TECHNICAL EFFICIENCY OF DRY SEASON VEGETABLE FARMERS AND ITS IMPLICATIONS ON HOUSEHOLDS' FOOD SECURITY IN THE UPPER EAST REGION OF GHANA

BY

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DECLARATION

I, James Anaba Akolgo, the author of this thesis titled "TECHNICAL EFFICIENCY OF DRY SEASON VEGETABLE FARMERS AND ITS IMPLICATIONS ON HOUSEHOLDS' FOOD SECURITY IN THE UPPER EAST REGION OF GHANA" do hereby declare that with the exception of references to past and current literature duly cited, this thesis is a result of research solely conducted by me in the Department of Agricultural Economics and Agribusiness, College of Basic and Applied Sciences, University of Ghana, Legon, from August 2018 to October 2020. This work has never been presented either in whole or in part for any other degree of this university or elsewhere.

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DEDICATION

I dedicate this work to the Almighty God, who is the very reason for my existence on this earth, to my parents, all of blessed memory, to my lovely wife, Nancy T. Ayariga, and my sons, Romeo and Reynold.

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ABSTRACT

Food and nutrition insecurity increasingly threaten the livelihoods of poor people in Northern Ghana. Most farmers turn to commercial production of vegetables during the dry season in the Upper East Region of Ghana to overcome food and nutrition insecurity challenges. However, crop yields are sub-optimal, affecting households' income relied upon for food security. Employing survey data from dry season vegetable farmers in the Upper East Region, this study hypothesised that improving the technical efficiency of dry season vegetable farmers will increase the productivity of the farms, enhance their income and lead to the achievement of their households' food security. This study analyzes the technical efficiency of dry season vegetable farmers and its implications on households' food security in the region. The study adopts the Stochastic Frontier Approach (SFA), incorporating flexible risk properties to account for production risk to estimate the technical efficiency level of the vegetable farmers. Also, the study identifies production risk and technical inefficiency factors affecting the output value of vegetables; determines the gross profits of farmers producing vegetables such as pepper, onions, tomatoes and garden eggs using gross margin analysis; and examines the extent of food insecurity among vegetable farm households with the Foster-Greer-Thorbecke (FGT) and Food Security Index (FSI) frameworks. Further, it adopts the probit and ordered probit models to identify the effect of the determinants of dry season vegetable income on the households' calorie availability and dietary diversity, respectively. A multistage sampling procedure was applied to select three hundred and twenty-two (322) dry season farmers from seven (7) irrigation districts in the region. The findings show that production risk and technical inefficiency exist in dry season vegetable production. The vegetable farms in the dry season exhibit increasing returns to scale. The results demonstrate that labour, seed and agrochemical costs decrease the output variability while fertilizer and irrigation costs increase the output variability of vegetables. The overall predicted mean technical efficiency score for dry season vegetable farms is 73%, which means 27% of the output value of the farms is lost due to production risk and technical inefficiency. The key factors that enhance the technical efficiency of dry season vegetable production are extension visits, usage of motorized pumps, gravity-fed irrigation technology and experience of the farmers. Pepper production gives the highest gross profit, followed by onions, tomatoes and garden eggs in that order. The headcount ratio of the FGT model shows that 45.7% of sampled households are food insecure. The depth and severity of food insecurity are 32.20% and 12.97%, respectively. The average per capita daily calorie availability for food secure households is 2,958kcal while that of the food insecure households is 1,670kcal, far below the mean per capita daily requirement of 2,421kcal. Higher technically efficient dry season vegetable farmers who adopt gravity-fed and motorised water pump irrigation technologies are food secure households whereas technically inefficient farmers who adopt a manual system of irrigation are food insecure. Factors such as dry season vegetable income, vegetable land size, technical efficiency positively improve the probability of achieving high households' calorie consumption. To improve the poor dietary diversity food consumption level of farm households in the region, dry season vegetable farmers should utilise water pumps and rehabilitate existing gravity-fed irrigation infrastructure to enhance the technical efficiency and productivity of the farmers. Also, the existing fertilizer and seeds subsidies should extend to include agrochemicals to enhance the technical efficiency of farmers to increase vegetables' output and (profit) income.

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ABBREVIATIONS AND ACRONYMS

FAO:	Food and Agriculture Organization
UN:	United Nations
MDGs:	Millennium Development Goals
SDGs:	Sustainable Development Goals
WFS:	World Food Summit
SSA:	Sub-Sahara Africa
GDP:	Gross Domestic Product
GHI:	Global Hunger Index
IFPRI:	International Food Policy Research Institute
DHS:	Demographic Health Survey
WFP:	World Food Programme
GSS:	Ghana Statistical Service
NGOs:	Non-Governmental Organizations
GIDA:	Irrigation Development Authority
ICOUR:	Irrigation Company of Upper Region
MOFA:	Ministry of Food and Agriculture
WHO:	World Health Organization
FASDEP:	Food and Agriculture Sector Development Policy
METASIP	Medium Term Agriculture Sector Investment Plan
GLSS:	Ghana Living Standards Survey
IWM:	International Water Management
CSIR:	Council for Scientific and Industrial Research
GFSI	Global Food Security Index
HCES:	Household Consumption and Expenditure Surveys
HDDS:	Household Dietary Diversity Score
USDA:	United States Department of Agricultural Development
HFIAS:	Household Food Insecurity Access Scale
HCSI:	Household Coping Strategies Index
IFAD:	International Fund for Agricultural Development
FGT:	Foster-Greer-Thorbecke
FANTA:	Food and Nutrition Technical Assistance Project
ODK:	Open Data Kit
USAID	United States Agency for International Development

CHAPTER ONE

INTRODUCTION

1.1 Background

The Ghanaian economy has witnessed tremendous growth, averaging above 5% annually since 2011, except in 2020 where it grew only by 0.4% as a result of the COVID -19 pandemic (ADB, 2022). The economic growth has however, been underpinned by the services and industrial sectors while the agriculture sector declines considerably (GSS, 2020). While earlier studies show that the livelihood of people who depend on agriculture were generally poorer than those who worked in other sectors of the economy (Cervantes-Godoy & Dewbre, 2010), most recent research opined that agricultural growth is much more positively related to poverty reduction than other sectors (World Bank, 2022). The declining share of agriculture's contribution to Ghana's economy, perhaps may be as a result of the income opportunities from the burgeoning services and industrial sectors, which attract some of the low waged agriculture labour force (Rodrik, 2016). This notwithstanding the agriculture sector still employs averagely about 40% of the Ghanaian population, more than other sectors (GSS, 2019b; ISSER, 2018).

Achieving poverty reduction and food security is the overarching goal of the government of Ghana. For this reason, the objective of the country's Food and Agriculture Sector Development Policies (FASDEP II) is to achieve "Food security, emergency preparedness and increased growth and incomes" (MOFA, 2007). This would ensure that "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"(FAO, 1996). The Medium-Term Agriculture Sector Investment Plans (METASIP I 2011-2015) and METASIP II 2014-2017) were the strategies for the FASDEP II to achieve poverty reduction and food security, in line with the objective of the United Nation's (UN's) Sustainable Development Goals' (SDGs) of zero hunger and food security by 2030 (Allen, Metternicht, & Wiedmann, 2018). Prior to the METASIPs, the implementation of the Ghana Poverty Reduction Strategy (GPRS I 2003-2005) and (GPRS II 2006-2009) had similar goals (IMF, 2012).

The government's third medium term plan, "Investing for Food and Jobs: An Agenda for Transforming Ghana's Agriculture (2018-2021)" is also being implemented through a number of flagship programmes including the Planting for Food and Jobs (PFJ), Rearing for Food and Jobs (RFJ), Greenhouse Villages, One District, One Warehouse, (1D1W), One District, One Factory (ID1F), One Village, One Dam (1V1D) among others. Agricultural transformation has been linked to poverty reduction and social development (Ecker, 2018). In the Coordinated Programme of Economic and Social Development Policies (2017-2024), Government of Ghana (GoG) has indicated establishing an Infrastructure for Poverty Eradication Programme (IPEP) and food security (MoSDI, 2020).

No doubt the implementation of the policy interventions have had positive impact on Ghana's economic growth which enabled the country to reduce poverty from 56.5% in 1992 to 23.4% in 2017 (GSS, 2019a; World Bank, 2018). The hungry population has also been reduced drastically. The evidence of this can be found in the Global Hunger Index (GHI) report by the International Food Policy Research Institute (IFPRI) which singled Ghana out in sub-Saharan Africa (SSA) among "the ten best performers who has been improving in the GHI score since 1990" (von Grebmer et al., 2017). The country has also made significant progress in meeting the SDG goal 2 of zero hunger (FAO, IFAD, UNICEF, WFP, & WHO., 2020).

These notwithstanding, high disparity of poverty, hunger and malnutrition persist in some regions in Ghana (MOFA, GSS, WFP, & FAO, 2020). While some regions and social groups within the country have shown remarkable improvement in reducing poverty and food insecurity, a large proportion of the population, mostly in farming communities remain impoverished and malnourished (P. P. Acheampong, Obeng, Opoku, Brobbey, & Sakyiamah, 2022). Stunting, wasting and underweight affect 17.5%, 6.8% and 14.2% of children under 5 as a result of inadequate nutrition and diseases in Ghana (FAO et al., 2020). The disparity is much more pronounced, particularly in Northern Ghana (GSS, 2014, 2019a; Tsiboe, Zereyesus, & Osei, 2016) where majority of the country's food insecure reside (MOFA et al., 2020). Food insecurity is "experienced by households and individuals when there is uncertainty about future food availability and access, insufficiency of the amount and kinds of foods (quality) required for a healthy lifestyle, or the need to use socially unacceptable ways to acquire food" (National Research Council, 2006).

