	0.0677	2.8656
TIME_plough	β_5	-0.2203*	0.0948	-2.3231
Variance Parameters				
Sigma squared	δ^2	1.7377***	0.1955	8.8896
Gamma	Γ	0.8180***	0.0519	15.771
Log-Likelihood		-600.727		
Chi-square		24.384		

***,**,* Statistically significant figures at 1%, 5% and 10% respectively

Source: Computation from field data, (2022)

When gamma equals zero, there is no inefficiency and *u* in the model is irrelevant. However, when gamma is one, it means that all deviations from the production frontier are due to technical inefficiency making the noise term *v* irrelevant. The coefficient estimates for seeds and labour are significant at one and five per cent significance levels, respectively, and are both positive, as shown in Table 7. The results imply that these two inputs determine the production of arable crops in Botswana and suggest that increasing the two inputs in the right proportion will increase arable crop production, *ceteris paribus*. These results agree with Obi and Ayodeji (2020. They found that seeds and labour were positive and significant inputs used in maize production when conducting their economic efficiency analysis of maize farm production in the Eastern Cape of South Africa.

The results from this study provide empirical evidence that the time of ploughing affects the farmers' productivity and performance. Time of ploughing was found to have a negative coefficient and significant at 10% significance. The implication is that not ploughing on time results in lower output. Therefore, the time of ploughing is an essential factor in production that significantly affects farmers' output. Given the limited amount of rainfall in the area, the timeliness of production from the onset of rains is crucial. Through the ISPAAD subsidy program, the Botswana government aimed to increase yields by assisting farmers in coping with the harsh environmental effects on crop production. Hence the provision of seeds and tractor services to farmers to ensure that they can capitalize on the small amount of rainfall and have their crops maturing in a shorter period when soil moisture still allows.

Nevertheless, the timeliness of ploughing, as determined by the farmers' receiving of the subsidy inputs and services, somehow negates these efforts. If the timeliness of production is not adhered to, it negatively affects productivity in Botswana, given the limited amount of rainfall. This study reveals this novel finding about the effects of time of ploughing on farmers' productivity. However, the current study did not pick data on the onset and cessation of rainfall which may have provided a better empirical insight into this phenomenon that needs further analysis with the onset and cessation of rainfall effects included in the model.

When estimating the stochastic frontier cost function, linear homogeneity of input prices was imposed, and this was done by dividing the input and output variables by the land variable. The coefficient estimates from the frontier production function were then used to derive the cost frontier dual analytically to the Cobb-Douglas production function. This formed the basis for the computation of the AE and EE. The efficiency scores were then computed.

The results showed cost inefficiency hence the gamma value of 0.6342 being statistically significant at a one per cent level of significance, as presented in Table 8. This result implies that 63.4% of the variations in the farm cost are attributable to cost inefficiency and other factors outside farmers' control (such as climatic factors and market forces) which are not captured by the model but represented by the noise term *v* in the model.

Seeds and labour show the theoretically expected positive signs indicating their positive relationship with cost. This means that cost increases with increased labour prices and seeds (Table 8). Against theoretical expectation, output showed a negative relationship with cost, indicating that an increase in farm output reduces the cost of production *ceteris paribus.* This negative relationship between cost and output may be because, with the ISPAAD program, the government is responsible for the cost of tractor services and seeds, reducing the cost burden for farmers. Thus, it makes it possible that since they incur part of the costs, i.e., labour for management of the farms, they can increase their production with reduced costs. Time was significant at 10% and had a negative sign meaning the timelier production is the reduction in the cost of production.

Table 8: Maximum Likelihood Estimates of Stochastic Frontier Cost Function decoupled into Allocative and Economic efficiencies with linear homogeneity in input prices

Variables	Parameters	Coefficients	Std Error	Z-value
Intercept	β_0	9.9328***	0.5799	17.1283
log(SEEDS/LAND)	β_1	0.4264***	0.0410	10.3888
log(TRACTOR/LAND)	β_2	0.1161	0.0738	1.573
log(LABOUR/LAND)	β_3	0.3100***	0.0262	11.8642
log(OUTPUT/LAND)	β_4	-0.1656***	0.0161	-10.244
TIME	β_5	-0.081275*	0.0394	-2.0653
Sigma squared	σ_2	0.2241***	0.0339	6.614
Gamma	Γ	0.6342***	0.1159	5.474

***,**,* Statistically significant figures at 1%, 5% and 10% respectively

Source: Computation from field data, (2022)

Estimates of the Technical, Allocative and Economic Efficiencies of the arable crop farmers

From the Cobb-Douglas production and its self-dual, the cost function, the production efficiencies estimates were computed. Table 9 presents the results of the summary statistics of the efficiencies discussed below.

Table 9: Summary Statistics of Technical, Allocative, and Economic Efficiencies

Efficiencies	Minimum	Mean	Maximum	Std dev
Technical (TE)	0.01886	0.44366	0.81643	0.1890
Allocative (AE)	0.02122	0.06606	0.12522	0.0140
Economic (EE)	0.00133	0.02925	0.07256	0.0142

Source: Computation from field data, (2022)

Technical Efficiency

The results showed that the average technical efficiency of the farmers is 0.44 ranging from 0.02 to 0.82. These results suggest that, on average, crop farmers are 44% technically efficient in their production, implying that production is about 56% below the frontier, meaning that a considerable amount of production is foregone due to technical inefficiency. Therefore, given the current state of technology and input levels, there is an opportunity for farmers to increase their arable crop output by up to 56 per cent on average if they can use the available resources more efficiently.

These findings are consistent with the earlier researchers' findings on Botswana's overall arable crop sector production low technical efficiencies (see Ntwiga, 2021, Temoso *et al*., 2018, Motsatsi, 2015). Compared to other studies in other countries in the same Southern African region (e.g., Bahta *et al*., 2020, Mwalupaso *et al*., 2019), these results present very low productivity of the arable crop farmers. For instance, Pangapanga-Phiri and Mungatana (2021) estimated an average technical efficiency of 63% for the maize farmers in Malawi. However, given the general semi-aridness of Botswana, in comparison to other semi-arid areas, this low technical efficiency average is not surprising. The technical efficiency results are similar to the study conducted in Kenya by Mibei *et al*. (2021). They also realized a technical efficiency estimate of 47.2% on average, with minimum and maximum values of 5.5% and 90.44%, respectively, in a study of the production of tomatoes in the Kajiado semi-arid region.

Allocative Efficiency

The allocative efficiency average score was 0.066, implying that farmers are 93.4% inefficient in production. The results suggest poor use of productive inputs given the input prices. Therefore, farmers do not allocate inputs correctly to produce the possible outputs at minimal costs in their production. Given that the subsidy program covers the main cost for the farmers (i.e., tractor service and seed costs), these results are not surprising but imply possible mismanagement of resources, possibly on both the farmers' side and on the other hand on the government's side. Although the government pays for the tractor services and provides seeds to farmers, farmers are responsible for searching for and agreeing with tractor service providers to plough for them. There is minimal monitoring of the tractor service work done by the extension area officers during ploughing. Again, as Marumo *et al*. (2014.p.16) noted, "ISPAAD program, seed distribution is done according to farmer preference and not according to crop performance based on land suitability zones". These two factors may be contributing to the low allocative efficiencies revealed by the current study. However, it was beyond the scope of the study to assess factors in the monitoring of the ISPAAD program.

Economic Efficiency

Economic efficiency averaged 2.9%. Economic efficiency was also very low, ranging between zero to 7.25%. Due to the low allocative efficiency, it is not alarming to find that economic efficiency is also very low. These results imply that farmers produce below the maximum possible output level but at higher production costs. The low economic efficiency shows that farmers can improve their production efficiency by 93% by improving both their technical and allocative efficiencies. Although other studies in other African countries have estimated production efficiencies and obtained low allocative and economic efficiencies, the current study results are possibly among the lowest in the crop production field. For instance, Ahmed *et al*. (2021) obtained 37.07% and 28.97% mean efficiencies for AE and EE, respectively, when estimating the production efficiencies of the maize farmers in Ethiopia. These findings necessitated further analysis to determine the factors explaining differences in the efficiencies, which are discussed in the next chapter.

Distribution of the arable farms' Efficiencies Scores

The individual farm efficiency scores were computed and presented in the Kernel density plots (*Figure 5*), and the plots showed a normal distribution of the efficiency scores. The results showed that the technical efficiency distribution fell mainly between 20% and 80%, while the allocative efficiency distribution fell between 2% and 13%. It can be noted from the density plot for TE distribution that most of the arable farms (over 60%) operate at efficiency levels between 40 and 80%, with a greater number above the computed mean efficiency level of 44%. However, for AE, it can be noted that the efficiencies scores mainly fall between 4% and 10%. As for EE, the distribution shows that the majority fall between 2% and 5% efficiency level. The findings show that farmers can be technically efficient but fail to be allocatively efficient, hence the need to estimate all three efficiency components.

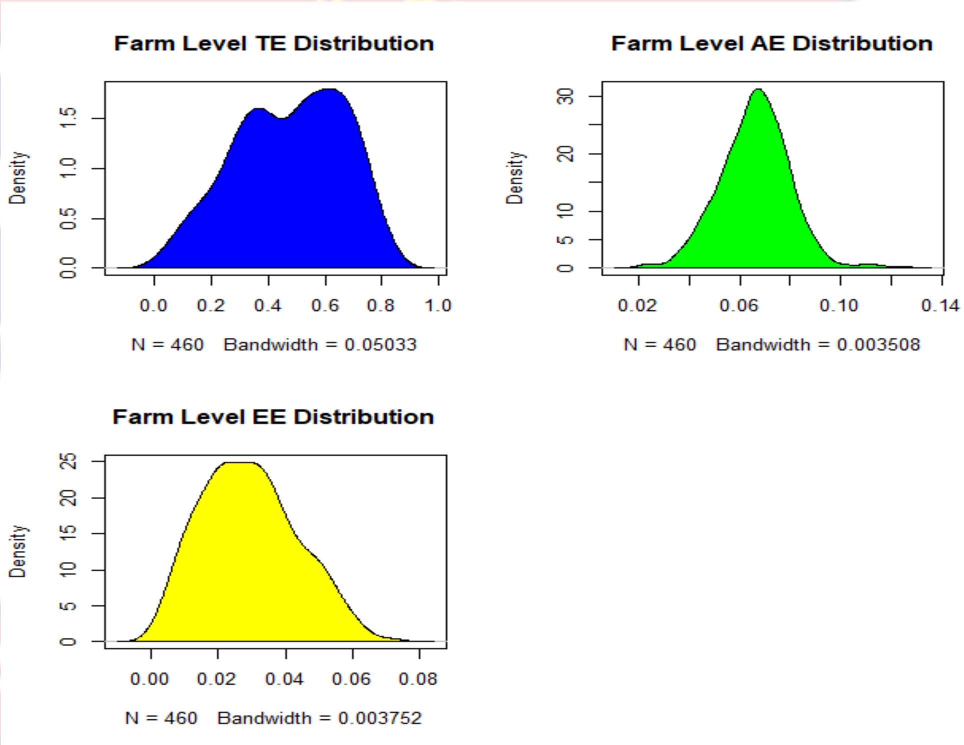


Figure 5: Density Plots showing the distribution of the farm-level efficiencies

Livelihood Status of the Farmers

Objective three of the study sought to evaluate the household livelihood status of the farmers. The livelihood status was evaluated using a Likert scale to measure the farmers' livelihood improvement attributed to the ISPAAD program. The Likert scale measured the improvement in farmers' assets guided by the Sustainable Livelihood Framework (SLF). Using the Livelihood Assessment Index (LAI) constructs, the study results revealed that the farmers in Botswana generally have a high livelihood status score, as shown by the overall LAI of 0.70 in Table 10. According to the farmer's perceptions, ISPAAD has brought a 70% improvement in their overall livelihoods as measured using the LAI. The LAI results are discussed in order of the subcomponents scores.

Table 10: Livelihood Assessment Index (LAI) scores for farmers in Botswana

Sub-Component	Mean	Index	Major index
NATURAL ASSETS			**0.74**
Increase in size of production land	2.94	0.73	
Increase in yield	2.79	0.70	
Increase in Productivity (yield per unit area)	2.70	0.67	
Increase adoption rate to appropriate technologies	3.33	0.83	
Increase in number of livestock holdings	3.14	0.79	
PHYSICAL ASSETS			**0.57**
Able to buy (bicycle, cars, trucks, tractors)	1.71	0.43	
Able to buy farm inputs (water tank, pumping machine)	2.07	0.52	
Able to get access to vehicles (trucks, tractors)	2.82	0.70	
Able to build house(s)	2.23	0.56	
Able to connect water to your yard	2.41	0.60	
Able to connect electricity to your house	2.37	0.59	
FINANCIAL ASSETS			**0.74**
Increase in income levels	2.95	0.74	

Table 10 continued

Increase in saving levels	3.18	0.79	
Decrease in debt levels	3.34	0.83	
Increase in access to financial facilities	2.34	0.59	
HUMAN ASSETS			**0.77**
A[illegible]mbers	3.62	0.90	
Ability to support other family members	3.64	0.91	
Increase in employment opportunities for household members	2.20	0.55	
Increase in access to labour	2.47	0.62	
Self-reliance	3.54	0.89	
SOCIAL ASSETS			**0.65**
Membership in association farmer group	1.50	0.38	
Support from association/farmer group	1.97	0.49	
Participation in social activities	2.89	0.72	
Support to family and friends	3.41	0.85	
Ability to pay for societal contributions, e.g., burial cover	3.01	0.75	
Access to services from extension officers	2.88	0.72	
OVERALL LAI			**0.70**

Source: Computation from field data, (2022)

Human Assets

Human assets improvement scored the highest index, specifically under the ability to support other family members and the ability to feed household members. These indicators scored 0.91 and 0.90 (Table 10), respectively, suggesting that, from the farmers' production, ISPAAD has improved the farmers' abilities to support family members and feed their households by 91% and 90%, respectively. Self-reliance also scored 0.89, suggesting an 89% improvement in their self-reliance. Interaction with the farmers in the field revealed they could not have formal employment since they are mainly aged above 65 years. They would either rely on younger family members for sustenance or, in extreme cases, be put under safety net programs that Mosha (2016) and Moseley (2016) purported that the government has to have for people with low or no incomes. Therefore, with the ISPAAD program, farmers reported being able to fend for themselves and not "*bother*" other people with their needs.

Increased access to labour and creating employment opportunities for household members scored low. Farmers reckon the youth and some elderly members of the society refuse to work in the fields and opt to work for the Ipelegeng program, which pays the same as farm labour but with fewer hours of engagement; hence the employment indicators scored low. According to Solesbury (2003), one of the concerns that led to the coining of sustainable livelihoods was citizen participation, emphasizing self-reliance. Therefore, for a program like ISPAAD set to improve the farmers' livelihoods, achieving an improvement in the self-reliance indicator of the farmers is a desirable outcome.

Natural Asset

Natural asset indicators all scored above 0.7 (Table 10) except for the increase in productivity. Although farmers reported an 83% improvement in the adoption rate for appropriate technologies such as row planting, the productivity improvement was lowest at 67%. Productivity is expected to increase with the increased adoption rate of improved technologies (Alem *et al.*, 2018; Inkoom & Micah, 2017). However, the results revealed that productivity improvement was lower than the adoption rate of appropriate technologies. This finding may be because, given the activities involved in row planting, farmers worry about soil moisture loss while awaiting the tractor services to complete the three activities, i.e., ploughing, harrowing and planting. Therefore, some preferred the broadcasting method as they would plough once and not lose time and soil moisture. By the time the dry spells hit, their crops would have reached some heat tolerance level, allowing them to have some harvest from their fields. Nevertheless, with broadcasting, some farm management activities, such as weeding and harvesting, may be challenging for farmers to perform, leading to poor management and low yields especially considering the average land cultivated and the age of farmers.