The challenges of food insecurity in northern Ghana are directly linked to the unimodal rainfall pattern which characterise the food production system. Also, the effect of climate change has not only shortened the length of the raining season but has extended the length of the dry season as well, causing high temperatures with negative consequences on crops yields, increasing poverty and food insecurity in the area. (Amikuzino & Donkoh, 2012; Baffour-Ata et al., 2021). Additionally, the occurrence of flood and drought annually cause declines in food production and productivity (E. N. Acheampong, Ozor, & Owusu, 2014).

Irrigation is one of the appropriate strategies to delinks food production from climate shocks and permit farmers to produce food all-year round (Burney & Naylor, 2012; Darko, Yuan, Hong, Liu, & Yan, 2016; Dillon, 2011; Domènech, 2015; J. K. Mwangi & Crewett, 2019; Venot, 2016; Wichelns, 2014). Irrigation also minimises the risk of unreliable raining season that hampers agricultural activities and decreases crops yield in most arid and semi-arid environments in SSA (Ahmed, 2020; Namara, Horowitz, Nyamadi, & Barry, 2011). Studies by Lipton, Litchfield, and Faurès (2003) and Tesfaw (2018) opined that irrigation extends the length of the farming season, increases the number of harvests per year, as such improves livelihoods through diversification of food and income sources.

Unfortunately however, Ghana's irrigation development like most other countries in SSA has not seen much development as compared to the rest of the world following a disappointing outcomes in 1980s and 1990s drew scepticism on whether large irrigation system was appropriate in Africa (Woodhouse et al., 2017). Ghana's irrigation has therefore remained limited, covering only about 4% of arable land area (Namara et al., 2011), compared to about 44% in China, 26% in India, 39% in South Asia and 29 in East Asia (Vince, 2010; WEF, 2015; Woodhouse et al., 2017).

Nevertheless, Ghana has about 22 known public managed irrigation schemes with water storage capacities between 5.9 to 93 cubic Mega metres (Mm^3) (Namara et al., 2011), many of them in the northern regions (FAO, 2020). Additionally, the District Assemblies and Development Partners (DPs) have constructed small dams across the region for agricultural purposes. Water from a network of lakes, streams and rivers such as the White Volta River are being used by farmers for cultivating crops along its catchment areas. Individuals and groups have also constructed wells and boreholes in areas close to high water tables, low-lying areas, river banks, riverbeds, swampy areas or malfunctioning irrigation schemes for irrigation purposes (Namara et al., 2011).

In the Upper East Region, farmers rely on these irrigation facilities to cultivate various crops mainly vegetables such as onions (*Allium cepa*), pepper (*Capsicum spp*), tomatoes (*Solanum lycopersicum*), garden eggs (*Solanum melongena*), okra (*Abelmoschus esculentus*) and other indigenous leafy vegetables during dry season to raise income to supplement households food provision since the food produced during the main cropping season is usually inadequate to feed the people (Balana et al., 2020). These vegetables produced are either sold at the district local market or to 'market Queen' (women traders) at the farm gate who transport them to major towns and cities in Accra, Kumasi, and Takoradi for sale (Van Asselt, Masias, & Kolavalli, 2018).

The returns from vegetable farming is two to three times higher than from the traditional rainfed vegetable farming (Danso, Drechsel, Wiafe-Antwi, & Gyiele, 2002). As such it creates employment, reduces poverty, hunger and malnutrition much more than other crops (Drechsel & Keraita, 2014; Joosten, Dijkxhoorn, Sertse, & Ruben, 2015; Mohammed, 2011). The income from vegetable can also be re-invested in the production of staples and livestock as well as acquire assets to reduce poverty and food insecurity (Abate, Dessie, & Mekie, 2019; Joosten et al., 2015; Keatinge, Yang, Hughes, Easdown, & Holmer, 2011; Weinberger & Lumpkin, 2007). Balana et al. (2019) and Balana et al. (2020) opined that irrigated vegetables production improves income and household food security in northern Ghana. However, farmers in the Upper East Region have been producing vegetables but their poverty status remains unchanged (World Bank, 2018) and household food insecurity is still high (MOFA et al., 2020) because the yield of the vegetables are low, sometimes making the farmers unable to break even (Van Asselt et al., 2018).

Ameliorating farm level productivity is the most effective strategy for poverty reduction through better food security and farm inflows in agrarian economies globally (Baffour-Ata et al., 2021; FAO, 2017). Improving farm productivity is the effect of economic efficiency but a farmer cannot be economically efficient without being technically efficient.(Ajao, 2012; Amoah, Debrah, & Abubakari, 2014). Technical efficiency refers to the ability of farmers to achieve maximum output with available resources and technology. Low yield and productivity of vegetable farms can therefore be attributed to the effect of technical inefficiency of farmers, which reduces profit and adversely affect food security status in many countries (Adeagbo & Adejumo, 2020; Al Salmi, Nadaf, Mbaga, Janke, & Al-Busaidi, 2020; Habiyaremye, Tabe-Ojong, Ochieng, & Chagomoka, 2019; Rai et al., 2019). Whether or not vegetable farmers are technically efficient determines the choice of productivity improvement strategies for achieving the sustainable development goals on no poverty and zero huger (Wongnaa & Awunyo-Vitor, 2018).

Researchers in recent years have placed much emphasis on technical efficiency studies due to its ability to provide outcomes for improving farmers' productivity (Modi, 2015; Ogunmola, Afolabi, Adesina, & IleChukwu, 2021; Ukpong & Idiong, 2013) and households' food security (Wongnaa & Awunyo-Vitor, 2018). This study therefore hypothesised that technical efficiency of dry season vegetable farmers can impact household food security differently along the four pillars: availability, accessibility, utilization and stability. Improving technical efficiency is expected to enhance food availability at the household level through increased opportunities for the farmers to produce more food. Technical efficiency is also likely to improve access via enhanced output and productivity, increased income from the sale of produce which ultimately enhances food purchases. The higher income generated from the sale of vegetable can also favours the purchase of diversified diet thus, enhances food utilisation. Again, utilizing the resources efficiently improves sustainable farm productivity and reduces production risks to farmers producing food hence promote households' food stability.

In Ghana, however, not enough empirical research has, so far, has been conducted on technical efficiency of vegetable farmers (Amoah et al., 2014; Tsiboe, Asravor, & Osei, 2019). Besides, only few studies found have linked the effect of technical efficiency of vegetable farmers on households' food security (Boateng, Donkoh, & Adzawla, 2022; Donkoh, Ayambila, & Abdulai, 2013) but not the Upper East Region. With evidence of high level of poverty and food insecurity in the Upper East Region of Ghana (MOFA et al., 2020) at the moment when there is a rising interest of farmers to cultivate vegetables during dry season (Van Asselt et al., 2018) makes it worth examining the technical efficiency of these farmers and its effect on households' food security in the region.

1.2 Problem Statement

The livelihood of over 80% people in northern Ghana depends on agriculture (GSS, 2019a) but declining yields (Baffour-Ata et al., 2021) is a major threat to poverty reduction and food security in most households (Quaye, 2008; Timler et al., 2014). The Upper East Region which in the past was considered one of the "food basket" in the country now is unable to produce enough to feed the households partly due to changing agroecological environment (Amikuzino & Donkoh, 2012; F. Asante, Guodaar, & Arimiyaw, 2021). The effects of climate change has not only shorten the length of the main cropping season but has caused annual drought and floods reducing crops yield (F. Asante et al., 2021; Baffour-Ata et al., 2021). The main cropping season of the region depends on the unimodal rain-fed system to produce, mainly cereals with low nutritional and market value, as such low potential for the reduction of poverty and malnutrition (Burney & Naylor, 2012).

In view of the above, the quantity of food produced and stored for consumption is usually inadequate (F. Asante et al., 2021) and get depleted within a short period, with some households experiencing food insecurity up to about 5-6 months annually (Quaye, 2008; Timler et al., 2014). Nyantakyi-Frimpong (2014) opined that about 20% of the people in northern Ghana including the Upper East Region either go to bed hungry each night or do not know where their next meal may come from, due to low yields of crops and poverty. The Comprehensive Food Security and Vulnerability Analysis (CFSVA) survey in 2020 also reported that majority of Ghana's 3.6 million food insecure people resides in the northern regions and the Upper East Region has the highest prevalence of food insecurity of 49 percent (MOFA et al., 2020).

The average income level of the people is also very low. While the national average per capita income is $1441, the average in northern Ghana including the Upper East Region is less than US$341 (GSS, 2014, 2019a), making food expenditure consume close to about 66% of the entire annual income of the people (Zereyesus, Embaye, Tsiboe, & Amanor-Boadu, 2017).

Though, a reduction from 72% (WFP, 2012), this rate still indicates that the food security status of the people largely depend on market purchases. This poses a challenge to households who cannot afford to remain in acute malnutrition. Infant mortality for example, is much higher in the Upper East Region, where one in every nine children dies before attaining 5 years as a result of malnutrition (WFP, 2016).

As a strategy to de-link the livelihood of farm households from the unreliable rainfall agriculture, irrigation interventions have been identified as a key driver to food production in the dry season (Balana et al., 2020). Currently, the government's flagship programme to construct at least one dam in every village in northern Ghana is in line with the agriculture sector policy of the country to expand irrigation for agriculture production so as to spur economic growth, reduce poverty and food insecurity in the country and the northern regions in particular (Christiaensen, Demery, & Kuhl, 2011; MoSDI, 2020).

During the dry season, farmers in the Upper East Region rely on existing water bodies (dams, dugouts, rivers, streams, wells, boreholes etc) to cultivate vegetables to raise income to purchase food to supplement the food produced in the raining season, however, poverty and food insecurity is still high among households in the region due to low yield of the vegetables (Tsiboe et al., 2019; Van Asselt et al., 2018). Indeed, most dry season vegetable farm households in the region still wallow in abject poverty, because they are unable to generate enough income from the vegetable farms even though the farmers sometimes enjoy premium prices (IFPRI, 2020; Van Asselt et al., 2018).

Generally, the yield of irrigated vegetables in Ghana are the lowest compared to the neighbouring countries, though with similar climatic and soil characteristics. For example, while farmers in Niger achieve about 28.1Mt/ha of onions, their counterparts in Ghana only harvest under 11.0Mt/ha of onions (Van Asselt et al., 2018), when the country's potential exceeds 30Mt/ha (MoFA, 2017). Similarly, while Egypt and Niger achieve 17Mt/ha and 14Mt.ha of chilli, respectively, farmers in Ghana only obtain a maximum of only 7.3Mt/ha relative a potential of 30Mt/ha (MoFA, 2017). The yields of tomatoes in Burkina Faso and Niger are more than double the yields in Ghana. For instance, while 10mt/ha is the attainable yields in Burkina Faso (IFPRI, 2020), the Ghanaian farmers produce under 7.5mt/ha (IFPRI, 2020; Van Asselt et al., 2018) far below the 20mt/ha achievable yield (MoFA, 2017). The low yields in Ghana suggest that there is potential to increase the productivity and income of dry season vegetable farms if the challenges affecting farmers' production efficiency can be subdued and or eliminated (Tsiboe et al., 2019).

Inadequate production resources including improved seeds, extension services, credit, irrigation facilities among others account for low productivity of vegetable farms in Ghana (IFPRI, 2020). Farmers also lack yield-boosting techniques and the variety of some crops are usually self-bred, causing persistent decline in yield each cropping season (Van Asselt et al., 2018). The Council for Scientific and Industrial Research (CSIR) for some years now, has not also developed improved varieties for certain vegetables like tomatoes, onions and carrot (Van Asselt et al., 2018). In such instances, farmers mostly rely on recycled old unimproved varieties of vegetables for cultivation, a situation which results in inbreeding, diseases and pests' transmission, further worsening the poor yield levels. The local Bawku red onion variety still in use in the region, for instance, was introduced to farmers since 1930s (Sinnadurai & Abu, 1977).

Low productivity of vegetable adversely affects outputs and incomes of farmers with adverse consequences on households' food security (Drechsel & Keraita, 2014). The resources necessary to expand production and productivity are limited.(IFPRI, 2020). Already, water is scarce during the dry season because the irrigation infrastructure is not found everywhere and the public irrigation facilities are limited to certain communities. Majority of farmers rely on natural water bodies such as rivers, lakes, streams which cannot sustain water beyond certain period in the year for cultivation of crops (Namara et al., 2011)..

In spite of the above challenges, the entire country at some period within the year, particularly during the dry season relies, largely on the farmers from Northern Ghana particularly the Upper East Region to produce and supply vegetables like tomatoes, onions, pepper and garden eggs (Van Asselt et al., 2018). At such periods, low outputs of the farmers creates deficits supply and traders often had to import (FAO, 2019), mainly from the neighbouring countries such as Niger for onions, Burkina Faso for tomatoes, Mali for both onions and tomatoes among others (Van Asselt et al., 2018).

The rising population and changing diets preferences of middle-income consumers causes the increases in demand for vegetables in the cities and towns in Ghana (Balana et al., 2016). Unfortunately, at peak demand, dry season farmers in the Upper East Region are unable to take advantage to raise more income due to low yields on their farms (Van Asselt et al., 2018). In view of that, the importation of vegetable is increasing annually, although, sometimes unnoticed due to its passage through unapproved routes (IFPRI, 2020). For instance, between 2008 and 2013, over 4,000Tons of vegetables were imported into Ghana to make up for the deficit in domestic production (FAO, 2019).

Low productivity of the domestic vegetable farmers renders the average per unit cost of the vegetables very high, making farmers less competitive in terms of pricing relative to the imported vegetables (Van Asselt et al., 2018). Yet farm outputs have to be sold, even when prices are low to avoid losses, which does not allow the farmers to at least break even. Additionally, the marketability of the local produce at times tends to suffer low patronage and glut, owing to perceived short shelf-life (M. K. Osei, Danquah, Blay, Danquah, & Adu-Dapaah, 2018), compared to the imported produce like tomatoes from Burkina Faso, onions from Niger and Mali among others (Van Asselt et al., 2018).

Although the above development creates good business opportunities for some traders, mainly women, who make good profit from selling imported vegetables it is clearly a huge drain on the country's foreign exchange reserve (Van Asselt et al., 2018). Therefore, vegetable farmers in the region, often register low income for producing similar products, who then see farming as unattractive, causing them to only cope to survive, further reducing their outputs, widening the country's supply deficit and further increasing the importations of vegetables into the country. Owing to these challenges, dry season vegetable farming which is relied upon for income to smoothen food consumption during the lean season in the region is unable to do so due the low yields (Van Asselt et al., 2018).

Low yields of vegetable are largely attributable to extreme vulnerability to abiotic and biotic factors as well as deficiencies in public and private investments in productivity-boosting technologies (Raheem, Dayoub, Birech, & Nakiyemba, 2021). The agricultural productivity can be improved with efficient use of the existing resources and technology (Combary, 2017). Most recent researchers have placed emphasis on improving productivity of farms through technical efficiency in developing countries due to its potential to reduce poverty reduction and enhance food security (Khonje et al., 2022; Sibhatu, Arslan, & Zucchini, 2022; Villacis, Mayorga, & Mishra, 2022). Technical efficiency of farmers positively relates to food security as was found by Ajayi and Oluntumise (2018) and Oyetunde-Usman and Olagunju (2019) in Nigeria, Majumder, Bala, Arshad, Haque, and Hossain (2016) in Bangladesh and Dessale (2019) in Ethiopia. In Ghana, earlier studies on production efficiency revealed that technical inefficiency is the main determinant of low productivity with negative consequences food insecurity (Abdallah, 2016; Anang, Bäckman, & Rezitis, 2017; Tsiboe et al., 2019).

Literature including but not limited to Tsiboe et al. (2019), Boateng et al. (2022) and Abunyuwah, Yenibehit, and Ahiale (2019) have examined the technical efficiency of vegetable production in Ghana but their studies did not directly relate to household food security. Most studies relevant to Ghanaian agriculture which have examined the effect of production shortfalls due to technical inefficiency and food security focussed mainly on crops such as rice (Addison, Ohene-Yankyera, & Fredua-Antoh, 2016; Azumah, Donkoh, & Awuni, 2019; Donkoh et al., 2013; Kuwornu, Demi, & PK, 2013), maize (Abdallah, 2016; Martey, Kuwornu, & Adjebeng-Danquah, 2019; Wongnaa & Awunyo-Vitor, 2018) bambara groundnuts (Adzawla et al., 2015), cotton (Adzawla, Fuseini, & Donkoh, 2013), cocoa (Attipoe, Jianmin, Opoku-Kwanowaa, & Ohene-Sefa, 2020) for specific regions. Studies linking technical efficiency of vegetable production and food security in northern Ghana, particularly the Upper East Region, remains scanty (Amoah et al., 2014; Boateng et al., 2022).

Besides, no study has examined the effect of technical efficiency on the product of a whole farm involving multiple vegetable on households' food security in the Upper East Region, a region with the highest incidence of poverty and food insecurity in Ghana (MOFA et al., 2020). Again, recent research including Balana et al. (2019) and Balana et al. (2020) have determined the effect of irrigated vegetables income on household food security in Northern Ghana but their studies did not examine the efficiency of the farmers. Therefore, beyond determining the yields of vegetables, empirical evidence that provides insight into the technical efficiency and food security nexus is an important policy concern. This study seeks to fill this gap by examining the technical efficiency of dry season vegetable farmers and its implications on households' food security in the Upper East Region of Ghana.

1.2.1 Conceptual Framework of the Study

Drawing from available literature, the conceptual framework that indicates the schematic transmission pathway linking dry season vegetables production and households' food security is shown in Fig. 1.1 below. Enhancing the technical efficiency of the dry season vegetable farmers will increase productivity of the farms and income (cash earnings). According to Owusu, Abdulai, and Abdul-Rahman (2011), the major challenge affecting food security in most agriculture dependent households is not just food production but low income and poverty.