The increase in the number of livestock holdings indicator also scored higher at 79%. Most farmers practice mixed farming. Therefore, production from the crop fields also helps them supplement their livestock, especially fowl and goats hence the increase in the number of livestock holdings. The results also show an improvement in production area size by 73%. This may be because the government sets the standard number of hectares for which farmers receive tractor service. Therefore, because the government bears the cost, farmers feel they need to plough the maximum number of hectares that government pays for. This finding agrees with Seleka and Mmopelwa (2018), who also reported that ISPAAD increased cultivated land size.

Financial Assets

All indicators except one in the financial subcomponent scored above 70%. These results suggest that, with the ISPAAD program, farmers realize an improvement in their financial assets. The indicators above 70% indicate that ISPAAD has removed the burden of farmers' financial struggles in accessing the necessary inputs and tractor services for their farms, translating into some financial benefit. The only access to financial facilities scored 59%. This result is not surprising because most farmers were 65years and above. Thus, they are not eligible for formal financial lending and do not seek to borrow finances for their production as no financial provider will allow it.

Social Assets

Social asset indicators included the ability to interact with other members of the society at the farm level and in the general community set-up. It is alarming that indicators relating to farm event interactions scored lower than the general community interaction indicators. The indicators scored below 50%, suggesting that farmers are mainly disinclined to work together on farm interactions. These low scores could result from the subsidy program effects reducing the interaction with the extension officers since most of the motivation to participate is derived from extension fieldwork days organized by the extension area officers. However, with the ISPAAD program, extension officers are responsible for registering farmers, issuing inputs, and recording the outputs. These officers are housed in central areas. They are more office-based, limiting their work to issuing inputs and delivering ISPAAD service requirements and less on the other extension service roles in the ploughing fields/farms. However, the other indicators showed some improvement in general.

Physical Assets

Physical assets scored the lowest, with all the indicators scoring below 60% except the ability to access vehicles, trucks, and tractors, which scored 70%. These results suggest that farmers can mechanize their farms due to the improvement brought about by the ISPAAD program. However, there is less improvement in their physical assets, which scored an overall 57%. This could mean that most of the benefits accrued due to the ISPAAD program are mainly towards providing food security for the household and physical assets improvement becomes a secondary benefit.

Comparing LAI between the Sub-Districts

The livelihood asset scores were compared between the subdistricts, and the results are presented in Table 11 and graphically in *Figure 6*. There is a slight disparity in the improvement scores according to the sub-districts. Machaneng sub-district recorded the lowest score in all the livelihood improvement scores except for the physical assets, where Machaneng scored slightly above the Tutume sub-district. During the survey, this sub-district farmer had the poorest yields among the four.

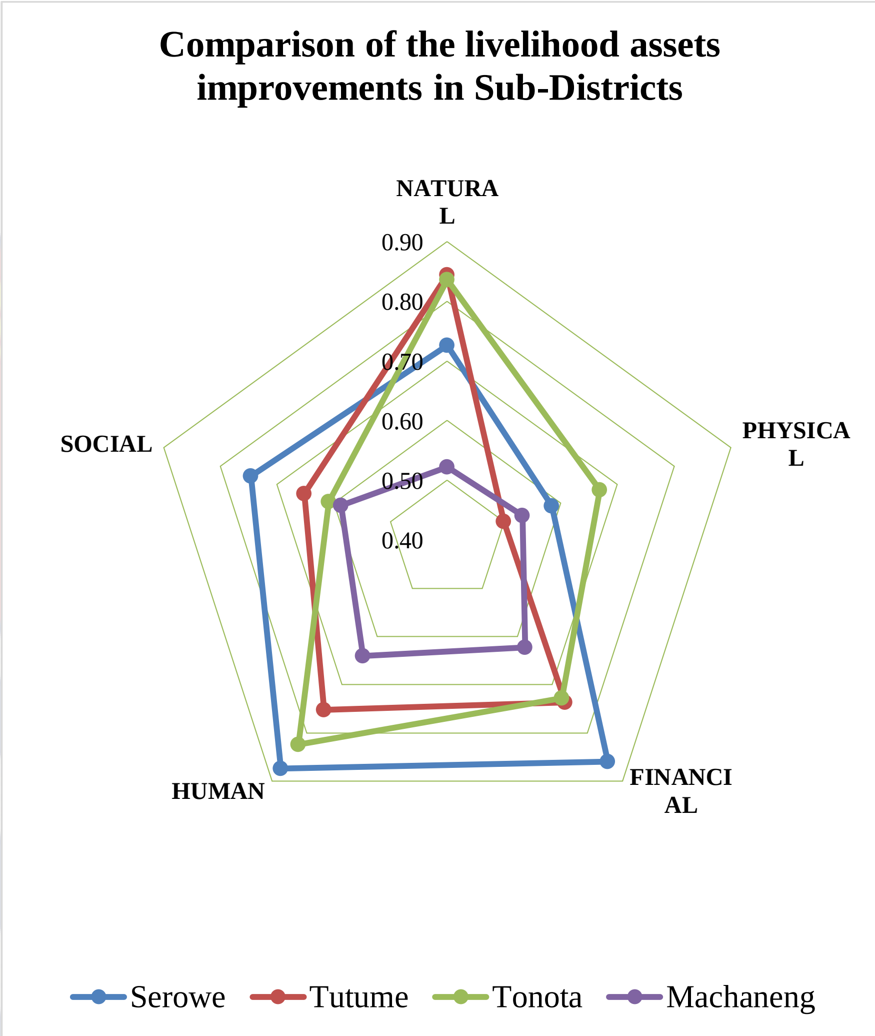


Figure 6: Livelihood assets pentagon comparing the Sub-Districts

Therefore, it could be possible that farmers were scoring the livelihood improvement based on their current farm performances. Tutume has the lowest score of 0.50 in physical assets, the lowest for all the assets among districts. However, all the areas scored above 0.50 in all the assets, suggesting that at least fifty per cent of the livelihood asset improvement for the farmers is attributable to the ISPAAD program benefits.

Table 11: Comparison of the livelihood assets improvement per Sub-Districts

	Human	Social	Natural	Physical	Financial
Serowe	0.87	0.75	0.73	0.58	0.86
Tutume	0.82	0.65	0.84	0.50	0.74
Tonota	0.75	0.61	0.84	0.67	0.73
Machaneng	0.64	0.59	0.52	0.54	0.62

Source: Computation from field data, (2022)

Test of significance for the livelihood assets improvement per Sub-Districts

The LAI between the sub-districts were subjected to a One-way analysis of variance (ANOVA) test to determine if there was any significant difference in the means between the various sub-districts. The results are presented in Table 12 and showed that there is no significant difference between the sub-districts LAI at a five percent significance level.

Table 12: Determining the significance of the difference between the subdistrict LAIs using ANOVA

Source of Variation	Sum of squares	df	Mean Square	F	P-value
Between Groups	0.0920	3	0.0307	2.8536	0.0701
Within Groups	0.1719	16	0.0107		
Total	0.2639	19			

Source: Computation from field data, (2022) $p>0.05$

Food security status of the arable farmers and their households

In this section, food security status results are presented. These results address the specific objective four (4) of the study (To examine the household food security status of the arable crop farmers in Botswana). The United States FANTA project Household Food Insecurity Access Scale (HFIAS) was used to measure the farmers' food insecurity status. The questions mainly focused on access and availability regarding farmers' ability to produce or have the financial means to buy what they cannot produce.

The results presented here answer the research question, "Are the arable crop farmers in Botswana food secure?". Table 13 presents farmers' responses to the Household Food Insecurity Access Scale (HFIAS) frequency of occurrence questions. The measure was determined by deriving a score from the frequency of occurrence questions. The lower the score, the more food secure and the higher the score, the more food insecure. The total maximum score possible was twenty-seven, and the lowest was zero. As shown in Table 11, most farmers responded with a "*no*" to the occurrence questions. The *"no"* responses increased as the level of intensity of food insecurity questions were asked. The "*no*" responses to the occurrence questions ranged from 64.7% to 94%. These results are consistent with Mohammadi *et al*. (2011), who also had a similar pattern of results.

Question 2, "*unable to eat preferred foods*," received more affirmative responses than all the other questions; hence, 35.3% of the respondents showed that they cannot always eat preferred foods. This question seemed to have a higher likelihood of an affirmative response due to two main observed reasons from the field. Firstly, farmers understood it as being unable to satisfy occasional cravings for "readily processed foods or certain preparations of foods and non-food basic food" such as fried potato chips, bread loaf, dairy products like yoghurt and soft drinks. Farmers explained this inability to eat the preferred foods mainly from not being available in the ploughing fields rather than the financial affordability and access. This finding could be explained by the households' different compositions, especially when there were younger children than when the household consisted only of adults. The question was then asked with a more profound clarity for farmers to provide the correct answer, but either way, the affirmations were accepted as correct answers.

Secondly, the question may have received more affirmations because of farmers having special diets recommended by doctors but could not access them in the ploughing fields, which was also recorded as a valid affirmative response. Farmers better-understood question 3, *"eat a limited variety of foods"*, when explained as eating the same sort of food unwillingly due to a lack of financial resources every time. These results suggest that farmers had fewer food supply issues during data collection. Instead, the preferred foods question received higher affirmations because foods were not readily available near them but did not necessarily make them food insecure. This finding may be due to farmers having a "normal struggle" with relish food supply according to their diet preferences, mostly meaty foods. Although this study did not have the specific foods guiding a balanced diet or culturally preferred foods in the area, this component would have provided a more insightful analysis.

Table 13: Farmers' responses to the Household Food Insecurity Access Scale (HFIAS) questions

	OPTIONS							
	No		Rarely		Sometimes		Often	
HFIAS Questions	*N*	*%*	*n*	*%*	*n*	*%*	*n*	*%*
Q1: Worry about food	342	72.8	52	11.1	37	7.9	39	8.3
Q2: Unable to eat preferred foods	304	64.7	62	13.2	59	12.6	45	9.6
Q3: Eat limited variety of foods	351	74.7	36	7.7	45	9.6	38	8.1
Q4: Eat foods you really did not want to eat	362	77.0	36	7.7	37	7.9	35	7.4
Q5: Eat a smaller meal	406	86.4	23	4.9	21	4.5	20	4.3
Q6: Eat fewer meals in a day	415	88.3	21	4.5	15	3.2	19	4.0
Q7: No food of any kind in the household	427	90.9	16	3.4	11	2.3	16	3.4
Q8: Go to sleep at night hungry	438	93.2	15	3.2	5	1.1	12	2.6
Q9: Go a whole day and night without eating anything	442	94.0	14	3.0	3	0.6	11	2.3

Source: Computation from field data, (2022) Generally, most farmers in the study area are, on average, food secure as indicated by the average food insecurity score of 3.07 calculated as follows: Average food insecurity score for the farmers = HFIAS scores in the sample ÷ n = **3.07.** This score is low based on the HFIAS range of 0-27 where zero means food security and 27 implies severe food insecurity. The results agree with Ndhleve, *et al*., (2021), who also used the same tool and found out that Botswana had more households falling in the food secure.

The responses were categorized into different groups according to their food insecurity experience severity, as presented in *Figure 7*. The numbers decrease as food insecurity increases. 63% and 17.23% fell among the mildly food insecure categories. The mildly food insecure category implies that farmers are food secure but with worries over supply. With the current study, the worry was more on the preferences due to ready access. Therefore the results suggest that about 81.5% of the subsistence farmers in Botswana are food secure. However, it should be noted that the study data collection was conducted just after the end of the ploughing season, which could mean most farmers still had supplies from their harvest. About eight per cent fell among the severe food insecure category. These results agree with the study by Bahta *et al.* (2017), who found that nine per cent of livestock farming households in Botswana were food insecure. Marumo *et al.* (2014) posited that since ISPAAD did not increase grain production and yields, farming households remain food insecure, contrary to the current study's findings.

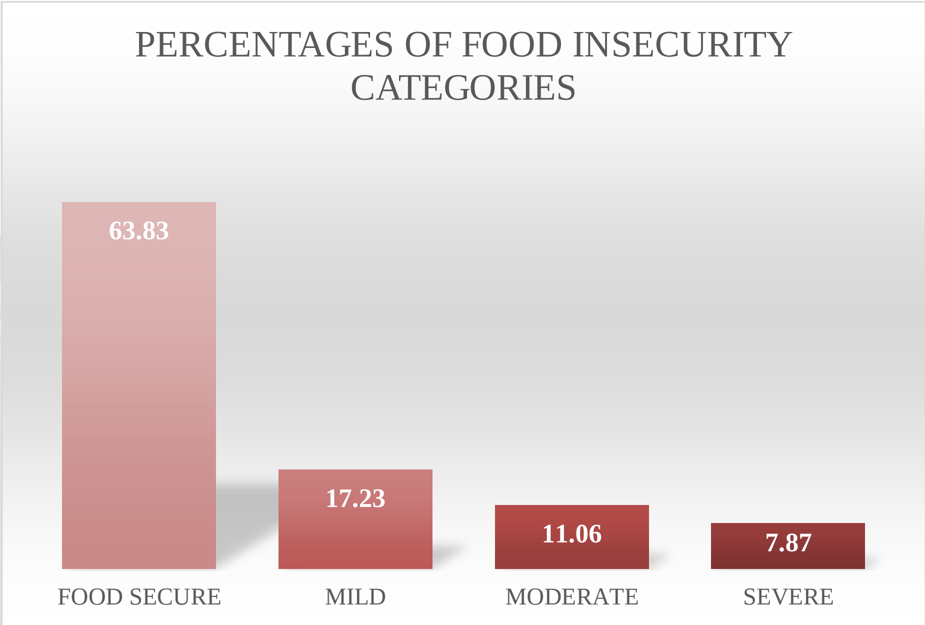


Figure 7: Categories of food insecurity (access)

Chapter Summary

The chapter has presented the summary description and discussion of the socio-economic characteristics, efficiency results, livelihood status, and food security status of the smallholder arable crop farmers. The results presented and discussed in this chapter addressed objectives one, three and four of the study. The findings showed that arable crop farming in the study area comprises mainly women (82%), and the farmers are elderly (i.e., aged 62 years on average).

The results showed that 81.8% of the total variation in farmers' output is due to production inefficiency. The production efficiencies levels of farmers were very low, with mean technical efficiency of 44%, allocative efficiency of 6.6% and economic efficiency of 2.9%. The study results revealed that time of ploughing attributable to the ISPAAD input subsidy delivery affects farmers' productivity. If the timeliness of receiving inputs subsidy is not adhered to, it negatively affects productivity in Botswana, given the limited amount of rainfall.

Farmers' livelihood status improvement measured high at an overall score of 70 per cent attributable to the government arable crop subsidy program, ISPAAD. A major improvement was found in human assets. The results also indicated that farmers were mainly food secure (63% secure and 17.3% secure with mild insecurity), with about eight per cent experiencing severe food insecurity.

CHAPTER FIVE

DETERMINANTS OF PRODUCTION EFFICIENCIES, LIVELIHOODS AND FOOD SECURITY IN BOTSWANA

Introduction

This chapter presents the results of the factors that explain the production efficiencies (i.e., technical, allocative and economic efficiencies of the farmers), livelihoods, and food security status of the farmers in Botswana. Here bi-directional relationships between production efficiencies and livelihoods and farmers' efficiencies and food security status are empirically verified. The chapter is divided into two sections. Section A discusses the relationship between production efficiencies and farmers' livelihoods, while Section B presents the relationship between production efficiencies and farmers' food security status.