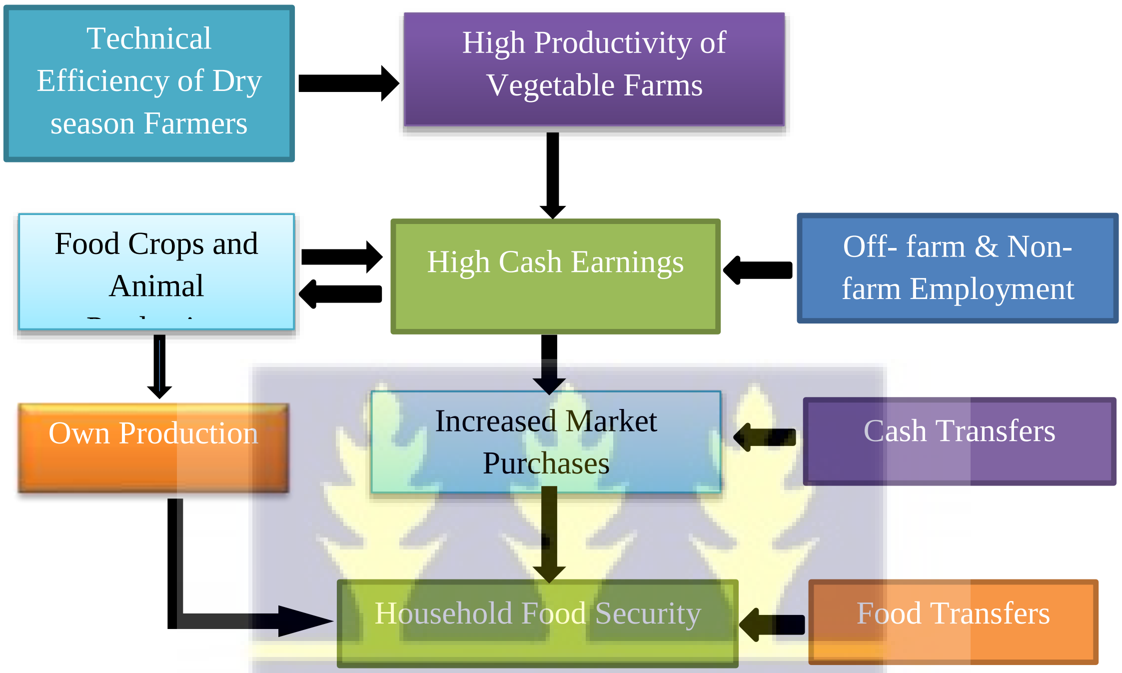

Fig 1. 1 Linkage between technical efficiency of dry-season vegetable farming and household food security

There are two pathways through which the income of dry season vegetable production can influence food security in farm households. That is the income effect via the market pathway and the food production effect via the own (subsistence) food production pathway. Market purchases have a great contribution to smallholder diets in SSA including Ghana (Frelat et al., 2016; Scott, 2017; Sibhatu, Krishna, & Qaim, 2015).

The income effect is achieved if both the food and the output markets are not interrupted at any stage. However, if the food and output markets are not completely functional, dry-season vegetable income would affect food security via the food (crops and animals) production effect. That is, if a vegetable farm household is not able to purchase food due to missing market as a result of transaction costs among other challenges, the household's ability to achieve food security would depend primarily on the ability to invest the vegetable income on producing households' own crops and rearing livestock. Off-farm and non-farm employment and transfers also play major roles in household food security purchases via the market channel.

Empirically, the food security of vegetable farm households is a function of own subsistence food production, market purchases and food transfers, given as:

$$HFS = f(own\ food\ production, martket\ purchases, food\ transfers) \quad (1.1)$$

The implication is that household can achieve food security through own food production (subsistence) farm, market purchases and or food transfers. In other words, cash income from dry season vegetable farming is very important given that it is a major surviving strategy where farm households to meet their food security needs via market purchases in the region. This makes cash income from dry-season vegetable production critical, although, cash income could also be obtained from other earnings including sales of food and livestock as well as income from non-farm employment and cash transfers.

In spite of this initiative to cultivate vegetables for income to support the households, food insecurity is still an annual recurrent problem in the region. Several studies (E. N. Acheampong et al., 2014; Owusu et al., 2011; Zereyesus et al., 2017) have documented empirical evidences on the challenges of food security due to low yields and incomes in northern Ghana. Low productivity limits the income dry season vegetable farming generates during dry season. Low vegetable income in turns, adversely affects the purchasing power of the farmers to acquire food.

To achieve the main objective of the study, the following research questions were asked: How technically efficient are dry season vegetable farmers in the production of vegetables like pepper, onions, tomatoes, and garden eggs in the Upper East Region of Ghana? What profit (income) margin do these farmers make from the vegetable farming in the region? To what extent are these farm households' food insecure? Does technical efficiency of farmers and profitability of dry season vegetable production affect farm households' food security status in the Upper East Region?

1.3 Main Objective

The main objective is to assess the technical efficiency of dry season vegetable farmers and its implications on household food security in the Upper East Region of Ghana. Specifically, the study seeks to:

i. Examine the technical efficiency with production of dry season vegetable farmers in the Upper East Region of Ghana.
ii. Estimate the gross profit (income) of the dry season vegetable farmers.
iii. Investigate the extent of food insecurity among dry season vegetable farm households in the Upper East Region of Ghana.
iv. Determine the effects of technical efficiency and profitability of dry-season vegetable production on the households' food security in the Upper East Region of Ghana.

1.4 Hypothesis of the Study

Generally, farming is resources driven activity but poverty has often been a challenge to policy makers and researchers wanting to improve the productivity of farmers in West Africa and Ghana is no exception (Dittoh, Bhattarai, & Akuriba, 2013; Ogundari, 2014). With limited resources especially for dry season farmers in the Upper East Region of Ghana, the most prudent option to improve output so as to increase income and food security is to enhance the technical efficiency of the farmers (Wongnaa & Awunyo-Vitor, 2018). Improving the productivity and efficiency directly improve food production by increasing supply of food and indirectly by increasing household income (Gallup, Radelet, & Warner, 1997; Villacis et al., 2022).

In the light of the above, the main hypothesis of the thesis is that enhancing the productivity of dry season vegetable farms through improving the technical efficiency of the farmers would improve their farm income, which would in turn, increase farm households' purchasing power and positively impact the food security needs of farm households since household income is a good predictor of food security (Aidoo, Mensah, & Tuffour, 2013; Haddad, Kennedy, & Sullivan, 1994; Iram & Butt, 2004; Sibhatu et al., 2022). Specifically, the study posits the following hypotheses:

1. H_O = Increasing the technical efficiency while reducing production risk improve dry season vegetable farms' productivity and the food security status of farm households.

   H_A = Increasing the technical efficiency while reducing production risk does not improve dry season vegetable farms' productivity and the food security status of farm households

2. H_O = Dry season vegetable farming is profitable in the Upper East Region.

   H_A = Dry season vegetable farming is not profitable in the Upper East Region

3. H_O = High level of food insecurity exists among dry season vegetable farm households in Upper East Region.

   H_A = High level of food insecurity does not exist among dry season vegetable farm households in Upper East Region.

4. H_0 = Increasing the technical efficiency and profitability of dry season vegetable farmers enhance the farmers households' food security.

H_A = Increasing the technical efficiency and profitability of dry season vegetable farmers do not enhance the farmers households' food security.

1.5 Justification for the Study

This research is important for Ghana and the Upper East Region in particular, due to the fact that income from dry season vegetable production is a major mitigating strategy for reducing poverty and food insecurity among vegetable farm households (Balana et al., 2019). However, the output of farmers has been characterised by stagnation and volatility for decades, affecting the income of farmers (Van Asselt et al., 2018). Therefore, assessing the technical efficiencies of the farmers and identifying yield-boosting factors would help find solutions to the low productivity, enhance outputs and generate income, which can be used to improve households' food security in the region.

Also, the Upper East Region has been the major source from which the entire country depends on for vegetables during the dry season. Therefore, low yields coupled population growth has led to short supply of vegetables like onions, tomatoes, pepper, etc, resulting in huge importation from neighbouring countries such as Niger, Mali and Burkina Faso (IFPRI, 2020). These importations could be avoided if the country can take advantage of the available idle labour force during the dry season in the Upper East Region of Ghana to cultivate vegetables to meet the increasing local market demand. This will save the country from depleting scarce foreign reserves that could be used for development. Improved income from dry season vegetable farms will also entice the youth to venture into farming and help reduce rural-urban drift especially to town and cities in Southern Ghana in search of non-existing jobs.

Favourable agronomic condition for vegetable cultivation coupled with its proximity to, and good bilateral relations with the European Union (EU) position Ghana at an advantage to benefit from vegetable export. However, the inability to address yield challenges and productivity related issues has waned the country and the Upper East Region's comparative advantages in vegetable cultivation and reduced export to the EU (Tsiboe et al., 2019). The low yield of dry season vegetables has also put the local farmers in a less competitive position in terms of prices, which is a disincentive for them to produce more vegetables. An investigation on the status of food security of farm households is highly relevant for most governments and people globally. Hence, a study such as this that focuses on livelihood strategy like vegetable cultivation helps to fight poverty. The outcome of the study will therefore enable households to secure nutritious food which will go a long to achieve the SDGs on zero hunger in the Upper East Region and Ghana as a whole.

Besides, the absence of a similar study in Ghana suggests that the findings will significantly fill the gap in literature as well as enhance the formulation of policies to strengthen and improve the productivity of vegetable in the study region and Ghana. Ultimately, the increased income from dry season vegetables would address the SDGs on no poverty and decrease food insecurity in Northern Ghana.

1.6 Organisation of the Study

This thesis is organised into five chapters. The first chapter is the introduction which begins with the background of the study, the problem statement and objectives, conceptual framework, hypothesis and organisation of the study. The second chapter presents a review of relevant literature. The third chapter comprises the theoretical framework underpinning the study, followed by data collection, sampling procedure, study area and methods of analysis. The fourth chapter presents the results together with the discussions. The last chapter comprises the summary, conclusion and recommendations based on the key findings of the study.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Overview of the Concept of Vegetable Production in Ghana

Historically, vegetable production and consumption in Africa and Ghana in particular dates back to an ancient practice spanning several decades ago. The Portuguese and European traders as well as the Christian missionaries were the people who introduced most of the vegetables into Gold Coast (now Ghana) in the 19th and 20th centuries (Norman, 2007). Since then, the production of vegetable in Ghana has grown and is currently one of the major sub-sectors that contributes to the growth of the country's economy (Drechsel & Keraita, 2014).

Ghana's vegetable industry can be classified into three distinct groups based on location and practices. The Urban/Peri Urban market gardening is a practice where vegetables are produced on land around major cities such as Kumasi, Accra, Takoradi, and Tamale etc (Obuobie et al., 2006). There is also truck farming where vegetables are cultivated in large quantities in the outskirts of towns/cities and are purchased by middlemen, mostly women (market Queen), and conveyed in trucks by road to the major urban towns and cities, a common practice during dry season in northern Ghana. Another class of vegetable farming is the small domestic/backyard gardening, a practise where vegetables are cultivated on a small portion of land which may be around households or within walking distance from the family home (Galhena, Freed, & Maredia, 2013).

The common vegetables usually cultivated in Ghana include local vegetables like tomatoes, sweet and chilli pepper, hot pepper, onions, okra, eggplant, local spinach as well as the exotic vegetables such as lettuce, cauliflower, cabbage, spring onions. Among these vegetables, tomatoes, onions, pepper, garden eggs and okra are the most predominantly cultivated especially in northern Ghana, in response to increasing demand for them in the cities and towns in the country (Drechsel & Keraita, 2014; C. Osei, Berchie, Ansah, Ankomah, & Gyasi-Boakye, 2003).

Vegetables are cultivated either under rain-fed or irrigation (dry season) systems. The rain-fed system is the normal cropping season, a practice that takes place country-wide, usually between May - October for most vegetables (Van Asselt et al., 2018). This makes vegetable supply during raining season high, saturating the market and resulting in low prices. However, during the dry season, the cultivation is limited to certain communities that have irrigation facilities resulting in high prices due to short supply, a situation that benefits vegetable farmers and disadvantage consumers. While commercial rainfed system of production is more prevalent in the southern regions, production during the dry season is common in the northern regions. The commercial cultivation of vegetables using irrigation in northern Ghana dates back to the 1960s, with the development of the irrigation schemes (Namara et al., 2011).

Ghana's irrigation system is broadly classified into public or conventional and emerging systems. The conventional systems are designed and developed by either the government or Non-Government Organisations (NGOs), majority of which are surface irrigations systems. The emerging system on the other hand, are mainly privately owned and mostly rely on diesel/petrol pump technology of irrigation even though other technologies such as drip and sprinkler systems are being introduced to farmers lately (Namara et al., 2011).

Currently, dry season smallholder vegetable farmers in the Upper East Region have adopted the petrol/diesel water pumping machine technology of irrigation with some few farmers using the drip and sprinkler technologies. A few other farmers still practice the gravity-fed and manual (employing watering cans, buckets and calabashes) irrigation technologies. The use of petrol water pumps by smallholder farmers for irrigating vegetable fields in Ghana is well documented (Laube, Schraven, & Awo, 2012; Namara, Hope, Sarpong, De Fraiture, & Owusu, 2014). Farmers mostly rely on water from open water bodies and shallow ground water sources such as lakes, rivers, streams, valley bottom shallow wells, dams and dugouts to irrigate their farms (Drechsel & Keraita, 2014; Laube et al., 2012; Namara et al., 2014).

The sizes of vegetable farms in Ghana are smaller, averaging less than 2 hectares due to the intensive nature of the practice coupled with water scarcity, especially during dry season in Northern Ghana. Other challenges such as lack of improved seed, diseases and pests attacks, lack of credit, fertilizer, agrochemical among others confront the vegetable sector in Ghana (IFPRI, 2020). Besides, the yields of dry season vegetables are low and are limited to certain period of the year, making the country a net importer for most vegetables (Van Asselt et al., 2018).

This notwithstanding, Ghana's vegetable industry has been one key sector that supports the growth and development of both rural and urban economies and by extension the entire country. Not until the prohibition of exports of vegetables from Ghana into the European Union (EU) markets in 2015 due to food safety or phytosanitary issues, the annual export value was worth over $15 million besides its direct employment to over 20,000 skilled Ghanaian labour force (CABI, 2019). Although, there is a strong growth prospects in the vegetable sector in most countries in SSA including Ghana, inadequate irrigation affects the productivity of the sector (Adeagbo & Adejumo, 2020; Joosten et al., 2015).

2.2 The Concept of Irrigation and its effects on the Productivity of Vegetables in SSA

Irrigation has become the best bet for the provision of food and income in developing economies (Domenech, 2013) including Ghana (Akrofi, Sarpong, Somuah, & Osei-Owusu, 2019; Okyere & Ahene-Codjoe, 2022). Currently, about 18% of global irrigated cropland feeds averagely 40% of the world's population, as such improving the present level of irrigation productivity will have great impact on future global food supply (FAO, 2012). Irrigation consumes approximately 70% of total global fresh water withdrawal (Steduto, Hsiao, Fereres, & Raes, 2012), making it a critical resource in drier regions globally (Dittoh et al., 2013). The competition for fresh water for agricultural, industrial and urban uses is much higher in arid and semi-arid regions in SSA given that only 7 million out of the over 40 million hectares of irrigable potential is actually utilised for agriculture (Chai et al., 2016). This affects vegetable cultivation in SSA compared to China and India which produce more than 60% of the world's vegetables (Joosten et al., 2015).

Improving the efficient utilization of irrigation water is the best way to enhance vegetable productivity in SSA (Al-Said, Ashfaq, Al-Barhi, Hanjra, & Khan, 2012; Maheshwari & Grewal, 2009; Patanè, Tringali, & Sortino, 2011). This will empower smallholder farmers to move their enterprises to marketed-oriented, commercial production stage (Mutabazi, Wiggins, & Mdoe, 2013). The system, however, must be accompanied by the development, dissemination and adoption of yield-boosting technologies to improve productivity (Wichelns, 2014). Bravo-Ureta, Higgins, and Arslan (2020) asserted that, providing irrigation infrastructure must be linked to adequate training to ensure growth in productivity. It is only when these important conditions are fulfilled that marketable surpluses can generate income to improve livelihood of beneficiaries (J. K. Mwangi & Crewett, 2019).

In many SSA countries, the push for the expansion of irrigation for rural income and food security is well-established in literature (De Fraiture & Giordano, 2014; Olayide, Tetteh, & Popoola, 2016; Playán & Mateos, 2006; Wichelns, 2014). The adoption of irrigation has proven to enhance the growth of high-value crops and improve the quality of lives of consumers (Burney & Naylor, 2012). Irrigation also stabilises yields and lower the risk of crop failure, thus motivates smallholder farmers to intensify their production systems by adopting technology-enhancing inputs. Additionally, irrigation increases the resilience of smallholder farmers to cope with climate shocks and permit the planning of production to respond to the prevailing market circumstances (Okyere & Ahene-Codjoe, 2022).

Improving the cultivation of vegetables through the provision of technology or yield-boosting inputs is as important as the efficient utilization of the inputs. As opined by Poudel, Johnson, Yamamoto, Gautam, and Mishra (2015), the growth and development in any agricultural system is much more dependent on how efficient the technology is applied in the system than the technology itself. This argument has been the basis for the growing interest of researchers on efficiency studies in SSA, many of them focussing on improving the technology for growing major food crops like rice, maize, sorghum (Chepng'etich, Nyamwaro, Bett, & Kizito, 2015; Mwalupaso, Wang, Rahman, Alavo, & Tian, 2019; Okello, Bonabana-Wabbi, & Mugonola, 2019) to the neglect of vegetable crops (Obuobie et al., 2006).

In Northern Ghana and the Upper East Region in particular, several interventions have been implemented and others are still being implemented to improve livelihoods. Currently, the government's flagship policy intervention dubbed "One-Village-One Dam" (1V1D) in Northern Ghana include the Upper East Region. The policy entails constructing at least one dam in every village throughout the region to provide reliable water, improved seed and extension services to improve agriculture production. Although this intervention is geared towards improving production, the efficiency with which the farmers utilise the resources is equally critical to improve farm productivity.