Section A: Relationship between the efficiencies and farmers' livelihood status

This section presents the results of the relationships between the different components of efficiency and the livelihood status of farmers. Regression equations were used to test for the research hypothesis stated below.

Hypothesis 1:

H_0: Production efficiency of the arable crop farmers in Botswana has no significant effect on their livelihood status.

H_a: Production efficiency of the arable crop farmers in Botswana significantly affects their livelihood status.

In this section, the estimated results from the SUR model to determine factors explaining technical, allocative and economic efficiencies, and livelihood status of farmers, food security, and different efficiencies.

Analysis of the bi-directional relationship between technical efficiency and livelihood of the farmers

This subsection presents the results that explore the bi-directional relationship between technical efficiency and the livelihoods of the farmers. Further, the subsection indicates other factors influencing livelihoods and farmers' technical efficiency. Table 14 presents the SUR model results of the bi-directional relationship between technical efficiency and livelihood. The results showed a significant positive relationship between livelihood and technical efficiency, shown by the coefficients for the LH_score and TE variables at a one percent level (i.e., 2.25e-01*** and 2.98e-01***, respectively). The positive coefficients imply that increasing technical efficiency improves the livelihood status of the farmers and vice-versa. Therefore, the study rejects the null hypothesis and concludes that the technical efficiency of the arable crop farmers in Botswana significantly affects their livelihood status. Previous findings of Danso-Abbeam and Baiyegunhi (2020) and Kehinde *et al*. (2021) support this result. They also found that household welfare and efficiency significantly complement each other. Therefore, an increase in technical efficiency improves the farmers' livelihood, and farmers with improved livelihoods have a greater propensity to increase their technical efficiency levels.

From Table 14, the results showed the determinants of livelihood status and technical efficiency. Farmers' source of livelihood, extension visits, household income, and farmer education were positive and significant in explaining the farmers' livelihood status. The source of livelihood and extension visits were positive and significant at a one percent significance level, suggesting that farmers' livelihoods significantly depend on agriculture. Results imply that farmers benefit positively from visits from the extension officers in their arable crop production. Through extension services, officers provide inputs and information that enhance human capital (Danso-Abbeam, Ehiakpor, & Aidoo, 2018; Rahman & Connor, 2022). These include increasing farmers' knowledge through technology transfer and assisting them in improving their farm management practices, potentially improving their livelihoods. Farmers' education and household income were also positive and significant at 10%, meaning the more years of school and the higher the farming household's income level, the better their livelihood status.

Table 14: SUR results on the bi-directional relationship between technical efficiency and livelihood of the farmer

Dependent Variable	**LH_SCORE**			**TE**		
Variables	Coefficient	Std error	T-value	Coefficient	Std error	T-value
Intercept	4.14e-01***	8.86e-02	4.6758	2.81e-01***	7.86e-02	3.5749
TE	2.98e-01***	5.35e-02	5.5808			
LH_SCORE				2.25e-01***	4.02e-02	5.5918
I(SEEDS*TRACTOR)	4.02e-09	2.46e-09	1.6341	1.84e-09	2.13e-09	0.8623
EXPERIENCE	1.23e-03	7.31e-04	1.6866	-9.81e-04	6.34e-04	-1.5474
HHSIZE	1.29e-03	3.61e-03	0.3572	-7.05e-03*	3.10e-03	-2.2765
SOURCE_LIVELIHOOD	7.72e-02***	2.07e-02	3.7219	4.27e-02*	1.81e-02	2.3553
INCOME	1.85e-05*	8.72e-06	2.1212	3.02e-06	7.60e-06	0.397
EXT_VISITS	2.23e-02***	4.57e-03	4.8804	-5.73e-03	4.05e-03	-1.4159
SEX	2.70e-02	2.78e-02	0.9715	-3.61e-02	2.40e-02	-1.5051
EDUCATION	6.83e-03*	3.08e-03	2.2172	-4.84e-04	2.68e-03	-0.1808
AGE	-2.28e-03	1.22e-03	-1.8674	1.14e-03	1.05e-03	1.0845
MARITALS	1.53e-02	2.12e-02	0.72092	2.25e-02	1.83e-02	1.2288
Credit	3.05e-02	2.10e-02	1.45229	-2.07e-02	1.82e-02	-1.1346
TIMEseeds				-2.49e-03	1.78e-02	-0.1398
TIMEtractor				-6.57e-02**	2.24e-02	2.9315
QLT_TS				-4.79e-02*	2.08e-02	-2.3064

***,**,* Statistically significant figures at 1%, 5% and 10% respectively

Source: Field data, Mokumako (2022)

For technical efficiency, the significant variables are the source (Khanal *et al*., 2022)of livelihood, household size, time of accessing tractor services and the quality of tractor services. The results show that the source of livelihood positively affects technical efficiency, suggesting that where agriculture is the primary source of livelihood for the farmer, their technical efficiency is likely to improve. This result is possibly explained by the amount of time dedicated to farming, where agriculture is the primary source of livelihood. Where agriculture is a secondary livelihood activity for the farmer, there may be competing needs for resource allocation, including time and labour. These results are consistent with Danso-Abbeam and Baiyegunhi (2020), who found that the farmers' agricultural livelihood activities positively affect technical efficiency. Household size was significant at a 10% level but negative, suggesting that the more people in the household, the less efficient their production is. Although household members are the primary sources of labour for farm activities, the study shows that technical efficiency decreases as household size increases. The results are consistent with other studies (e.g. Kehinde *et al*., 2021, Inkoom, Dadzie & Ndebugri, 2020), which also reported that technical efficiency reduces as household size increases.

The subsidy effect variable, i.e., I(SEEDS*TRACTOR), was insignificant, but the results show that the TIMEtractor and QLT_TS were significant and negative. These results suggest that the quality and timeliness of tractor services negatively affect farmers' technical efficiency. The results imply that the longer it takes for farmers to access the tractor service, the less efficient their production becomes. Poor quality of tractor hire services also negatively impacts the farmer's technical efficiency. According to the farmers, some fields had patches of non-germinated areas. Farmers attributed patches in the field to the failure of the planter to drop the seeds. Farmers alluded that some tractor operators do a "shady job", rushing to plant to gather as many fields as possible at the expense of farmers' satisfaction in ploughing. Given that tractor-hire services are left for farmers to sort on their own, and the extension officers arrange payments for the service providers, there is likely poor monitoring of the work done by tractor-service providers. TIMEseeds was negative, suggesting that the farmers' timeliness of receiving seeds from the extension officers likely affects technical efficiency negatively. However, the coefficient was insignificant, possibly explaining that although seeds determine production, farmers may have other alternatives for seeds and not only rely on the seeds from the ISPAAD program.

Analysis of the bi-directional relationship between allocative efficiency and livelihood of the farmers

This subsection presents the results on the relationship between allocative efficiency and livelihood. It further looks into factors influencing livelihood and farmers' allocative efficiency, and the results are presented in Table 15.

Table 15: SUR results on the bi-directional relationship between allocative efficiency and livelihood of the farmers

Dependent Variable	**LH_SCORE**			**AE**		
Variables	Coefficient	Std error	T-value	Coefficient	Std error	T-value
Intercept	5.98e-01***	9.87e-02	6.0542	6.67e-02***	5.88e-03	11.338
AE	-8.81e-01	7.39e-01	-1.1914			
LH_SCORE				-3.82e-03	3.03e-03	-1.2617
I(SEEDS*TRACTOR)	5.59e-09*	2.53e-09	2.2066	7.42e-10***	1.60e-10	4.6503
EXPERIENCE	9.74e-04	7.37e-04	1.3215	-3.17e-05	4.74e-05	-0.6691
HHSIZE	-1.25e-03	3.62e-03	-0.3442	-2.88e-04	2.32e-04	-1.2426
SOURCE_LIVELIHOOD	9.56e-02***	2.06e-02	4.6349	-1.20e-03	1.36e-03	-0.8881
INCOME	2.00e-05*	8.82e-06	2.2641	-9.85e-07	5.69e-07	-1.7328
EXT_VISITS	2.20e-02***	4.61e-03	4.7739	-8.33e-05	3.03e-04	-0.2751
SEX	1.61e-02	2.80e-02	0.5752	-7.54e-04	1.79e-03	-0.4208
EDUCATION	7.55e-03*	3.11e-03	2.4238	3.57e-04	2.00e-04	1.7828
AGE	-2.05e-03	1.23e-03	-1.6665	5.47e-05	7.89e-05	0.6931
MARITALS	2.36e-02	2.13e-02	1.1047	1.12e-03	1.37e-03	0.8149
Credit	2.59e-02	2.12e-02	1.2219	-1.42e-03	1.36e-03	-1.0388
TIMEseeds				1.53e-03	1.34e-03	1.1438
TIMEtractor				-3.37e-04	1.69e-03	-0.1994
QLT_TS				-4.79e-02	2.08e-02	-2.3064

***,**,* Statistically significant figures at 1%, 5% and 10% respectively

Source: Field data, Mokumako (2022)

The results present negative coefficients for the AE and LH_score variables. This result implies a negative relationship between allocative efficiency and farmers' livelihood status. Allocative efficiency ensures a proper combination of inputs to optimize output using minimal cost; therefore, the results show that farmers are not optimizing their production hence affecting their output thus negatively influencing their livelihoods. The lack of allocative efficiency may be because farmers do not pay for the inputs, as government subsidy covers the costs, hence misapplication of the inputs on the farmers' end. However, the coefficients are insignificant, implying that the influence on livelihood is not statistically significant, showing no effect of the allocative efficiency on the livelihood status of the farmers.

The regression results present no significant evidence of the association between the two variables; therefore, the study fails to reject the null hypothesis that the allocative efficiency of the arable crop farmers in Botswana does not significantly affect their livelihood status. These findings are against Kehinde *et al*. (2021), who found a positive two-way relationship between farm productivity and income translating into better-improved welfare of the farmers. However, there is little literature on the effects of allocative efficiency on livelihoods to support this finding.

Table 15 shows that the subsidy significantly influences allocative efficiency. This is shown by the I(SEEDS*TRACTOR) coefficient, which is positive and significant at 1%. This means that to achieve allocative efficiency, farmers depend on the subsidy input provided by the government. Household size, farming experience, source of livelihood, income extension visits, time of accessing tractor services, and quality of tractor service were all negative, showing that these particular variables negatively determine the allocative efficiency. Farmers' age, education, and marital status were positive, implying that they positively influence allocative efficiency. However, all these variables were not significant in explaining the allocative efficiency. These results agree with the previous studies that had similar findings on the determinants of allocative efficiency (e.g. Gela *et al*., 2019; Hassan *et al*., 2022; Tesema, 2021).

As in the previous model of the effects of technical efficiency on livelihood, for livelihood status, the results also showed that the source of livelihood, household income, farmer education, and household income are significant and positive. The results imply that the variables positively influence livelihoods. Moreover, the subsidy effect was significant at a 10% level and positive, suggesting that the government subsidy has positive effects on the farmers' livelihood. These findings imply that despite the allocative efficiency not having significant effects on farmers' livelihood status, the subsidy is necessary for the farmers to continue their arable crop subsistent livelihood. This is because, without the subsidy program, farmers may possibly not be able to afford the cost of production inputs especially the tractor hire services.

Analysis of the bi-directional relationship between economic efficiency and livelihood of the farmers

This subsection presents the results on the relationship between economic efficiency and livelihood. In this sub-section, results on the determinants of economic efficiency are presented. From Table 16, the results show a highly significant relationship between economic efficiency and farmers' livelihood status (i.e., 3.48*** and 1.39-2***). The positive coefficients of EE and LH_SCORE show that an increase in economic efficiency improves farmers' livelihood status and vice versa. EE is highly significant in explaining the livelihood status of the farmers. Therefore, the study rejects the null hypothesis and concludes that the economic efficiency of the arable crop farmers in Botswana significantly affects their livelihood status.

Economic efficiency is a product of technical efficiency and allocative efficiency. Therefore, because technical efficiency also had a significant positive effect on livelihood status, economic efficiency also turned out to have the same effect despite allocative efficiency not significantly affecting livelihoods. This result suggests that farmers' economic efficiency can be best improved by increasing technical efficiency to improve the economic efficiency of farmers thus, improving the livelihood status of the farmers.

Like the other components of efficiency discussed above, source of livelihood, farmer education, extension visits, and household income affect the farmers' livelihood status. However, with economic efficiency, farmers' age was significant at a 10% level and negative, suggesting that their age negatively affects their livelihood status. As age increases, the livelihood status declines. This finding may be because as individuals grow older, their productive capacity reduces, and they may not be able to perform the same tasks as before, impacting their agricultural livelihood; farmers in the study area were average, above the age of 60 years.

Table 16: SUR results on the bi-directional relationship between economic efficiency and livelihood of the farmer

Dependent Variable	LH_SCORE			EE		
Variables	Coefficient	Standard error	T-value	Coefficient	Standard error	T-value
Intercept	4.65e-01***	8.73e-02	5.3274	1.71e-02**	5.84e-03	2.9222
EE	3.48e+00***	7.33e-01	4.7406			
LH_SCORE				1.39e-02***	2.96e-03	4.7067
I(SEEDS*TRACTOR)	2.94e-09	2.50e-09	1.1791	4.94e-10**	1.57e-10	3.1492
EXPERIENCE	1.25e-03	7.33e-04	1.7024	-7.95e-05	4.66e-05	-1.7066
HHSIZE	1.04e-03	3.62e-03	0.2865	-5.49e-04*	2.28e-04	-2.4118
SOURCE_LIVELIHOOD	8.41e-02***	2.07e-02	4.0734	2.15e-03	1.33e-03	1.6111
INCOME	2.05e-05*	8.73e-06	2.3424	-2.19e-07	5.59e-07	-0.3921
EXT_VISITS	2.23e-02***	4.58e-03	4.8699	-3.62e-04	2.97e-04	-1.2176
SEX	2.39e-02	2.79e-02	0.8561	-2.12e-03	1.76e-03	-1.2017
EDUCATION	6.26e-03*	3.09e-03	2.0246	1.72e-04	1.97e-04	0.874
AGE	-2.45e-03*	1.22e-03	-2.0006	1.36e-04	7.75e-05	1.7534
MARITALS	1.44e-02	2.13e-02	0.6781	2.28e-03	1.34e-03	1.6924
Credit	3.15e-02	2.10e-02	1.4982	-1.85e-03	1.34e-03	-1.3777
TIMEseeds				6.01e-04	1.31e-03	0.4593
TIMEtractor				-4.31e-03**	1.65e-03	2.6113
QLT_TS				-4.12e-03**	1.53e-03	-2.6909

***,**,* Statistically significant figures at 1%, 5% and 10% respectively

Source: Field data, Mokumako (2022)

Regarding factors explaining economic efficiency, farmers' livelihood status was significant at a one per cent level and positive, as shown in Table 16. This result suggests a positive causal effect between farmers' overall production efficiency and livelihood status. The subsidy effect variable was also significant at a five per cent significance level. The result suggests that the input subsidy highly influences farmers' economic efficiency. Therefore, an improvement in the subsidy will improve farmers' efficiency.

Economic efficiency is also explained by the quality and timeliness of tractor services, as depicted by the significant coefficients in Table 16. These variable coefficients are negative, suggesting they negatively affect farmers' production efficiency. These results are consistent with the above results on the factor explaining technical efficiency showing that there is a need to improve the subsidy inputs for farmers' production to reach some efficiency level.

Section B: Relationships between food insecurity status and the efficiencies

This section presents the results of the relationships between the different components of efficiency and the farmers' food insecurity status. Regression equations were used to test for the research hypothesis stated below.