2.3. The Concept of Vegetables Productivity in the Upper East Region.

Achieving poverty reduction and food security are the among the overarching goals of the government of Ghana (MOFA, 2007). Recent researchers Birhanu, Tsehay, and Bimerew (2021); (Khonje et al., 2022) have given heavy emphasis on the growth of agricultural productivity as a means to increase output and income so as to achieve poverty reduction and food security (Wongnaa & Awunyo-Vitor, 2018; Wongnaa, Awunyo-Vitor, Mensah, & Adams, 2019). Productivity which refers to output per unit inputs (Wongnaa & Awunyo-Vitor, 2018), is achieved via economic (technical and allocative) efficiency (Chirwa, 2007; Farrell, 1957). The establishment of irrigation infrastructure by the government and private sector in northern Ghana are meant to enhance all-year round production to generate income, alleviate poverty and curb food insecurity but low yields and productivity hamper the achievement of these objectives (MoFA, 2017).

Several studies including but not limited to Birhanu et al. (2021), Gassner et al. (2019), and Mozumdar (2012) have illustrated the relationship between agricultural productivity growth and poverty and food security in developing countries. Agricultural productivity largely depends on the sort and quality of the inputs and how efficient these inputs are combined (Mechri, Lys, & Cachia, 2017). Whereas the type and quality of inputs represent technology enhancement, an efficient combination of the various production inputs improves technical efficiency of the farmers. Amfo and Baba Ali (2021) have examined the application of organic and inorganic fertilizer on different types of vegetables in Ghana to improve productivity but the results were mixed. This means productivity gains in agriculture can be achieved through a combination of technological change and efficient use of existing resources as opined by Anang et al. (2017) in their study on production and technical efficiency of irrigated and rain-fed rice in Northern Ghana.

Studies on the production efficiency of vegetable crops show that technical inefficiency is a major cause for low productivity, where farm and household-specific factors are the determinants (B. Asante et al., 2013; Boateng et al., 2022; Nanii, Isaac, & Evelyn, 2020). Most of these studies focus largely on estimating the efficiency with emphasis on physical quantities (Tsiboe et al., 2019). For instance, study by Ofosu, Van der Zaag, Van de Giesen, and Odai

(2010) conclude that adequate application of fertilizer is a major contributor to irrigation productivity in the Upper East Region. Also, study by Anang, Bäckman, and Sipiläinen (2016) on the productive efficiency of rice farmers in northern Ghana identified gender, years of formal education, farmers' association as the factors influencing rice productivity. The utilization of irrigated water also shifted the rice production frontier, implying that irrigation is a significant contributor to rice productivity. This study examines the productivity of a whole farm rather than a specific product as such adopts the monetary value (Akamin, Bidogeza, & Afari-Sefa, 2017; Habiyaremye et al., 2019) instead of using physical quantities of measurements (Tsiboe et al., 2019).

2.4 Barriers to Vegetables Productivity and Profitability in Ghana

Ghana like many other SSA countries suffers a lot of barriers in productivity and profitability of vegetable production. For instance, inadequate water sources, changing climatic condition, high cost of water pumping machines, pests and diseases attack, high cost of equipment, lack of credit, lack of storage facilities and high cost of inputs have been identified as major factors affecting dry season's vegetables cultivation in SSA (Alam, Idoko, Dauna, Yengo, & Iko, 2015; Osabohien et al., 2020).

According to Tsiboe et al. (2019), certain compelling barriers limiting the productivity growth of vegetables in Ghana are the reasons for the importation of vegetables into the Ghanaian market. also a study by Lawrence Guodaar and Asante (2018) on climatic adaptation affecting smallholder tomato production in Offinso North District identified barriers such as personal, institutional labour, irrigation technology, credit access, farm inputs, cost of land among other limiting tomato production in Ghana. Similarly the erratic rainfall pattern and high temperatures coupled with adaptive barriers (including financial constraints, pests and diseases) are some of the factors affecting vegetable production in Ghana (B. Asante et al., 2013; L Guodaar, Asante, & Eshun, 2017). Similar challenges were identified by Bediako, Abatania, and Bapule (2005) and Drechsel and Keraita (2014). These challenges affect yields (Van Asselt et al., 2018) and drive up importation which is estimated above 4000MT per annum in Ghana (Tsiboe et al., 2019).

The farm profitability is achieved when the challenges affecting the marketability of vegetables farmers are effectively addressed. For instance, literature suggests that most Ghanaian smallholder vegetable farmers like many others in Sub-Saharan Africa lack the capacity to participate in bigger markets to raise agricultural income due to marketing barriers (J. K. Mwangi & Crewett, 2019). This is because, issues such as supply chain complexity, food safety standards, the power of super-markets, the need for facility upgrades and procurement practices have often squeezed smallholders out of bigger markets, despite their advantages of lower costs due to their access to family labour. Also, inadequate transport infrastructure, poor storage facilities and lack of refrigeration capacity in tropical environment are also blamed on the growth of pathogens with adverse consequences on food safety, quality and marketability (Aworh, 2020).

A study by Kader (2009) reveals the unreliability of power supply, inefficient utilization of cold store and lack of proper maintenance and refrigerated transport facilities are among the reasons for the failure to preserve perishables horticultural crops. Other infrastructural barriers are caused by inefficiencies in irrigation schemes. Dilapidated water supply systems, poor construction quality and lack of resources to maintain infrastructure adversely affect the productivity and marketability of vegetable farmers (De Fraiture & Giordano, 2014). Improving these challenges will make the sector increase productivity, improve output which will go a long way to increase incomes and profits as well as achieve food security of farm households.

2.5 Theoretical Background of Production Efficiency

Agricultural productivity is an index of the total value of farm output to total value of farm inputs in an agricultural enterprise (Tabe-Ojong Jr & Molua, 2017). Production efficiency analysis is a key area in production economics. The theoretical framework of most empirical research on efficiency are based on microeconomics theory of production (Coelli, Rao, O'Donnell, & Battese, 2005)

Production efficiency consists of three components: technical efficiency, allocative efficiency and scale efficiency (Coelli, Rahman, & Thirtle, 2002). Farrell (1957) distinguished a firm’s production efficiency into technical efficiency and allocative (price) efficiency. Benedetti, Branca, and Zucaro (2019) defined technical efficiency (TE) as the ratio of actual output to maximum output (or the ratio of minimum input to actual output). TE can be analysed based on two approaches: an output-oriented approach and an input-oriented approach. An output-oriented approach is when the goal of the firm is to achieve maximum output from a given bundle of inputs while an input-oriented approach is when the firm’s goal is to apply the minimum feasible level of inputs to achieve a given level of output (Tegegne, Tadesse, & Zemedu, 2014) .

Allocative or price efficiency is the ability of a farm unit to apply inputs in optimal quantities at given prices within a given production technology, with the goal to minimise cost (Kumbhakar, Biswas, & Bailey, 1989). On the other hand, scale efficiency is when a farmer produces at a certain level of output where the product price is equal to the marginal cost. An economic efficiency (also termed production efficiency) is the combination of technical and allocative efficiency (Coelli et al., 2002).

The study adopts the production theory to explain the decision-making process of dry season farmers’ and how vegetable outputs are generated by a given set of inputs. The theory guiding the efficiency of a farmer explains the technical relationship regarding the limit of output achievable from the combination of inputs, otherwise termed production function. A farmer in a production process is expected to convert a certain level of inputs into outputs or obtain a certain level of outputs by employing a certain level of inputs to reach a certain production frontier. Failure to reach that frontier could be due to two things: inefficiency and idiosyncratic error. Wrongful combination of inputs and entrepreneur wastefulness indicate that the farmer is inefficient.

2.5.1 Technical Efficiency in Agriculture Analysis in Developing Countries

The initial work by Farrell (1957) formed the foundation for other approaches for analysing productivity and efficiency. The Data Envelopment Approach (DEA) and Stochastic Frontier Approach (SFA) are two common approaches used by researchers lately (Chavas, 2001). The SFA method evolved after the ground-breaking research by Aigner, Lovell, and Schmidt (1977) and Meeusen and van Den Broeck (1977) and has two estimation approaches (Bravo-Ureta & Pinheiro, 1993). The first approach is the stochastic corrected ordinary least square (COLS) which is employed when there is no clearly specified distribution of the efficiency component. On the other hand, the Maximum Likelihood Estimation (MLE) technique is applied if the distribution is clearly specified. The COLS is less efficient than the MLE because the COLS does not use specific distribution of the error term (Greene, 2012.). The stochastic frontier and the inefficiency model can be jointly estimated using computing packages such as FRONTIER, STATA, LIMDEP which apply MLE (Greene, 2002; Pan & Fang, 2002).

Table 2.1 indicates some empirical agriculture studies that employed the DEA and SFA in developing countries. The DEA employs linear programming methodology which is simple and easy to understand (Kalirajan & Shand, 1999) and involved multiple outputs (Djoumessi, Afari-Sefa, Kamdem, & Bidogeza, 2018). It also gives detailed analysis of results and does not

Table 2. 1 Empirical Literature on Technical Efficiency studies in Agriculture

Product	Approach	Type of data	Mean TE (%)	Min.TE	Max.TE	Location	Author (s)/year
Maize	SFA	Cross-sectional	85	18	97	China	(Hong, Heerink, Zhao, & van der Werf, 2019)
Onion	SFA	Cross-sectional	73.69	76.80	82.6	Ethiopia	(Tegegne et al., 2014)
Oil-palm	SFA	Cross-sectional	83	74	na.	Indonesia	(Alwarritzi, Nanseki, & Chomei, 2015)
Apple	SFA	Panel	86.8	74.5	93.8	China	(Bai et al., 2019)
Vegetable	SFA	Cross-sectional	66.9	0	94.7	Cameroon	(Akamin et al., 2017)
Pineapple	SFA	Cross-sectional	60.3	10	99.4	Nigeria	(Balogun, Adewuyi, Disu, Afodu, & Ayo-Bello, 2018)
Maize	SFA	Cross-sectional	65	49	82	Zimbabwe	(Mango, Makate, Hanyani-Mlambo, Siziba, & Lundy, 2015)
Tomato	SFA	Cross-sectional	75.2	29	89	Ethiopia	(Weldegiorgis, Mezgebo, Gebremariam, & Kahsay, 2018)
Tomato	DEA	Cross-sectional	42.3	42.3	54.8	Nigeria	(Ogunniyi & Oladejo, 2011)
Vegetable	DEA	Cross-sectional	89	12.4	100	Cameroon	(Djoumessi et al., 2018)
Maize	DEA&SFA	Cross-sectional	75	59.5	77.2	Zimbabwe	(Etienne, Ferrara, & Mugabe, 2019)
Cocoa	DEA	Cross-sectional	82	35.4	94.3	Indonesia	(Pratama, Rauf, Antara, & Basir-Cyio, 2019)
Vegetable/ Poultry	SFA	Cross-sectional	44	03	95	Tanzania	(Habiyaremye et al., 2019)
Rice	DEA	Cross-sectional	80.9	60.7	100	Vietnam	(Lee, Peng, & Chung, 2019)
Vegetable	SFA	Time series	< 98	>75.0	99	China	(Xu, Zhang, & Zhang, 2018)
Pepper	SFA	Cross-sectional	65.76	18.62	92.1	Ghana	(Asravor, Onumah, & Osei-Asare, 2016)
Vegetable	SFA	Cross-sectional	24	2	85	Ghana	(Amoah et al., 2014)
Vegetable	SFA	Cross-sectional	66.7	22	95	Ghana	(Abdulai, Fialor, Bakang, & Jumpah, 2018)

Author’s Literature Review, (2020)

require unnecessary restrictions and the use of specific functional form which could affect the estimates and distort findings (Fraser & Cordina, 1999). However, it is only a deterministic approach, as such, attributes all deviations from the frontier to inefficiencies.

The Maximum Likelihood Estimate (MLE) decomposes the error term into two components (Aigner et al., 1977). The two-sided random error captures the effects outside the control of the farmer and the one-sided random inefficiency error term controls the idiosyncratic effects. The random error captures the variations attributed to the farm such as weather, inputs quality, luck, measurement errors, and omitted variables. The inefficiency component on the other hand, captures farm specific factors such as the skills of management, and other bottlenecks and disruptions.

2.5.2 Production Risks in Technical Efficiency studies in Developing Countries

Risk according to Knight (1921) is a “case where the distribution of outcomes is known either a prori or statistically through experience whereas uncertainty is the case where probabilities cannot be quantified”. de Mey et al. (2016) classified risks into five namely: Production risk, market risk, institutional risk, personal risk and financial risk

The perception of risks often shapes agriculture in developing countries. A common conclusion from research on agriculture production in developing countries is that smallholder farmers often obtain low yields from their farms because they do not usually apply the right level of inputs on their farms. Similarly, some farmers also fail or partially adopt new technologies even though these technologies could enhance their marginal revenues for labour and land than the existing technologies result from the risks associated with adopting one technology over another. One possible reason for this reluctance is the perceived risk profile associated with the adoption of one technology or the other (Feder & Umali, 1993; M. Mwangi & Kariuki, 2015). For example, an input that could increase expected return but increase risk is fertilizer (Duflo, Kremer, & Robinson, 2008).

High cost, lack of capital or credit could possibly be the reasons for the low adoption of some technologies in developing countries than elsewhere (M. Mwangi & Kariuki, 2015). But even when a technology is made free or less expensive in the case of fertilizer in some developing countries, some farmers do not still use it as expected due to perceived risks. Farmers do not trust that, they have adequate training, as such, they tend not to use the technology at the level expected.

In view of the above, the adoption of some technologies or the use of inputs like fertilizer, agrochemicals etc could increase expected output but also increase risk. For instance, the Ghanaian government has implemented fertilizer subsidy since 2008 as part of the strategy to increase the production of food and to spur economic growth (Banful, 2009) but the level of fertilizer usage still remains low as compared to elsewhere because of the perceived risk outcome (Feder & Umali, 1993; Guttormsen & Roll, 2014; Hardaker, Huirne, Anderson, & Lien, 2004). Most studies dealing with risk in agriculture production employ the model by Just and Pope (1978).

2.5.2 Theory of Production Risk in Technical Efficiency

Most technical efficiency studies adopt the conventional SFA model proposed by Aigner et al. (1977) and Meeusen and van Den Broeck (1977) which decomposes the error term into the random and the inefficiency effects. However, incorporating only these two random effects into the efficiency production analysis are loudly criticised because it does not adequately capture all the random noises in the stochastic model.

Just and Pope (1978) then argued that a stochastic production function should reflect all potential production risks components since it is possible for all input levels to have positive, zero and negative marginal risk in a production process. In other words, inputs can increase or reduce the level of output risk. This contrasts with the commonly used translog production function that restricts output risk to increases.

One main characteristic of agricultural production processes is that, random production shocks are only observed after input decisions are made. Therefore, input levels influence both the expected level of output and the level of output risk. Although it is often expected that, all inputs would increase output, some inputs may reduce the level of output risk, whereas others may increase it (Bai et al., 2019; Kara, Shamsudin, Mohamed, Latiff, & Seng, 2019)

To accommodate production risks in technical efficiency analysis, Just and Pope proposed a general production function given as:

$$y = f(x;\beta) + \varepsilon = f(x;\beta) + g(z;\theta)\varepsilon \qquad (2.1)$$

Where: $f(x;\beta)$ is mean production function, $g(x;\theta)$ is production risk function, the x and z are vectors of inputs with parameter $(\beta \text{ and } \theta)$. The exogenous stochastic production shocks are represented by ε where $E(\varepsilon) = 0$, and $var(\varepsilon) = \sigma_\varepsilon^2$. One key characteristic of the Pope and Just model is that it is able to separate the mean and the variance effects changes in inputs level.

2.5.3 Empirical Literature on Production Risk in Agriculture

Technical efficiency which incorporates production risk is gaining popularity in agriculture analysis globally (Kostyuchenko, Gracheva, Telnova, Tenishchev, & Cheremnykh, 2022; Sarker, Rolfe, & Ananda, 2022; Tenaye, 2020). One of the objectives of this study assesses how dry season vegetable farmers use inputs to increase the productivity of farms. The study extends further to determine how to reduce yield variability of farmers.

Table 2. 2 Empirical Literature on Technical Efficiency with Production risk in Agriculture

Product	Approach	Data type	MTE	Min.TE	Max.TE	Location	Author (s)	Variables' explanations
Maize	SFA	Cross-sectional	48	5	95	Ethiopia	(Lemessa, Yismawu, Daksa, & Watabaji, 2017)	**Inefficiency effects:** Age, family size, education, sex, credit access, nearness to market, nearness to fertilizer dealer, extension contact, plot size, terrace and soil bund negatively influence maize farmers technical inefficiency. **Risk effect:** fertilizer, chemical application and ox plough reduce output variability (reduce production risk).
Organic/ conventional	SFA	Panel	92.8/ 93.5	na	na	Germany	(Tiedemann & Latacz-Lohmann, 2013)	**Inefficiency effects**: Land size, training, farm specialisation negatively influence technical inefficiency. **Risk effects**: labour is risk-increasing on organic farm, seed is risk-reducing in both farms, and farm diversification reduces risk on organic farm.
Fish	SFA	Cross-sectional	74	71	80	Ghana	(Onumah, Onumah, & Onumah, 2018)	**Inefficiency effects:** Experience, age^2, sex, fish farming education, pond size (proxy for farm size) negatively affect farm inefficiency. **risk effect**: hired labour, family labour and other cost are risk reducing inputs
Rice	SFA	Cross-sectional	82	48	95.5	Taiwan	(Weinberger & Lumpkin, 2007)	Land size and family negatively affect the technical inefficiency of rice farmers. **Risk effect:** hired labour and fertilizer are risk-decreasing while pesticides and machinery and fertilizer are risk-increasing
Peanuts	SFA	Cross-sectional	92	77	92	Bulgaria	(Ligeon, Jolly, Bencheva, Delikostadinov, & Puppala, 2013)	**Inefficiency effect:** age, gender had negative effect on technical inefficiency. **Risk effect:** seed was risk increasing factor.
Fish	SFA	Cross-sectional	79.2	46.9	96.9	Nigeria	(Ogundari & Akinbogun, 2010)	**Inefficiency effects:** labour, education, experience, market negatively affect technical inefficiency. **Risk effect:** fertilizer and feed are risk increasing while labour is a risk decreasing input.
Maize	SFA	Cross-sectional	62	8	99	Ghana	(Oppong, Onumah, & Asuming-Brempong, 2016)	**Inefficiency effect:** land size farm location, ploughing had negative effect on technical inefficiency. **Risk effects**: seed and labour are risk decreasing inputs while land and intermediate inputs cost is risk increasing.