Hypothesis 2:

H_0: Production efficiency of the arable crop farmers in Botswana has no significant effect on their food security status.

H_a: Production efficiency of the arable crop farmers in Botswana significantly affects their food security status.

Analysis of the linkages between technical efficiency and farmers' food insecurity status

This subsection presents the results of the bi-directional relationship between farmers' food insecurity status and technical efficiency. The results of the analysis are presented in Table 17. The negative sign for the equation 1 results (presented under FIS_SCORE) show a negative effect of food insecurity; hence farmers' food security improves. A positive sign means an increase in food insecurity; hence farmers' food security decreases. The results show a negative relationship between food insecurity and technical efficiency. This negative relationship means that an increase in technical efficiency will likely reduce farmers' food insecurity. This is because, with an increase in technical efficiency, farmers optimize their productivity and increase production output, thereby providing more food for the household. The technical efficiency coefficient is highly significant at a one per cent level, suggesting that improving technical efficiency reduces farmers' food insecurity. These results align with literature on productivity, livelihoods and food security factors (e.g., Kehinde *et al.*, 2021, Oyetunde-Usman & Olagunju, 2019), who found that food security improved with increased farm productivity. The results provide enough evidence to reject the null hypothesis and conclude that the technical efficiency of the arable crop farmers in Botswana significantly affects their food security status.

Table 17: SUR results on the linkages between technical efficiency and farmers' food insecurity status

Dependent Variable	FIS_SCORE			TE		
Variables	Coefficient	Standard error	T-value	Coefficient	Standard error	T-value
Intercept	3.03e-01***	8.38e-02	3.6088	4.38e-01***	7.41e-02	5.9119
TE	-4.55e-01***	5.02e-02	-9.0757			
FIS_SCORE				-3.73e-01***	4.07e-02	-9.1726
I(SEEDS*TRACTOR)	3.63e-09	2.33e-09	1.5564	3.71e-09	2.09e-09	1.7771
EXPERIENCE	-4.72e-04	6.92e-04	-0.682	-7.96e-04	6.22e-04	-1.2799
HHSIZE	6.07e-03	3.43e-03	1.7684	-3.68e-03	3.07e-03	-1.1982
SOURCE_LIVELIHOOD	-6.36e-02**	1.96e-02	-3.2382	2.90e-02	1.79e-02	1.6261
INCOME	-2.30e-05**	8.29e-06	-2.7744	-1.86e-06	7.50e-06	-0.2478
SEX	-2.89e-02	2.64e-02	-1.0963	-3.74e-02	2.36e-02	-1.588
EDUCATION	-3.47e-03	2.92e-03	-1.1877	-4.26e-04	2.62e-03	-0.1623
AGE	1.90e-03	1.16e-03	1.6351	1.28e-03	1.04e-03	1.2361
MARITALS	-8.05e-03	2.01e-02	-0.3999	1.99e-02	1.80e-02	1.1065
Credit	2.04e-02	1.99e-02	1.0234	-5.72e-03	1.79e-02	-0.3195
EXT_VISITS				-6.67e-04	3.80e-03	-0.1757
TIMEseeds				3.11e-03	1.73e-02	0.1802
TIMEtractor				-6.40e-02**	2.17e-02	2.9475
QLT_TS				-4.17e-02*	2.02e-02	-2.0657

***,**,* Statistically significant figures at 1%, 5% and 10% respectively

Source: Field data, Mokumako (2022)

At the same time, an increase in farmers' food insecurity levels results in a decrease in the technical efficiency of their production. This result may be because, as food insecurity increases, farmers may seek other quick sources of income, such as off-farm employment, to be able to buy food, which may negatively impact their arable production. In the earlier discussion, some farmers participated in off-farm employment, such as the Ipelegeng program to get work for cash. Therefore, farmers may be forced to share their time between off-farm employment and the farm when food insecurity increases, compromising productivity.

Like the previous chapter section, the results also show that the timeliness of accessing tractor services and the quality of tractor services are negative and significant determinants of technical efficiency in the current model. The results show that the quality and timeliness of tractor services explain farmers' technical efficiency as they were both significant at 10% and 5% levels, respectively. This finding presents the novelty of the current study, and results could not be supported by other literature as the study is the first to empirically establish the effects of timeliness of inputs on productivity and efficiency. For food security, the source of livelihood and household income were negative and significant at a five per cent level. These results imply that farmers' food security status is affected by their economic activity and household income. An increase in income improves farmers' food insecurity status. Sex, education, age and marital status have negative coefficients, meaning they have a negative relationship with food insecurity. However, these variables do not significantly influence the food security status of the farmers. Credit is positive, which means access to credit by the farmers may likely decrease their food security.

Analysis of the linkages between allocative efficiency and farmers' food insecurity status

Table 18 presents the results of the effects of allocative efficiency on farmers' food insecurity status. The results show a positive relationship between food insecurity and allocative efficiency, as shown by the coefficients of FIS_SCORE and AE. The results suggest that increasing allocative efficiency increases farmers' food insecurity. This finding is against the expectation that increasing allocative efficiency will likely improve farmers' welfare (Kehinde *et al.*, 2020). This finding suggests that allocative efficiency does not significantly affect farmers' food security. Hence, there is no evidence to reject the null hypothesis and conclude that allocative efficiency has no significant effect on farmers' food security status.

On the contrary, model results from equation 2 (shown under AE) show that all the model coefficients are insignificant in determining allocative efficiency, except for the I(SEEDS + TRACTOR) variable, which is the subsidy component. The results show that farmers' allocative efficiency is determined mainly by the ISPAAD subsidy, as shown in Table 18 by the highly significant coefficient of the interaction between tractor and seeds representing the subsidy component. The variable coefficient is positive, meaning that an increase in the subsidy inputs, ceteris paribus, will likely increase allocative efficiency.

Table 18: SUR results on the linkages between allocative efficiency and farmers' food insecurity status

Dependent Variable	FIS_SCORE			AE		
Variables	Coefficient	Standard error	T-value	Coefficient	Standard error	T-value
Intercept	7.21e-02	9.49e-02	0.759	6.44e-02***	5.64e-03	11.411
AE	5.87e-01	7.14e-01	0.8222			
FIS_SCORE				2.72e-03	3.16e-03	0.8604
I(SEEDS*TRACTOR)	1.80e-09	2.44e-09	0.7373	7.17e-10***	1.59e-10	4.5136
EXPERIENCE	-1.04e-04	7.08e-04	-0.1467	-3.53e-05	4.73e-05	-0.7467
HHSIZE	9.72e-03**	3.50e-03	2.7809	-3.10e-04	2.34e-04	-1.327
SOURCE_LIVELIHOOD	-9.28e-02***	1.99e-02	-4.6709	-1.32e-03	1.36e-03	-0.9685
INCOME	-2.60e-05**	8.52e-06	-3.0529	-9.94e-07	5.71e-07	-1.7412
SEX	-1.27e-02	2.70e-02	-0.4724	-7.83e-04	1.79e-03	-0.4367
EDUCATION	-4.31e-03	3.00e-03	-1.4377	3.41e-04	2.00e-04	1.7069
AGE	1.60e-03	1.19e-03	1.3433	5.82e-05	7.88e-05	0.7386
MARITALS	-2.00e-02	2.06e-02	-0.9712	1.08e-03	1.37e-03	0.7904
Credit	2.62e-02	2.04e-02	1.2824	-1.59e-03	1.36e-03	-1.164
EXT_VISITS				-1.68e-04	2.95e-04	-0.5685
TIMEseeds				1.50e-03	1.35e-03	1.1117
TIMEtractor				-3.50e-04	1.69e-03	-0.2068
QLT_TS				-1.50e-03	1.57e-03	-0.9558

***,**,* Statistically significant figures at 1%, 5% and 10% respectively

Source: Field data, Mokumako (2022)

The HHSIZE coefficient shows that food insecurity status positively correlates with the size of the farmers' households. This finding indicates that food insecurity increases with an increase in household size. An additional member to the household means an additional mouth to feed hence this finding. The results align with previous studies (e.g. Mota *et al*., 2019; Tuholske *et al*., 2020, Otekunrin *et al*., 2021), which found food security to decrease with increased household size. Household income is also significant and negative, implying that increasing household income decreases food insecurity. The household's ability to buy food relies mainly on income. This finding is consistent with the theoretical expectation that households can afford more food and improve their food security status as income increases. The results align with those of Otekunrin *et al*. (2021).

Analysis of the linkages between economic efficiency and farmers' food insecurity status

Analyzing the bidirectional relationship between economic efficiency and food security revealed a strong correlation between food insecurity and farmers' economic efficiency. The EE coefficient was negative and significant at a one per cent significance level, as presented in Table 19. This result suggests that increasing farmers' economic efficiency reduces farmers' food insecurity. Hence, the study rejects the null hypothesis that economic efficiency does not affect farmers' food security. This finding is consistent with Iheke and Onyendi (2017). This result was expected because economic efficiency is the interaction of technical and allocative efficiencies. Therefore, since technical efficiency was highly significant in determining food insecurity, economic efficiency also does.

Other factors that explain the farmers' food insecurity were the source of livelihood and household income, which both had a negative coefficient. The results suggest that food insecurity reduces with increased income and when the farmer's main source of livelihood is agriculture. The I(SEEDS+TRACTOR) variable coefficient was positive and significant at a 10% level. This result implies that an increase in the subsidy effect worsens the farmers' food insecurity. Economic efficiency ensures the optimization of output from the proper combination of inputs at the least possible cost; the results show that farmers are not optimizing their production given the inputs and their costs affecting their output, thus failing to produce enough for food security.

Table 19: SUR results of the linkages between economic efficiency and farmers' food insecurity status

Dependent Variable	FIS_SCORE			EE		
Variables	Coefficient	Standard error	T-value	Coefficient	Standard error	T-value
Intercept	2.27e-01**	8.30e-02	2.7403	2.25e-02***	5.47e-03	4.1231
EE	-5.42e+00***	6.93e-01	-7.8306			
FIS_SCORE				-2.38e-02***	3.02e-03	-7.885
I(SEEDS*TRACTOR)	5.34e-09*	2.37e-09	2.2485	6.11e-10***	1.54e-10	3.9634
EXPERIENCE	-5.04e-04	6.97e-04	-0.7239	-6.83e-05	4.59e-05	-1.4876
HHSIZE	6.38e-03	3.45e-03	1.8471	-3.33e-04	2.27e-04	-1.4692
SOURCE_LIVELIHOOD	-7.38e-02***	1.97e-02	-3.7568	1.24e-03	1.32e-03	0.9389
INCOME	-2.60e-05**	8.34e-06	-3.117	-5.37e-07	5.54e-07	-0.9698
SEX	-2.43e-02	2.65e-02	-0.9173	-2.21e-03	1.74e-03	-1.2703
EDUCATION	-2.57e-03	2.94e-03	-0.8737	1.72e-04	1.94e-04	0.8896
AGE	2.17e-03	1.17e-03	1.8576	1.46e-04	7.65e-05	1.9027
MARITALS	-6.47e-03	2.03e-02	-0.3186	2.10e-03	1.33e-03	1.5835
Credit	1.86e-02	2.01e-02	0.9287	-9.07e-04	1.32e-03	-0.6859
EXT_VISITS				-4.83e-05	2.82e-04	-0.1716
TIMEseeds				9.28e-04	1.28e-03	0.7232
TIMEtractor				-4.26e-03**	1.61e-03	2.6389
QLT_TS				-3.71e-03*	1.50e-03	-2.4761

***,**,* Statistically significant figures at 1%, 5% and 10% respectively

Source: Field data, Mokumako (2022)

This result could mean that the subsidy negatively affects farmers' food security because they rely on its inputs and services to produce, especially the tractor hire service. Therefore, when the tractor services are delayed or unsatisfactory, it negatively impacts the output, thus affecting the food security of the farmer. Further research could be necessary to understand why the subsidy effects would worsen farmers' food insecurity levels.

Equation 2 of the model results show that farmers' food insecurity status coefficient (FIS_SCORE) was highly significant in explaining economic efficiency. The negative coefficient implies that farmers' food insecurity decreases their economic efficiency. As in the previous model, TIMEtractor and QLT_TS were also significant at five and ten per cent significant levels, respectively. These coefficients have negative signs, suggesting that they affect economic efficiency negatively. This result may be because technical efficiency is determined by the use of tractor services and a delay in accessing the tractor service by the farmer, and the poor quality of the tractor service negatively impact the farmers' technical efficiency, thus affecting their economic efficiency of production. Again, the subsidy component is highly significant but positive, suggesting that improving the subsidy component would positively influence the farmers' economic efficiency.

Chapter Summary

The preceding chapter presented the bidirectional relationship between livelihoods and production efficiencies and food (in)security and production efficiencies, showing the factors determining farmers' livelihood, food security, and the different efficiencies. These results addressed specific objectives two, five and six and provided the evidence to conclude the two main hypotheses of the study. The results showed the determinants of the efficiencies, farmers' livelihood status and food security status, as summarized in Table 20.

Table 20: Summary of the results from the SUR models

Livelihood	Food Security	TE	AE	EE
TE (+)	TE (+)	Livelihood status (+)	Production subsidy (+)	Livelihood status (+)
EE (+)	EE (+)	Household size (-)		Production subsidy (+)
Source of livelihood (+)	Source of livelihood (+)	Source of livelihood (+)		Household size (-)
Household income (+)	Household income (+)	Timeliness of tractor services (-)		Timeliness of tractor services (-)
Extension visits (+)	Household size (-)	Quality of tractor services (-)		Quality of tractor services (-)
Education (+)	Production subsidy (-)	Food insecurity status (-)		Food insecurity status (-)
Production subsidy (+)				
Age of farmer (-)				

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter entails a summary of the key findings, conclusion and recommendations based on the study's objectives. The chapter also highlights the contribution of the study to knowledge as well as provides recommendations for further studies.

Summary

Sustainable Development Goal (SDG-2) calls for a commitment to end hunger, achieve food security, and promote sustainable food security by 2030. Attainment of food security is a primary policy focus for many countries worldwide. Food security can be achieved through Agriculture, the primary source of food security and livelihood through household farming for the rural population. However, low agricultural productivity aggravates the food insecurity situation in Africa and Botswana is no different.

Botswana is a landlocked, semi-arid country in Southern Africa with an estimated population of 2,346,179. Through smallholder subsistence farming, agriculture provides Batswana with food, income, and jobs. Despite the smallholder farmers collectively producing the bulk of the food available in the local market, their yields are relatively low compared to the commercial sector and the neighbouring countries. They face many challenges, such as poor soil fertility and unfavourable climatic conditions, which necessitated the government to set up subsidy programs to make it possible for farmers to produce under these factors. The government has tried to encourage farmers to expand production and increase productivity through various subsidy programs, the current being the Integrated Support Program for Arable Agriculture (ISPAAD). ISPAAD provides seeds for the major grain crops sorghum, maize, millet, and cowpeas to farmers and pays for mechanization. Farmers are eligible to receive these inputs to cover up to 5ha. The program engages private contractors to provide mechanization to farmers. These contractors plough the farmers' fields and get paid for the hectares covered. ISPAAD consumes about twenty million dollars ($20m) annually, but the crop output does not match this expenditure. Arable farmers continue to realize decreasing yields, and thus productivity is still very low. In this case, the government must improve agricultural productivity to ensure household food security.

Despite the low productivity, the arable crop sector has generally received minimal research on the effects of subsidy programs on the performance and productivity of the farmers. The study aimed to measure the productive efficiencies of the farmers and how they contribute to improving farmers' livelihood and food security status. Three different efficiency components were estimated: technical, allocative, and economic efficiencies. The study further examined other determinants of efficiencies, livelihood and food security status of the farmers.

The study employed a quantitative research approach using a descriptive correlational research design. A multistage sampling technique was employed to select farmers, starting with a purposive selection of the four sampled subdistricts, followed by a census of the extension areas to select a sample size of 470 randomly for the study. A structured interview schedule validated by research supervisors was used for the data collection. Results were analyzed with descriptive statistics and different regression models. The Cobb-Douglas Stochastic Frontier Production Function (SFPF) and its self-dual were used to estimate farmers' production efficiencies. A Livelihood Assessment Index (LAI) was adopted for livelihood assessment, while food security was measured using the Household Food Insecurity Access Scale (HFIAS). Finally, the Seemingly Unrelated Regression (SUR) models were used to establish the linkages between efficiencies, livelihood, and food security statuses. The significant findings of the study, according to the specific objectives, are as follows;

The Production Efficiencies

The study used the Maximum Likelihood Estimates of the Cobb-Douglas SFPF, and the results showed the model diagnostics confirming the goodness of fit for the model and the correct distributional assumption with sigma squared (δ^2) of 1.7377 and gamma (γ) of 0.8180. The coefficients from the SPFF were then used to estimate the three components of efficiency, and the results revealed that farmers' productivity was very low, with production efficiencies of farmers being very low, with mean technical efficiency of 44%, allocative efficiency of 6.6%, and economic efficiency of 2.9%. Seeds and labour were found to positively determine production output while the time of (late ploughing) affects farmers' output negatively.

Livelihood Status of the farmers

The livelihood status was evaluated using a Livelihood Assessment Index (LAI) to establish the perception of the farmers' livelihood improvement attributed to the ISPAAD program. The Likert scale measured farmers' asset improvements guided by the Sustainable Livelihood Framework (SLF). According to the LAI, ISPAAD brought a 70% improvement in farmers' overall livelihood status. The results showed more improvement in human assets, which scored an average of 77%. The results suggested that ISPAAD has improved the farmers' abilities to support family members and feed their households from their arable production. The results also revealed improvement in their self-reliance. Natural assets showed an overall increase score of 74%. However, the results revealed that productivity improvement was lower than the adoption rate of appropriate technologies.

Financial assets also showed a 74% improvement. The financial indicators scored above 70%, indicating that ISPAAD has removed the burden of farmers' financial struggles in accessing the necessary inputs and tractor services for their farms, translating into some financial benefit. Social asset indicators included the ability to interact with other members of the society at the farm level and in the general community set-up. Indicators relating to farm event interactions scored lower than the general community interaction indicators. The indicators scored below 50%, suggesting that farmers are mainly disinclined to work together on farm interactions. Physical assets scored the overall lowest of 57%, with all the indicators scoring below 60% except the ability to access vehicles, trucks, and tractors, which scored

70%. These results suggest that farmers can mechanize their farms due to the improvement brought about by the ISPAAD program.

Food Security measurement

The United States FANTA project Household Food Insecurity Access Scale (HFIAS) was used to measure the farmers' food insecurity. The questions mainly focused on access and availability regarding farmers' ability to produce or have the financial means to buy what they cannot produce. The average HFIAS score was 3.07 (maximum being 27) for the sampled farming households showing that, generally, farmers in Botswana are, on average, food secure. The results showed that farming households could not eat preferred foods rather than have worries about food.

Effects of the production efficiencies on farmers' livelihood and food security

The study used the SUR models to establish the effects of the different production efficiencies on farmers' livelihoods and food security statuses. The results showed the following;

Livelihood and efficiencies

There is a significant positive relationship between livelihood and technical efficiency, implying that increasing technical efficiency improves the livelihood status of the farmers and vice-versa.

Allocative and technical efficiency showed a negative relationship meaning that farmers are not optimising their production hence affecting their output thus negatively influencing their livelihoods. However, the results presented no significance, implying that the influence on livelihood is not statistically significant, hence no significant effect of the allocative efficiency on the livelihood status of the farmers.

There is also a highly significant relationship between economic efficiency and farmers' livelihood status. The results showed that increasing economic efficiency improves farmers' livelihoods and vice versa.

Food security and efficiencies

The results showed that increasing technical efficiency would likely reduce farmers' food insecurity. This is because, with increased technical efficiency, farmers optimize their productivity and increase production output, thereby providing more food for the households.

The results presented a positive relationship between food insecurity and allocative efficiency. These suggest that increasing allocative efficiency increases farmers' food insecurity, which was against expectation. However, the results presented no significant effect of allocative efficiency on farmers' food security status.

Analyzing the bidirectional relationship between economic efficiency and food security revealed a strong correlation between food insecurity and farmers' economic efficiency. This result suggests that increasing farmers' economic efficiency reduces farmers' food insecurity.

The study also established factors influencing the efficiencies, livelihoods and food security and the results are summarized below.

Determinants of technical efficiency: The study results have indicated that the following factors determine farmers' technical efficiency.

1. Whether the farmer subsists on agriculture or not: the more reliant on agriculture, the better the technical efficiency in production
2. the household size: larger households were found to be technically inefficient in production.
3. The timeliness of the tractor services received by the farmers was also negatively affecting farmers' technical efficiency when the services are not rendered on time.
4. Quality of the tractor services received by the farmer: poor tractor services also negatively affected farmers' technical efficiency.
5. The livelihood status score of the farmer was found to have a positive correlation with technical efficiency. The higher the livelihood status of the farmer, the more technically efficient their production.
6. The food (in)security status of the farmer also affects the technical efficiency of the farmer. An increase in farmers' food insecurity levels results in a decrease in the technical efficiency of their production.

Determinants of allocative efficiency:

According to the study results, allocative efficiency is mainly determined by the government subsidy program. The subsidy positively influences allocative efficiency. This finding implies that allocative efficiency increases with subsidy inputs. Other factors were not significant in explaining allocative efficiency.

Determinants of economic efficiency: Economic efficiency was found to correlate with all the other determinants of technical efficiency.

Moreover, the subsidy component was also positive, suggesting that the economic efficiency of the farmers increases with the subsidy.

Determinants of farmers' livelihoods: The results showed that farmers' livelihood status is affected by technical and economic efficiencies. An increase in these production efficiencies improves the farmers' livelihood status. Other factors positively influencing the livelihood status included the following.

1. Source of livelihoods
2. Household income
3. Extension visits
4. Education
5. Production subsidy

However, age was negatively correlated to livelihood status, showing that farmers' livelihood status declines with age.

Determinants of farmers' food (in)security: The results showed that technical and economic efficiency influence farmers' food (in)security status. An increase in these farmers' production efficiencies reduces their food insecurity situation. Other significant factors in explaining the food insecurity status were the following.

1. Source of livelihood
2. Household income
3. Household size

An increase in the above factors reduced the farmers' food insecurity situation. However, a more surprising finding was that the subsidy component was significant and positive, suggesting that the subsidy has adverse effects on food security.

Conclusions

The following conclusions were drawn from this study's findings based on the objectives and research questions.

Farmers are generally not efficient in their production. Their production efficiencies averages estimated were 44%, 6.6% and 2.9% for technical, allocative and economic efficiencies, respectively. Allocative and economic efficiencies were found to be very low, considering the amount of assistance the government renders. The factors that determine their production output are seeds and labour. Time of ploughing as a factor of production is important, considering the farmers' dependence on rainfall. However, given the timeliness of receiving the inputs from the ISPAAD subsidy program, the timeliness of production hinders the farmers from attaining maximum productivity.

Timeliness on access to and quality of subsidy production inputs is significant in improving production efficiencies. The timeliness of receiving tractor-hire services improves technical and economic efficiencies. Therefore, for farmers to optimize their production, the timeliness of tractor hire service ought to be considered and aligned with the onset of rains. The quality of tractor-hire services by farmers also impacts their productivity. It should be monitored to ensure quality work for farmers to increase production efficiency.

The producer subsidy is essential to arable farmers' production despite the time effect. The subsidy provision is necessary for farmers to stay in production. The input subsidy positively influences allocative, economic efficiency, and livelihood. The farmers subsist on agriculture as their primary source of economic activity and to feed households. Therefore, a subsidy should be provided to maintain the livelihood. Farmers' production depends on the subsidy program to avail inputs and services. Furthermore, extension visits are essential for farmers to improve their livelihoods.

However, the subsidy negatively affects farmers' food security because they rely on its inputs and services to produce, especially the tractor hire service. Therefore when the tractor services are delayed or unsatisfactory, it negatively impacts the output, thus affecting the food security of the farmer. Further research should be conducted to establish further insight into this.

Although farmers are not efficient in their production, they have a fair livelihood score and are mainly food secure. Farmers' livelihoods have improved, attributable to the ISPAAD subsidy program. Most farmers are food secure due to their crop production attributable to the ISPAAD subsidy effect.

In conclusion, improving technical and economic efficiencies results in improved livelihoods and food security statuses of farming households. However, the study was without limitations. The study did not have any data on the weather (rainfall), which may have brought better insight into the timeliness and efficiency of production.

Policy Recommendations

Based on the study's findings, the following recommendations are made.

1. The Ministry of Agricultural Development and Food Security should continue providing farmers with the subsidy. However, with enhanced and proper monitoring schemes to ensure that significant gains are made from implementing the programme.
2. The Ministry of Agricultural Development and Food Security must ensure that farmers acquire the input subsidy on time, especially tractor services.
3. The Ministry of Agricultural Development and Food Security must ensure that quality assurance of the tractor-hire services is improved to be effective and efficient. This can be achieved by thoroughly monitoring the subsidy program and ensuring the subcontracted service providers serve farmers as required and are duly monitored.
4. Through The Ministry of Agricultural Development and Food Security, the government should employ more extension area officers to bridge the gap between the extension officers to farmer ratio. When coupled with adequate logistics, this increase would go a long way to improve the frequency of extension visits and positively impact farmers' livelihoods.

Contributions to Knowledge

The study has contributed to the knowledge gap in the following:

1. The effects of time as a factor of production to efficiencies.
2. The effect of timeliness on the access of tractor-hire services to efficiency.
3. The effect of quality of tractor-hire services on efficiency

The study provides empirical evidence to serve as reference literature to other researchers, especially in Botswana, where there is scanty literature on production efficiencies.

Recommendations for Further Studies

The study recommends the following for further research.

1. Further research can extend onto this work and include the weather (rainfall) data to provide more insight into the effect of production timeliness on production efficiencies.
2. Further studies can be conducted to explore the farmers' livelihoods and food security status.
3. The study can be expanded to other districts of Botswana to augment the empirical finding for better policy implications.

REFERENCES

Abate, T. M., Dessie, A. B., & Mekie, T. M. (2019). Technical efficiency of smallholder farmers in red pepper production in North Gondar zone Amhara regional state, Ethiopia. *Journal of Economic Structures*, 8(1), 1-18.

Abdullah, Zhou, D., Shah, T., Ali, S., Ahmad, W., Din, I. U., & Ilyas, A. (2019). Factors affecting household food security in rural northern hinterland of Pakistan. *Journal of the Saudi Society of Agricultural Sciences*, 18(2), 201-210.

Abukari, A.-B. T., & Alemdar, T. (2019). Measuring the technical and cost efficiencies of maize farming in the Northern Region of Ghana: Deterministic and Stochastic approaches. *Agricultural Socio-Economics Journal*, 19(1), 47-64.

Acquah, H. D.-G. (2013). *An Introduction to Quantitative Methods.* Aachen: Shaker Verlag.

Adjimoti, G. O., & Kwadzo, G. T. (2018). Crop diversification and household food security status: evidence from rural Benin. *Agriculture & food Security*, 7(1), 1-12.

Adu, D. T., Kuwornu, J. K., Anim-Somuah, H., & Sasaki, N. (2018). Application of livelihood vulnerability index in assessing smallholder maize farming households' vulnerability to climate change in Brong-Ahafo region of Ghana. *Kasetsart Journal of Social Sciences*, 39(1), 22-32.

Afriat, S. N. (1972). Efficiency estimation of production functions. *International economic review*, 568-598.

Ahmed, A. S., & Mustapha, A. L. (2020). Evaluation of livelihood status among smallholder cowpea Farmers in Kano State, Nigeria. *Journal of Agricultural Economics, Environment and Social Sciences*, 6(1) 118-130.

Ahmed, M. H., Tazeze, A., Mezgebo, A., & Andualem, E. (2018). Measuring maize production efficiency in the eastern Ethiopia: Stochastic frontier approach. *African Journal of Science, Technology, Innovation and Development*, 10(7), 779-786.

Ahmed, M., Saha, S. M., Hossain, M. E., Khan, M. A., & Prodhan, M. M. (2021). Assessment of livelihood and food poverty status of the floating fishermen in riverine system of Bangladesh. *Social Sciences & Humanities Open*, 4(1), 1-10.

Ahmed, U. I., Ying, L., Bashir, M. K., Abid, M., & Zulfiqar, F. (2017). Status and determinants of small farming households' food security and role of market access in enhancing food security in rural Pakistan. *PLOS ONE*, 1-15.

Aigner, D. J., & Chu, S. F. (1968). On Estimating the Industry Production Function. *The American Economic Review*, 58(4), 826-839.

Aigner, D. J., Lovell, C. A., & Shmidt, P. (1977). Formulation and Estimation of Stochastic Frontier Production Function Models. *Journal of Econometrics*, 6(1), 21-37.

Alem, H., Lien, G., & Hardaker, B. J. (2018). Economic performance and efficiency determinants of crop-producing farms in Norway. *International Journal of Productivity and Performance Management*, 1418-1434.

Alexendri, C., Saman, C., & Pauna, B. (2021). Exploring the relationship between farm productivity and the CAP subsidies for the NMS. *Romanian Journal of Economic Forecasting*, 2(4), 124-140.

Bahta, S., Wanyoike, F., Katjiuongua, H., & Marumo, D. (2017). Characterisation of food security and consumption patterns among smallholder livestock farmers in Botswana. *Agriculture & Food Security*, 6(1), 1-11.

Bahta, Y. T., Jordaan, H., & Gunda, S. (2020). Agricultural Management Practices and Factors Affecting Technical Efficiency in Zimbabwe Maize Farming. *Agriculture*, 10(3), 1-14.

Baltagi, B. (2008). *A companion to theoretical econometrics.* Melbourne: John Wiley & Sons.

Barret, C. (2010). Measuring food security. *Science*, 327(5967), 825–828.

Bashir, M., & Khan, D. (2005). An Analysis of Allocative Efficiency of Wheat Growers in Northern Pakistan. *The Pakistan Development Review*, 643–657.

Batisani, N. (2012). Climate variability, yield instability and global recession: the multi-stressor to food security in Botswana. *Climate and Development*, 4(2), 129-140.

Batlang, U., & Nthoiwa, G. P. (2018). *Analysis of the Crop Agriculture Sub-sector Data with emphasis on 2004 and 2015 census results*. Ministry of Agriculture. Gaborone: Government of Botswana.

Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(2), 325-332.

Battese, G., & Corra, G. S. (1977). Estimation of a production frontier model: With application to the pastoral zone of Eastern Australia. *Australian Journal of Agricultural Economics*, 21(3), 169-179.

Beasley, M. T. (2008). Seemingly unrelated regression (SUR) models as a solution to path analytic models with correlated errors. *Multiple linear regression viewpoints*, 34(1), 1-7.

Berger, A. N., & Humphrey, D. B. (1997). Efficiency of financial institutions: International survey and directions for future research. *European Journal of Operational Research*, 98(2), 175–212.

Bertelli, O. (2019). Food security measures in Sub-Saharan Africa. A validation of the LSMS-ISA scale. *Journal of African Economics*, 29(1), 90-120.

Beyene, T., Mulugeta, W., & Merra, T. (2020). Technical efficiency and impact of improved farm inputs adoption on the yield of haricot bean producer in Hadiya zone, SNNP region, Ethiopia. *Cogent Economics & Finance*, 8(1), 1-21.

Birhanu, F. Z., Tsehay, A. S., & Bimerew, D. A. (2022). Cereal production practices and technical efficiency among farm households in major “teff” growing mixed farming areas of Ethiopia: A stochastic meta-frontier approach. *Cogent Economics & Finance*, 10(1), 1-33.

Blanche, M. T., Blanche, M. J. T., Durrheim, K., & Painter, D. (Eds.). (2006).. *Research in practice: applied methods for the social sciences.* Cape Town: University of Cape Town Press.

Bushara, M. O., & Ibrahim, H. H. (2017). Food Security Status for the Household: A Case Study of Al-Qadarif State, Sudan (2016). *Journal of Socialomics*, 6(217), 1-12.

Cadavez, V. A., & Henningsen, A. (2012). The use of seemingly unrelated regression to predict the carcass composition of lambs. *Meat science*, *92*(4), 548-553.

Cafiero, C., Melgar-Qui˜nonez, H. R., Ballard, T. J., & Kepple, A. W. (2014). Validity and reliability of food security measures. *Annals of the New York Academy of sciences*, 1331(1), 230–248.

Chambers, R. (1988). *Applied Production Analysis. A Dual Approach.* Cambridge: Cambridge University Press.

Chambers, R., & Conway, G. R. (1992). *Sustainable rural livelihoods: practical concepts for the 21st century.* Institute of Development Studies (UK).

Chandio, A. A., Jiang, Y., Abrham, T. G., & Dunya, R. (2019). The Nexus of Agricultural Credit, Farm Size and Technical Efficiency in Sindh, Pakistan: A Stochastic Production Frontier Approach. *Journal of the Saudi Society of Agricultural Sciences*, 18(3), 348-354.

Chandrasekara, A., & Kumar, T. J. (2016). Roots and Tuber Crops as Functional Foods: A Review on Phytochemical Constituents and Their Potential Health Benefits. *International Journal of Food Science*, 1-16.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European journal of operational research*, 2(6), 429-444.

Clapp, J., & Moseley, W. G. (2020). This food crisis is different: COVID-19 and the fragility of the neoliberal food security order. *The Journal of Peasant Studies*, 47(7),1393-1417. doi:https://doi.org/10.1080/03066150.2020.1823838

Coates, J., Swindale, A., & Bilinsky, P. (2007). Household food insecurity access scale (HFIAS) for measurement of food access: Indicator guide: version 3. Food and Nutrition Technical Assistance Project, Academy for Educational Development: Washington, DC.

Coelli, T. (1995a). Estimators and Hypothesis Tests for a Stochastic Frontier Function: A Monte Carlo Analysis. *The Journal of Productivity Analysis*, 6(3), 247-268.

Coelli, T. (1995b). Recent developments in frontier modelling and efficiency measurement. *Australian Journal of Agricultural Economics*, 39(3), 219-245.

Coelli, T., & Henningsen, A. (2013). *frontier: Stochastic Frontier Analysis. R package version 1.1.* Retrieved from http://CRAN.R-Project.org/package=frontier.

Coelli, T., Rao, P. D., O'Donnel, C. J., & Battesse, G. E. (2005). *An introduction to efficiency and productivity analysis.* US: Springer science and business media.

Collis, J., & Hussey, R. (2014). *Business Research: a Practical Guide for Undergraduate and Postgraduate Students.* Palgrave Macmillan.

Converse, J. M., & Presser, S. (1986). *Survey questions: Handcrafting the standardized questionnaire*. London: Sage Publications.

Córdova, R., Hogarth, N. J., & Kanninen, M. (2018). Sustainability of Smallholder Livelihoods in the Ecuadorian Highlands: A Comparison of Agroforestry and Conventional Agriculture Systems in the Indigenous Territory of Kayambi People. *Land*, 7(2), 1-31.

Cresswell, J. W., & Cresswell, D. J. (2018). *Research Design : qualitative, quantitative, and mixed methods approaches.* Sage Publications.

Cresswell, J. W. (2014). *Research Design* (4 ed.). Sage Publications.

Dadi, L., Burton, M., & Ozanne, A. (2004). Duration Analysis of Technological Adoption in Ethiopian Agriculture. *Journal of Agricultural Economics*, 55(3), 613-631.

Danso-Abbeam, G., & Baiyegunhi, L. J. (2020). Do farm-level technical efficiency and welfare complement each other? Insight from Ghana's cocoa industry. *Journal of Economic Structures*, 9(1), 1-15.

Danso-Abbeam, G., Ehiakpor, D. S., & Aidoo, R. (2018). Agricultural extension and its effects on farm productivity and income: insight from Northern Ghana. *Agriculture & Food Security*, 7(1), 1-10.

Darko, F. A., & Ricker-Gilbert, J. (2013). Economic Efficiency and Subsidized Farm Inputs: Evidence from Malawi Maize Farmers. *International Conference of the African Association* (pp. 1-25).

DFID. (2000). *Sustainable livelihoods guidance sheets.* London: Department for International Development .

Etikan, I., & Bala, K. (2017). Sampling and sampling methods. *Biometrics & Biostatistics International Journal*, 5(6), 1-3.

FAO. (2009). *Declaration of the world food summit on food security*. Rome: FAO.

FAO. (2013). *The Food In-security Experience Scale. Development of a Global Stan-dard for Monitoring Hunger Worldwide. Rome.* Rome: FAO.

FAO. (2014). *Global Strategic Framework for Food Security & Nutrition (GSF).* Rome: FAO.

FAO. (2017). *The Future of Food and Agriculture-Trends and Challenges. Annual Report*, 296, Rome: FAO.

FAO. (2019). *The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns.* Rome, Italy: FAO.

FAO, & GoB. (2014). *Country Program Framework for Botswana.* Gaborone: Government of Botswana.

FAO, IFAD, & WFP. (2013). *The State of Food Insecurity in the World 2013, The multiple dimensions of food security*. Rome: FAO.

FAO, IFAD, UNICEF, WFP, & WHO. (2019). *The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns.* Rome, Italy: FAO.

FAO, IFAD, UNICEF, WFP, & WHO. (2022). *The State of Food Security and Nutrition in the World 2022. Repurposing Food and Agricultural Policies to make healthy diets more affordable.* Rome: FAO. doi:https://doi.org/10.4060/cc0639en

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society*: *Series A, (General),* 120(3), 253-281.

Frankenberger, T. R., & McCaston, K. M. (1998). The household livelihood security. *Food Nutrition and agriculture*, 30-35.

Fried, H. O., Lovell, K. C., & Schmidt, S. S. (2008). *The Econometric Approach to Efficiency Analysis and Productivity Growth.* New York: Oxford University Press.

Gela, A., Haji, J., Ketema, M., & Abate, H. (2019). Technical, Allocative and Economic Efficiencies of small-scale sesame farmers: The case of West Gondar Zone, Ethiopea. *Review of Agricultural and Applied Economics*, 10-17.

Giannakas, K., Tran, K. C., & Tzouvelekas, V. (2003). On the choice of functional form in stochastic frontier modeling. *Empirical economics*, *28*(1), 75-100.

Gichure, J. N., Njeru, S. K., & Mathi, P. M. (2020). Sustainable livelihood approach for assessing the impacts of slaughterhouses on livelihood strategies among pastoralists in Kenya. *Pastoralism: Research, Policy and Practice*, 10(1), 1-10.

Gujarati, D. N., & Porter, D. C. (2003). *Basic Econometrics Fouth Edition.* Mc Grew Hill.

Hahn, M. B., Riederer, A. M., & Foster, S. O. (2009). The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. *Global Environmental Change*, 19(1), 74-88.

Haji, J. (2008). *Economic Efficiency and Marketing performance of Vegetable Production in the Eastern and Central Parts of Ethiopia.* (Vol. 2008, No. 2008: 17).

Hassan, C. K., Jonathan, S., & Idris, A. (2022). Determinants of allocative efficiency among rainfed rice farmers in Ardo-Kola and Jalingo Local Government Areas of Taraba State, Nigeria. *Journal of Agripreneurship and Sustainable Development*, 5(1), 94-102.

Heidari, S., Keshavarz, S., & Mirahmadizadeh, A. (2017). Application of Seemingly Unrelated Regression (SUR) in Determination of Risk Factors of Fatigue and General Health among the Employees of Petrochemical Companies. *Journal of Health Sciences and Surveillance System*, 5(4), 180-187.

Henningsen, A., & Hamann, J. D. (2007). systemfit: A Package for Estimating Systems of Simultaneous Equations in R. *Journal of Statistical Software*, 1-40.

Hussein, K. (2002). *Livelihood approaches compared: A multi-agency review of current practice. Commissioned by the UK Department for International Development's (DFID's) Sustainable Livelihoods Support Office (SLSO).* . London: DFID.

Iheke, O. R., & Nwankwo, N. F. (2016). Analysis of the Technical Efficiency of Snail Farmers in Abia State, Nigeria. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 16(1), 201-212.

Iheke, O. R., & Onyendi, C. O. (2017). Economic Efficiency and Food Security Status of Rural Farm Households in Abia State of Nigeria. *American Journal of Food Science and Nutrition*, 4, 52-58.

Inkoom, E. W., & Micah, J. A. (2017). Estimating Economic Efficiency of Mango Production in Ghana. *ADRRI Journal of Agriculture and Food Sciences*, 3(7), 29-46.

Inkoom, E. W., Dadzie, S. K., & Ndebugri, J. (2020). Promoting improved agricultural technologies to increase smallholder farm production efficiency: Ghanaian study of cassava farmers. *International Journal of Food and Agricultural Economics*, 271-294.

Irz, X., & Thirtle, C. (2004). Dual Technological Development in Botswana Agriculture : A Stochastic Input Distance Function Approach. *Journal of Agricultural Economics*, 55(3), 455-478.

Ismail, M. (2010). Concept and Measurement of Efficiency : A Review. *Voice of Academia*, 5(1), 17–26.

Jambor, A., & Szerletics, A. (2022). Regional Impacts of Direct Payments on Farm Productivity and Efficiency in the European Union. *n Agris On-line Papers in Economics and Informatics*, 14(665-2022-510), 59-68.

Jayne, T. S., & Rashid, S. (2013). Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence. *Agricultural Economics*, 44(6), 547–562.

Jayne, T. S., Mather, D., Mason, N., & Ricker-Gilbert, J. (2013). How do fertilizer subsidy programs affect total fertilizer use in sub-Saharan Africa? Crowding out, diversion, and benefit/cost assessments. *Agricultural Economics*, 44(66), 687-703.

Kalirajan, K. P. (1990). On Measuring Economic Efficiency. *Journal of Applied Econometrics*, 5(1), 75-85.

Kansiime, M. K., van Asten, P., & Sneyers, K. (2018). Farm diversity and resource use efficiency: Targeting agricultural policy interventions in East Africa farming systems. *Wageningen Journal of Life Sciences*, 85, 32-41.

Kashe, K., Kolawole, O. D., Moroke, T. S., Mogobe, & Oarabile. (2019). Dryland crop production in Botswana: Constraints and opportunities for smallholder arable farmers. *Smallholder farmers and farming practices: Challenges and prospects* (pp. 1-35). New York: Nova Science Publishers.

Kehinde, A. D., Ademoyo, R., & Ogundeji, A. A. (2021). Does social capital improve farm productivity and food security? Evidence from cocoa-based farming households in Southwestern Nigeria. *Heliyon*, 7(3) 1-14.

Kebakile, P. G. (2008). Rising Global Food Prices: Causes and Implications for Botswana.

Khanal, S., Lohani, S., & Khanal, S. (2022). Multicollinearity diagnostics upon Cobb-Douglas production function for estimating resource use efficiency of tomato in Chitwan, Nepal. *RJOAS*, 168-178.

Kodua, T. T., Onumah, E. E., & Bonsu, A. M. (2022). Technical efficiency of improved and local variety seed maize farms in Ghana: A meta-frontier analysis. *Cogent Economics & Finance*, 10(1), 1-17.

Koopmans, T. C. (1951). Efficient allocation of resources. *Econometrica: Journal of the Econometric Society*, 455-465.

Kumbhakhar, S. C., & Lovell, K. C. (2000). *Stochastic Frontier Analysis.* Cambridge: The Press Syndicate of the University of Cambridge.

Kumbhakar, S. C. (1991). The measurement and decomposition of cost-inefficiency: The Translog cost system. *Oxford Economic Papers*, 43(4), 667-683.

Kumbhakar, S. C., Parmeter, C. F., & Zelenyuk, V. (2020). Stochastic frontier analysis: Foundations and advances I. *Handbook of Production Economics* (pp. 1-40).

Kuwornu, J. K., Suleyman, D. M., & Amegashie, D. P. (2013). Analysis of food security status of farming households in the forest belt of the Central Region of Ghana. *Russian Journal of Agricultural and Socio-Economic Sciences*, 13(1), 26-42.

Lado, C. (2001). Environmental and socio-economic factors behind food security policy strategies in Botswana. *Development Southern Africa*, 18(2), 141-168.

Laux, P., Jäckel, G., Munang, R. T., & Kunstmann, H. (2009). *Onset of the rainy season and crop yield in Sub Saharan Africa: tools and perspectives for Cameroon.* Hyderabad, India: IAHS Press.

Leavy, P. (2017). *Research Design: Quantitative, qualitative, mixed methods, arts-based, and community-based participatory research approaches* New York, London: The Guilfold Press.

Lemenkova, P. (2022). Mapping Climate Parameters over the Territory of Botswana using GMT and Gridded Surface Data from TerraClimate. *International Journal of Geo-Information*, 11(9), 1-25.

Liu, Z., Chen, Q., & Xie, H. (2018). Influence of the farmer's livelihood assets on livelihood strategies in the Western Mountainous Area, China. *Sustainability*, 10(3), 1-12.

Lovell, K. C. (1993). Production Frontiers and Production Efficiency. *Measurement of Productive Efficiency: Techniques and Applications* (pp. 3-67). New York: Oxford University Press.

Magaña-lemus, D., Ishdorj, A., Rosson III, P. C., & Lara-álvarez, J. (2016). Determinants of household food insecurity in Mexico. *Agricultural and Food Economics*, 4(1), 1-20.

Mahama, T. A., & Maharjan, K. L. (2019). Determining the nature and spatial-temporal changes of the livelihood asset pentagon and its relationship with livelihood opportunities in Ghana. *Community Development*, 50(4), 460-483.

Manlosa, A. O., Hanspach, J., Schultner, J., Dorresteijn, I., & Fischer, J. (2019). Livelihood strategies, capital assets, and food security in rural Southwest Ethiopea. *Food Security*, 11(1), 167–181.

Marumo, D. S., Tselaesele, N. M., Batlang, U., Nthoiwa, G., & Jasen, R. (2014). *Poverty and Social Impact Analysis of the Integrated Support Programme for Arable Agriculture Development in Botswana.* Gaborone, Botswana: UNDP-UNEP-GoB Poverty Environment Initiative (PEI) Working Paper No.2.

Mashame, G., & Akinyemi, F. (2016, July 12-19). Towards a Remote Sensing based assessment of land susceptibility to degradation: Examining seasonal variation in land use-land cover for modelling land degradation in a semi-arid context. *ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences*, 3(8), 137-144.

Mastewal, D. K., & Wondaferahu, M. D. (2019). Smallholders' technical efficiency of teff production in Ethiopea. *African Journal of Agricultural Research*, 14(33), 1641-1648.

Maxwell, S. (1996). Food security: a post-modern perspective. *Food Policy*, 21(2), 155-170.

Meeusen, W., & van den Broeck, J. (1977). Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. *International Economic Review*, 435-444.

Mibei, S. B., Macharia, I. N., & Mwenjeri, G. W. (2021). Technical and Allocative Efficiencies among Smallholder Tomato Farmers in Kajiado County, Kenya. *East African Agricultural and Forestry Journal*, 85(1&2), 271-278.

Mingsheng, F., Jianbo, S., Lixing, Y., Rongfeng, J., Xinping, C., William, D. J., & Fusuo, Z. (2012). Improving crop productivity and resource use efficiency to ensure food security and environmental quality in China. *Journal of Experimental Botany*, 63(1), 13–24.

Minviel, J. J., & Latruffe, L. (2017). Effect of public subsidies on farm technical efficiency: a meta-analysis of empirical results. *Applied Economics*, 49(2), 213–226.

MoA. (2013). *Revised guidelines for integrated support programme for arable agriculture development (ISPAAD)*. Gaborone: Ministry of Agriculture.

Mohammadi, F., Omidvar, N., Houshiar-Rad, A., Khoshfetrat, M., Abdollahi, M., & Mehrabi, Y. (2011). Validity of an adapted Household Food Insecurity Access Scale in urban households in Iran. *Public Health Nutrition*, 15(1),149-157.

Moikgofe, L. (2020). *An assessment of effect of input subsidies on economic efficiency of sorghum producers in Botswana (Masters thesis)*. Kenya: University of Nairobi.

Moseley, W. G. (2016, June 27). Agriculture on the Brink: Climate Change, Labor and Smallholder Farming in Botswana. *Land*, 5(3), pp. 1-14.

Mosha, A. C. (2016). Urban agriculture in Botswana. *Commonwealth Journal of Local Governance*, (18), 48-67.

Mota, A. A., Lachore, S. T., & Handiso, Y. H. (2019). Assessment of food insecurity and its determinants in the rural households in Damot Gale Woreda, Wolaita zone, southern Ethiopia. *Agriculture & Food Security*, 8(1), 1-11.

Motlhalamme, T. (2019). *Value-addition of cereal crop residues using low technology oyster mushroom (pleurotus spp) production to improve smallscale farmers' income a)nd nutrition in Botswana.* (Masters thesis BUAN.

Motlhwa, G., Mgale, Y. J., & Yan, Y. (2019). Effects of Integrated Support Programme for Arable Agricultural Development (ISPAAD) on the Income of Sorghum Farmers: Evidence from Kweneng District, Botswana. *Asian Journal of Agricultural Extension, Economics & Sociology*, 1-10.

Motsatsi, J. M. (2015). Technical Efficiency and Evidence of Economies of Scope in Botswana Agriculture: A Stochastic Input Distance Function Approach (1979-1996). *Journal of Economics and Public Finance*, 1(92), 1-24.

Moyo, S. (2016). *Family farming in sub-Saharan Africa: its contribution to agriculture, food security and rural development*,Working Paper, No.150, International Policy Centre for Inclusive Growth (IPC-IG). Brasilia

Mujuru, N. M., Obi, A., Mishi, S., & Mdoda, L. (2022). Proft efficiency in family-owned crop farms in Eastern Cape Province of South Africa: a translog proft function approach. *Agriculture & Food Security*, 11(1), 1-9.

Muzari, W. (2013). Agricultural productivity and food security in sub-Saharan Africa. *International journal of science and research*, 1769-1776.

Mwalupaso, G. E., Wang, S., Rahman, S., Alavo, E. J.-P., & Tian, X. (2019). Agricultural Informatization and Technical Efficiency in Maize Production in Zambia. *Sustainability*, 11(8), 1-17.

Myeni, L., Moeletsi, M., Thavhana, M., Randela, M., & Mokoena, L. (2019). Barriers Affecting Sustainable Agricultural Productivity of Smallholder Farmers in the Eastern Free State of South Africa. *Sustainability*, 11(11), 1-18.

Natarajan, N., Newsham, A., Rigg, J., & Suhardiman, D. (2022). A sustainable livelihoods framework for the 21st century. *World Development*, 155, 1-15.

National Planning Commission. (2017). *National Development Plan 11 Volume 1 April 2017 – March 2023*. Gaborone: Government of Botswana.

Ndhleve, S., Dapira, C., Kabiti, H. M., Mpongwana, Z., Cishe, E. N., Nakin, M. D., Walker, K. P. (2021). Household food insecurity status and determinants: The Case of Botswana and South Africa. *AGRARIS: Journal of Agribusiness and Rural Development Research*, 7(2), 207-224.

Ngango, J., & Seung, G. K. (2019). Assessment of Technical Efficiency and Its Potential Determinants among Small-Scale Coffee Farmers in Rwanda. *Agriculture*, 9(7), 1-12.

Ngema, P. Z., Sibanda, M., & Musemwa, L. (2018). Household food security status and its determinants in Maphumulo local municipality, South Africa. *Sustainability*, 10(9), 1-23.

Nkomoki, W., Bavorová, M., & Banout, J. (2019). Factors Associated with Household Food Security in Zambia. *Sustainability*, 11(9), 1-18.

Nthoiwa, G. P., Gombalume, T., & Nthoiwa, M. K. (2013). Processing and utilization of sorghum and maize in Botswana: Current status and opportunities. *Asian Journal of Agriculture and Rural Development*, 3(11), 788-800.

Ntwiga, D. B. (2021). Determinants of Technical Efficiency in Agricultural Production among Sub-Saharan African Countries. *Journal of Agriculture and Environmental Sciences*, 6(1), 10-18.

Nyairo, R., Machimura, T., & Matsui, T. (2020). A combined analysis of sociological and farm management factors affecting household livelihood vulnerability to climate change in rural Burundi. *Sustainability*, 12(10), 1-20.

Obi, A., & Ayodeji, B. T. (2020). Determinants of Economic Farm-Size–Efficiency Relationship in Smallholder Maize Farms in the Eastern Cape Province of South Africa". *Agriculture*, 10(4), 1-18.

Otekunrin, O. A., Sawicka, B., & Pszczółkowski, P. (2021). Assessing food insecurity and its drivers among smallholder farming households in rural Oyo State, Nigeria: The HFIAS Approach. *Agriculture*, 11(12), 1-20.

Oyetunde-Usman, Z., & Olagunju, K. O. (2019). Determinants of Food Security and Technical Efficiency among Agricultural Households in Nigeria. *Economies*, 7(4), 1-13.

Pangapanga-Phiri, I., & Mungatana, E. D. (2021). Adoption of climate-smart agricultural practices and their influence on the technical efficiency of maize production under extreme weather events. *International Journal of Disaster Risk Reduction*, 61, 1-10.

Peremans, K., & Stefan, V. A. (2018). Robust Inference for Seemingly Unrelated Regression Models. *Journal of Multivariate Analysis*, 167, 212-224.

Pitt, M. M. & Lee, L.F., (1981). The measurement and sources of technical inefficiency in Indonesian weaving industry. *Journal of Development Economics*, 9(1), 43-64.

Rahman, M. M., & Connor, J. D. (2022). Impact of Agricultural Extension Services on Fertilizer Use and Farmers'Welfare: Evidence from Bangladesh. *Sustainability*, 14(15),1-16.

Raosoft, I. (2004). Sample size calculator. *Available from:www.raosoft com/samplesize*.

Reynold, T. W., Waddington, S. R., Anderson, L. C., Chew, A., True, Z., & Cullen, A. (2015). Environmental impacts and constraints associated with the production of major food crops in Sub-Saharan Africa and South Asia. *Food Security*, 7(4), 795–822.

Richmond, J. (1974). Estimating the efficiency of production. *International economic review*, 515-521.

Rizov, M., Pokrivcak, J., & Ciaian, P. (2013). CAP Subsidies and Productivity of the EU Farms. *Journal of Agricultural Economics*, 64(3), 537–557.

Salmerón, R., García, C. B., & García, J. (2018). Variance Inflation Factor and Condition Number in multiple linear regression. *Journal of Statistical Computation and Simulation*, 2365-2384.

Sallu, S. M., Twyman, C., & Stringer, L. C. (2010). Resilient or vulnerable livelihoods? Assessing livelihood dynamics and trajectories in rural Botswana. *Ecology and Society*, *15*(4).

Sassi, M. (2018). *Understanding food insecurity. Key features, indicators, and response design.* Cham, Switzerland: Springer.

Seleka, T. B. (1999). The performance of Botswana's traditional arable agriculture: growth rates and the impact of the accelerated rainfed arable programme (ARAP). *Agricultural Economics*, 20(2), 121-133.

Seleka, T. B., & Mmopelwa, D. (2018). *Effects of Input Subsidies on Subsistence Crop Acreage Diversity in Botswana.* Gaborone: BIPDA.

Shiferaw, S., Haji, J., Ketema, M., & Sileshi, M. (2021). Technical, allocative and economic efficiency of malt barley producers in Arsi zone, Ethiopia. *Cogent Food & Agriculture*, 8(1), 1-17.

Sibande, L., Bailey, A., & Davidova, S. (2015). The impact of farm input subsidies on household welfare in Malawi. *Agriculture in an Interconnected World* (pp. 1-33). Milan: International Conference of Agricultural Economists.

Siderious, W. (1978). *Soil transitions in Central East Botswana (Africa).* (Doctoral dessertation, International Institute for Aerial Survey and Earth Sciences.

Sigwele, H. k., & Orlowski, D. (2014). *Botswana Agriculture Public Expenditure Review 2000-2013.* Gaborone: World Bank.

Solesbury, W. (2003). *Sustainable Livelihoods: A Case Study of the Evolution of DFID Policy* (pp. 1-36). London: Overseas Development Institute.

Staniszewski, J., & Borychowski, M. (2020). The impact of the subsidies on efficiency of different sized farms. Case study of the Common Agricultural Policy of the European Union. *Agricultural Economics*, 66(8), 373-380.

Statistics Botswana. (2014). *2012 Annual Agricultural Survey Report.* Gaborone: Government of Botswana.

Statistics Botswana. (2018). *Botswana Agricultural Census Report 2015.* Gaborone: Government of Botswana.

Statistics Botswana. (2019). *Annual Agricultural Survey Report 2017.* Gaborone: Government of Botswana.

Statistics Botswana. (2022). *2022 Population and Housing Census Preliminary Results V2.* Gaborone: Government of Botswana.

Taherdoost, H. (2020). Validity and reliability of the research instrument; how to test the validation of a questionnaire/Survey in a research. *International Journal of Academic Research in Management*, *5*, 28-36.

Tanle, A. (2013). Assessing livelihood status of migrants from northern Ghana resident in the Obuasi Municipality. *GeoJournal*, 79(5), 577–590.

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International journal of medical education*, 2, 53.

Taylor, G., & McGuire, G. (2005). *Synchronous bootstrapping of seemingly unrelated regressions.* University of Melbourne: Centre for Actuarial Studies, Department of Economics.

Temoso, O., Villano, R. A., & Hardley, D. (2018). Agricultural productivity, efficiency and growth in a semi-arid country: a case study of Botswana. *African Journal of Agricultural and Resource Economics, 10(311-2016-5636),* 192-206.

Tesema, T. (2021). Determinants of allocative and economic efficiency in crop-livestock integration in western part of Ethiopia evidence from Horro district: data envelopment approach. *Heliyon*, 7(7), 1-7.

Thirtle, C., Piesse, J., Lusigi, A., & Suhariyanto, K. (2003). Multi-factor agricultural productivity, efficiency and convergence in Botswana, 1981–1996. *Journal of Development Economics*, 71(2), 605-624.

Tlhalefang, J., & Galebotswe, O. (2013). Welfare effects of higher energy and food prices in Botswana: a SAM price multiplier analysis. *Botswana Journal of Economics*, 11(15), 21-31.

Tuholske, C., Andam, K., Blekking, J., Evans, T., & Caylor, K. (2020). Comparing measures of urban food security in Accra, Ghana. *Food Security*, 12(2), 417–431.

Watkins, B. K., Hristovska, T., Mazzanti, R., Wilson, C. E., & Schmidt, L. (2014). Measurement of Technical, Allocative, Economic, and Scale Efficiency of Rice Production in Arkansas Using Data Envelopment Analysis. *Journal of Agricultural and Applied Economics*, 46(1), 89-106.

Wongnaa, C. A. (2016). *Economic Efficiency and Productivity of Maize Farmers in Ghana.* Kumasi: (Doctoral dissertation, Kwame Nkrumah University of Science and Technology).

World Bank. (2019). *Global financial development report 2019/2020: Bank regulation and supervision a decade after the global financial crisis*. Washington DC: World Bank.

WWF. (2008). *Livelihoods Outcomes: Study and Analysis of Changes in the Livelihoods of Bottleneck-level.* Nepal: WWF.

Yurdugül, H. (2008). Minimum sample size for Cronbach's coefficient alpha: a Monte-Carlo study. *Hacettepe Üniversitesi eğitim fakültesi dergisi*, *35*(35), 1-9.

Yusuf, I. M. (2018). Analysis of family labour utilization in the production of selected crops in dry-lands: evidence from Kahutu, Katsina State, Nigeria. *Agrosearch*, 18(2), 15-27.

Zellner, A. (1962). An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for. *Journal of the American Statistical Association*, 348-368.

Zhu, X., & Lansink, A. O. (2013). Impact of CAP Subsidies on Technical Efficiency of Crop Farms in Germany, the Netherlands and Sweden. *Journal of Agricultural Economics*, 61(3), 545-564.

APPENDICES

Appendix A: A structured household interview schedule

SECTION 1: INTRODUCTION

My name is Mrs. Tebogo Mokumako, an Agricultural Economics PhD student in the University of Cape Coast, Ghana. I am conducting a scholarly research on the productive efficiency, livelihoods and food security status of the smallholder arable crop farmers. The study is to be conducted in the Central District of Botswana. This instrument is set to collect data for my scholarly research and all the information shared will be treated with high confidentiality and shall in no way be used against the respondent. You are kindly requested to respond to the following questions.

Name of Interviewer:	…………………………………………………
Questionnaire number:	…………………………………………………
Sub- District:	…………………………………………………
Extension Area:	…………………………………………………
Date:	…………………………………………………
Time of interview:	From:…………………To:………………………
Name of respondent :	…………………………………………………
Relationship to farmer: *(e.g., spouse, daughter, son etc, if it is farmer record as 1)*	…………………………………………………

SECTION 2: FARMER AND HOUSEHOLD CHARACTERISTICS

NB: A household is made of people that live together in one house and share a meal.

Please place a tick [√] the most appropriate response.

1. Sex of farmer: Male [ ] Female [ ]
2. Age in years or year born: _________
3. Marital Status:

Single [ ] Living together [ ] Married [ ] Separated [ ]
Divorced [ ] Widowed [ ]

4. What is the highest level of education attained by farmer?

None [ ] Primary [ ] Junior Secondary [ ] Senior Secondary [ ]
Tertiary [ ] Others *(specify)*___________________________

5. Do you have any short courses / practical training related to arable crop farming? Yes [ ] No [ ] *(If NO skip to Q7)*
6. If yes, what was the training about? _________________________
7. Years of crop farming experience; ______________
8. What is the size of the household? __________Males __________ Females
9. Highest level of education attained by the most educated member of household other than farmer

Primary [ ] Junior Secondary [ ] Senior Secondary [ ]
Tertiary [ ] Others *(specify)*___________________________

10. Which of the following statements best describes your (farmer's) employment status?
    1) Employed by the government [ ] 5) Retired
    2) Employed by a private company [ ] 6) Unemployed
    3) Employed by a parastatal organization [ ] 7) Others *(specify)*____________
    4) Self-employed [ ]
11. Is there any other member of the household working/ employed? Yes [ ] No [ ]
12. If yes, state the type of employment____
13. Which of the following income ranges best represents the household estimated total monthly income?

1	Less than P2000		3	P4000-P6000	
2	P2001-P4001		4	More than P6000	

14. What would you say is the main source of household livelihood?

1. Arable farming [ ] 2. Pastoral farming [ ] 3. Mixed farming [ ] 4. Employment [ ] 5. Transfer payments from relatives [ ] 6. Others [ ] *(specify)*____________________

15. What would you say is the main source of family food supplies?
    1. Harvest from the farm [ ] 2. Food bought from the shops [ ]
    3. From the farm and bought from shops[ ] 4. Others [ ] *(specify)*__________________
16. Which of the following ranges best represents the household estimated monthly total expenditure on food?

1	Less than P300		2	P301- P500	
3	P501 – P1000		4	More than P1000	

SECTION 3: PRODUCTION FACTORS

Recall the following from the last cropping season (2020/2021)

17. Total land planted in hectares ______________________________
18. Ownership of land *(tick the appropriate)*
    1. Own land [ ] 2. Borrowed [ ] 3. Rented [ ] 4.

Others *(specify)* _________________

19. Rented fee if land is rented (Pula/hectare) ______________________
20. What were the crops planted in the field? Circle the appropriate.
    1. Maize 2. Millet 3. Sorghum 4. Cowpeas 5. Lablab 6.Bambara/Jugo beans
    7. Groundnuts (manoko) 8. Sweet reed 9. Watermelons 10. Marotse
    11. Maraka 12. Others *(specify)*______________________________
21. Inputs used (*fill under the applicable crop and put x for non-applicable crops*)

Production Variable	**Crop**				
	Maize	**Millet**	**Sorghum**	**Cowpeas**	**Others**
Land planted per crop (ha)					
Broadcasted land (ha) (mixed crops)					
Seed Use and					

Costs					
Quantity acquired/used per crop *(kg/litres)*					
Source of acquisition *(refer to key for code)*					
Cost of seeds					
Month acquired					
Fertilizers					
Quantity acquired *(kg/litres)*					
Source of acquisition *(refer to key for code)*					
Cost of fertilizers					
Month acquired/used					
Agrochemicals					
Quantity acquired/used *(kg/litres per area)*					
Source of acquisition *(refer to key for code)*					
Cost of agrochemicals					
Month acquired/used					

Key: Sources of acquisition 1=ISPAAD; 2=BAMB; 3=Agro Dealer; 4=Previous season 5= Others (specify)

	Household labour	Unpaid external labour	Hired labour	Average wage	Total cost per

Mechanization					
Tractor services					
Coverage Area in ha					
Price per hectare					
Month received					
Broadcasted land (ha)					
Price					
Month received					
Animal					
Coverage Area in ha					
Price					
Month received					

Labour Costs

22. Fill in the following table indicating the number of men and women involved in each activity performed.

	Men	Women	Men	Women	Men	Women		
Land preparation								
Transporting inputs to the field								
Planting								
Fertilizer application								
Weeding								
Application of agrochemicals								
Harvesting								
Transporting harvest from field to homestead								
Threshing and packing								

23. On average, how many days did each household member/worker work on the field?

____

24. On average, how many hours did each household member/worker work per day on the field? _______________

Information on output, sale, and consumption

25. Fill in the table below on the appropriate output.

	Total quantity harvested (kg/Bags)	Quantity sold (kg/Bags)	Unit Price (Pula/Bag)	Total Revenue (Pula)	Quantity Consumed (kg/Bags)	Quantity given away (kg/Bags)
2020/2021						
Maize (grain)						
Millet						
Sorghum						
Beans						
Other sales from harvest						
Morogo						
Lechotlho						
Lablab						
Furu						
Ditloo						
Manoko						
Sweet reed						
2019/2020						
Maize (grain)						
Millet						
Sorghum						
Beans						
Other sales from harvest						
Morogo						
Lechotlho						
Lablab						

Furu						
Ditloo						
Manoko						
Sweet reed						
2018/2019						
Maize (grain)						
Millet						
Sorghum						
Beans						
Other sales from harvest						
Morogo						
Lechotlho						
Lablab						
Furu						
Ditloo						
Manoko						
Sweet reed						

26. Did you ever have any interactions with the extension officer during the last ploughing season? Yes [ ] No [ ]
27. If yes, how many times? (State number of visits/meetings) ______________________
28. Kindly rate the following on a scale of 1-10, 1 being the least concern and 10 being the most concerning. Show by a tick [√].

Factors hindering attainment of maximum productivity

Factor	Rate the following according to how you feel is the major hinderance to best farm performance.										
	0	1	2	3	4	5	6	7	8	9	10
1) Pests and diseases											
2) Weeds											
3) Unfavourable climatic conditions											
4) Wild animals											

5) Distance to the farm											
6) Extension service concerns											
7) Late acquisition of seeds											
8) Delayed access to tractor services											
9) Poor tractor services											
10) Acquisition of fertilizers											
11) Acquisition of pesticides / herbicides (agrochemicals)											
12) Lack of good storage facility for harvest											
13) Unavailability of labour											
14) Lack of access to credit/ financial facilities											
15) Lack of good storage facility for inputs and harvest											
16) Poor access to market to sell											
17) Low output prices											
18) Unavailability/ Lack of transport facilities for inputs and output											
19) Lack of portable water for drinking in the fields											
20) Personal reasons (e.g. age, personal security, family issues)											

29. How could the identified major concerns be addressed or solved?

30. Did Covid-19 pandemic affect your arable production? Yes [ ] No [ ]
31. If yes, how?
    1) Failure to sell the produce
    2) Failure to transport the harvest from the farm to the household storage facility
    3) Failure to harvest
    4) Failure to scare away the birds and animals
    5) Failure to weed
    6) Increased opportunity to sell the produce
    7) Increased opportunity to transport the harvest from the farm to the household storage facility
    8) Increased opportunity to harvest
    9) Increased opportunity to scare away the birds and animals
    10) Increased opportunity to weed
    11) Others (specify)
32. Explain how

PART 2: LIVELIHOODS

33. How has ISPAAD impacted on your household livelihoods and food security? (Please indicate the extent to which the following under listed aspects of your livelihood have been improved because of the ISPAAD production inputs assistance program.) Place a tick [√] for the applicable rating.

Key: No Improvement = 0 Very Low = 1 Low = 2 High = 3 Very High = 4

Livelihood Assets Indicators	Extent if Benefits				
Natural Benefits	**0**	**1**	**2**	**3**	**4**
1. Increase in size of production land					
2. Increase in Yield					
3. Increase in Productivity (yield per unit area)					
4. Increase adoption rate to appropriate technologies					
5. Increase in number of livestock holdings					
Physical Assets	**0**	**1**	**2**	**3**	**4**
1. Able to buy (bicycle, cars, trucks, tractors)					
2. Able to buy farm inputs (e.g., farm implements, pumping machine)					
3. Able to get access to vehicles (hire trucks, tractors and implements)					
4. Able to build house(s)					
5. Able to connect water to your yard					
6. Able to connect electricity to your house					
Financial Assets	**0**	**1**	**2**	**3**	**4**
1. Increase in income levels					
2. Increase in saving levels					
3. Decrease in debt levels					
4. Increase in access to financial facilities					
Human Assets	**0**	**1**	**2**	**3**	**4**
1. Ability to feed household members					
2. Ability to support other family members					
3. Increase in employment opportunities for household members					
4. Increase in access to labour					
5. Self-reliance					
Social Assets	**0**	**1**	**2**	**3**	**4**
1. Join membership to association farmer group					
2. Support from association/farmer group					

3. Participation in activities					
4. Support to family and friends					
5. Ability to pay for societal contributions e.g., burial cover					
6. Access to services from extension officers					
Livelihood strategies	**0**	**1**	**2**	**3**	**4**
1. Non-farm income generation					
2. Mix crops to diversify production					
3. Use different crop varieties for production to minimize risk of crop failure					

PART 3: FOOD SECURITY

(Circle only 1 applicable answer)

NO	QUESTIONS	RESPONSE OPTIONS
34	In the past four weeks, did you worry that your household would not have enough food?	0 = No (skip to Q35) 1=Yes
34. a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)
35	In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?	0 = No (skip to Q36) 1=Yes
35. a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)

36	In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?	0 = No (skip to Q37) 1=Yes
36. a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)
37	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?	0 = No (skip to Q38) 1=Yes
37. a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)
38	In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?	0 = No (skip to Q39) 1=Yes
38. a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times

		in the past four weeks)
39	In the past four weeks, did you or any other household member have to eat fewer meals in a day because there was not enough food?	0 = No (skip to Q40) 1=Yes
39. a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)
40	In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food?	0 = No (skip to Q41) 1=Yes
40. a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)
41	In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?	0 = No (skip to Q42) 1=Yes
41. a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten

		times in the past four weeks) 3 = Often (more than ten times in the past four weeks)
42	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?	0 = No (end of questions) 1=Yes
42. a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)

END OF INTERVIEW! THANK YOU FOR YOUR TIME

Appendix B: Ethical Clearance

UNIVERSITY OF CAPE COAST

INSTITUTIONAL REVIEW BOARD SECRETARIAT

TEL: 0558093143 / 0508878309
E-MAIL: irb@ucc.edu.gh
OUR REF: UCC/IRB/A/2016/1305
YOUR REF:
OMB NO: 0990-0279
IORG #: IORG0009096

5TH APRIL, 2022

Mrs. Tebogo Mokumako
Department of Agricultural Economics and Extension
University of Cape Coast

Dear Mrs. Mokumako,

ETHICAL CLEARANCE – ID (UCCIRB/CANS/2021/24)

The University of Cape Coast Institutional Review Board (UCCIRB) has granted Provisional Approval for the implementation of your research **Improving Production Efficiencies and Food Security and Livelihood Nexus: Study of Smallholder Cereal Crop Producers in the Central District of Botswana.** This approval is valid from 5th April, 2022 to 4th March, 2023. You may apply for a renewal subject to submission of all the required documents that will be prescribed by the UCCIRB.

Please note that any modification to the project must be submitted to the UCCIRB for review and approval before its implementation. You are required to submit periodic review of the protocol to the Board and a final full review to the UCCIRB on completion of the research. The UCCIRB may observe or cause to be observed procedures and records of the research during and after implementation.

You are also required to report all serious adverse events related to this study to the UCCIRB within seven days verbally and fourteen days in writing.

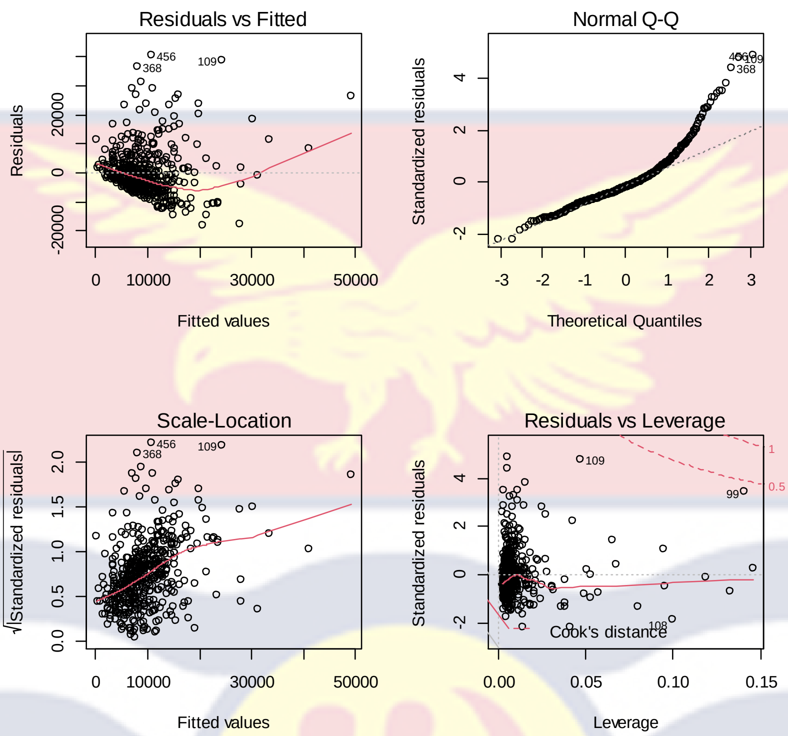
Always quote the protocol identification number in all future correspondence with us in relation to this protocol.

Yours faithfully,

Samuel Asiedu Owusu, PhD
UCCIRB Administrator

ADMINISTRATOR
INSTITUTIONAL REVIEW BOARD
UNIVERSITY OF CAPE COAST

Appendix C: Examining the Residuals to Check for Outliers



Appendix D: Multicollinearity and Heteroscedasticity Test Results for Cobb-Douglas Production Function

vif(reg.cob)

log(LAND)	log(SEEDS)	log(TRACTOR)	log(LABOUR)	TIME
1.025724	6.064512	1.724446	5.337089	1.085514

bptest(reg.cob)

studentized Breusch-Pagan test

data: reg.cob

BP = 8.6427, df = 5, p-value = 0.1242

Appendix E: Multicollinearity and heteroscedasticity test results for Translog Production Function

vif(trans.reg)

X1	X2	X3	X4	X5
2435.0682	4620.226384	2197.19971	6470.949045	848.9587
X6	X7	X8	X9	X10
3490.4925	373.382117	153.381748	5885.098193	719.5759
X11	X12	X13	X14	TIME
2023.7123	3436.88077	4789.558336	1705.068876	1.040587

bptest(trans.reg)

studentized Breusch-Pagan test

data: trans.reg

BP = 13.855, df = 15, p-value = 0.5365

Appendix F: Translog Production Frontier Estimation Output

Definition of variables used for the model

y=log(OUTPUT)	x1=log(SEEDS)	x2=log(TRACTOR)
x3=log(LABOUR)	x4=log(LAND)	x5=I(0.5*x1^2)
x6=I(0.5*x2^2)	x7=I(0.5*x3^2)	x8=I(0.5*x4^2)
x9=I(x1*x2)	x10=I(x1*x3)	x11=I(x1*x4)
x12=I(x2*x3)	x13=I(x2*x4)	x14=I(x3*x4)

translog.PF<-
sfa(y~x1+x2+x3+x4+x5+x6+x7+x8+x9+x10+x11+x12+x13+x14+TIME)

Results of the Translog Production Frontier

	Estimate	Std Error	z-value	Pr(>|z|)
(Intercept)	44.020962	29.921349	1.4712	0.141231
x1	-7.464412	3.793620	-1.9676	0.049111 *
x2	-2.495385	5.047478	-0.4944	0.621036
x3	-1.676392	2.946035	-0.5690	0.569334
x4	6.652103	6.309623	1.0543	0.291755
x5	0.546800	0.362890	1.5068	0.131864
x6	0.161528	0.531492	- 0.3039	0.761193
x7	0.219990	0.160438	1.3712	0.170316
x8	0.658414	0.890241	0.7396	0.459548
x9	0.385316	0.428221	0.8998	0.368223
x10	0.222433	0.169560	1.3118	0.189580
x11	-0.443393	0.478172	-0.9273	0.353788
x12	-0.122687	0.312061	-0.3932	0.694208
x13	-0.251128	0.610833	-0.4111	0.680983
x14	-0.274130	0.366694	-0.7476	0.454718
TIME	-0.264880	0.093886	-2.8213	0.004783 **
sigmaSq	1.733574	0.194121	8.9304	<2.2e-16 ***
gamma	0.840215	0.048029	17.4940	<2.2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

log-likelihood value: -591.4509

cross-sectional data

total number of observations = 460

mean efficiency: 0.4731886