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Production risk measures the output variance and specifies inputs to either be risk-decreasing risk neutral, or risk-increasing (Kumbhakar, 2002). The approach investigates the correlation between mean production and production risk on one hand and individual and socio-economic characteristics on the other (Just & Pope, 1978). Chang and Wen (2011) examined off-farm technical efficiency and production risks in Taiwan and concluded that farmers with off-farm faces high risks than their counterparts without off-farm work. Also, Onumah et al. (2018) study on the effects of production risks on fish farms in Ghana concluded that feed and other costs are risk increasing whiles hired labour, family labour and fingerlings are risks decreasing inputs.

The hurdle when employing the Just and Pope's model to examine production is to first test whether any significant production risk is present in the data (Just & Pope, 1978). Given that the study specifies production risk as being heteroskedastic in the Just and Pope's framework, then it goes further to adopt any relevant test to ascertain the presence of heteroskedasticity. Failure to detect the presence of heteroskedascity is a proof against that production risk exist and the researcher proceeds to adopt the conventional deterministic framework (Guttormsen & Roll, 2014). Table 2.2 indicates empirical literature that incorporated production risk into stochastic frontier analysis to investigate agriculture production in developed and developing countries including Ghana.

2.6 Cash Cropping and Food Security Nexus in Developing Countries.

One major ongoing topic in food policy discourse has been the role of cash crops for ensuring sustainable food security in developing countries (Anderman, Remans, Wood, DeRosa, & DeFries, 2014; Anderson, 2002; Govereh & Jayne, 2003; Longhurst, 1988). Cash cropping can contribute to poverty and food security in many different ways. Cash crop production builds households' resilience against food insecurity via market purchases (Frelat et al., 2016;

Muthini, Nzuma, & Qaim, 2020; Sibhatu et al., 2015). For instance, specialising in a particular crop production increases the income of farmers and households, which can be used to purchase food and non-food consumption goods thereby achieving households' welfare (Assefa Wendimu, Henningsen, & Gibbon, 2015; Theriault & Tschirley, 2014).

In addition, the production of food cash crops like vegetable is labour demanding as such, benefits non-cash producers through employment and enhances the utilization of inputs for the production of other crops. The income from cash crops also provides opportunities for farmers to improve upon the management of other farms, through innovations, increase in yield and market access (Govereh & Jayne, 2003; von Maltitz, Gasparatos, Fabricius, Morris, & Willis, 2016).

This notwithstanding, cash cropping may not necessarily enhance household welfare, especially when the food system of the household is linked to consumption habits, the frequency and amount of household's income, spousal control over resources, local market and vulnerability to changes in food prices (Von Braun, 1995). In addition, specialising in cash crop production exposes one to more risk-related to production, markets and prices than those who diversify the choice of crops (Birhanu et al., 2021).

Therefore, rather than specialising in a single crop which increases the risk exposure of the farmers, diversification spreads the risk portfolios thus, smoothens household consumption (Birhanu et al., 2021). As pointed out by Manjunatha, Anik, Speelman, and Nuppenau (2013), diversifying in crop production improves soil fertility and consumption of diversified food. This, Muthini et al. (2020) argued does not necessarily result in increased consumption of diversified and nutritious food since much of the food consumed by households are market purchases which can be obtained by increased income from specialising in one crop.

The debate on the contribution of cash crop production to food security has been inconclusive in literature. For instance, the findings of Belsky and Siebert (2003) conclude that the cultivation of cacao in Central Sukawesi region of Indonesia adversely affected the long-term agricultural productivity, sustainability and livelihood security including food self-sufficiency. Mintz-Habib (2013) also obtained similar negative correlation between Jatropha productions, income and food security in Sarawak in Malaysia.

On the contrary, Kuma, Dereje, Hirvonen, and Minten (2019) in Ethiopia found that coffee income relaxes seasonal liquidity challenges and reduces household food insecurity. Additionally, there were other studies that concluded similar positive correlation between castor oil and food availability in Ethiopia (Negash & Swinnen, 2013), peanuts cultivation and diet diversity in Mali (Pierre-Louis, Sanjur, Nesheim, Bowman, & Mohammed, 2007) rice production in Gambia, maize production in Zambia as well as potatoes cultivation in Rwanda (Von Braun, 1995).

Other empirical studies linking cash crop production and food security produced mixed outcomes. For example, Lam, Boafo, Degefa, Gasparatos, and Saito (2017) study the effect of industrial crop expansion and food security outcomes on cotton production in Northern Ghana and sugarcane production in Central Ethiopia revealed a mixed outcome. Kanyamurwa, Wamala, Baryamutuma, Kabwama, and Loewenson (2013), also found mixed outcome among women farmers engaged in coffee production in Uganda. While women who engaged in coffee production had more income to cater for household needs including food and health care, the same study revealed that increasing poor diet quality led some households to sell their assets to purchase food. On the basis of the above findings, whether vegetable cultivation in the Upper East Region has any positive implication on households' food security remains thin hence the need for this investigation.

2.7 Effects of Vegetable Production on Income and Food Security in Ghana

Dry season vegetable production in the Upper East Region has attracted the attention of many farmers lately due to its importance as a major source for income and foreign exchange earnings for households and by extension the governments of Ghana (Amfo & Baba Ali, 2021; Amoah et al., 2014). The production of vegetable is more beneficial to farmers than the traditional staple crops in terms of employment, cash income and food security opportunities (Muriithi & Matz, 2015; Rai et al., 2019). Several empirical studies (Gebru, Leung, Rammelt, Zoomers, & van Westen, 2019; Hunde, 2017; Huong, Everaarts, Neeteson, & Struik, 2013; Joosten et al., 2015) have documented the positive effect of vegetable business on income and food security in many countries.

The production of vegetable encourages export, develops the rural labour market and improves wage earnings. The multiplier effect via the marketability and profitability of high value crops like vegetable improves income and the livelihood of farmers (Gebru et al., 2019; Joosten et al., 2015; Rai et al., 2019). Furthermore, the intensive demand for labour for vegetable production and processing industries contributes to high employment (Hunde, 2017). A research by McCulloch and Ota (2002) revealed that the income of smallholder vegetable farmers is four times higher than non-vegetable smallholder farmers in Naroibi, Kenya. Their study further concluded that poverty rates of workers, mostly women, employed in the vegetable sector was less than workers employed in the non-vegetable sectors.

In terms of consumption, vegetables helps countries to have healthier population, who would work to contribute to the growth and development of the economy. Fan, Dang, Tong, and Li (2019) state that the consumption of vegetable by people of different age groups including children, women, the working class and the aged led to a significant reduction in the health budget in China. Vegetables are rich in biochemical, phytochemical compounds, fibre and antioxidants such as vitamin A, C and E, which are important in neutralising free radicals, known to cause a wide range of non-communicable diseases such as diabetes, ischaemic cardiovascular diseases, cerebrovascular diseases, lung and gastrointestinal cancers, and hypertension, stroke, and cataracts among others. Non-communicable diseases account for about 63% of deaths globally (Mishra, Neupane, Shakya, Adhikari, & Kallestrup, 2015). Thus, vegetables are major source of preventive health care system, particularly among elderly people (Nicklett & Kadell, 2013; Ridberg et al., 2019).

Studies have also established that diets deficient in vegetables are known causes of "hidden hunger", a disease conditions that results from deficiency in micronutrients such as iron, zinc and vitamins (Afari-Sefa, Tenkouano, Ojiewo, Keatinge, & Hughes, 2012; Wang et al., 2014). Hidden hunger leads to deleterious long term health consequences including stunted growth, delayed cognitive development, reduced immunity and high mortality among women and children less than 5 years (Keatinge et al., 2011). Children who are deficient in Vitamin A are at risk of childhood diseases and maternal mortality in SSA including Ghana (Afari-Sefa et al., 2012; Keatinge et al., 2011).

Given the health benefits of vegetables to the body, the World Health Organisation (WHO) recommends the consumption of averagely 400g of fruits and vegetable per person per day to avoid micronutrient deficiencies, minimise diseases and ensure healthy living (FAO, 2015; Mason-D'Croz et al., 2019; Ruel, Minot, & Smith, 2005). Unfortunately, less than a third of the 43 countries in sub-Saharan countries consume the recommended quantity of vegetable due to poverty (Mason-D'Croz et al., 2019). Averagely, Ghanaians consume about 73g of fruits and vegetables per day, far below the WHO's recommended quantity (Joosten et al., 2015). High level of poverty particularly in rural areas is the main cause of low consumption of vegetables in poor countries (Keatinge et al., 2011). To meet the increasing demand for vegetable in Ghana, there is the need to increase the production output (Keraita & Drechsel, 2015)

In Ghana, vegetables are eaten by nearly all households in both rural and urban communities. Van Asselt et al. (2018), reported that vegetable purchases consume about 12.8% of the annual budget expenditure of Ghanaians. Hence, it's production is a main source of income, increases access to food and has the potential to improve the socio-economic status of majority of people both in rural and urban communities across the country (Amoah et al., 2014).

Yields of vegetable have however, remained low due to a myriad of challenges including abiotic (erratic rainfall, poor soils, etc) and biotic (arthropod pests, fungal, bacterial and viral diseases) factors (Joosten et al., 2015; Van Asselt et al., 2018). But the incessant overreliance and indiscriminate use of agrochemical products to control diseases and pests in vegetable cultivation in Ghana have cost implications for farmers as well as poses health risk to both growers and consumers alike, besides its consequences on the environment.

2.8 The Evolution of Food Security Concepts

The 'Hot Springs Conference' of the Food and Agriculture Organisation (FAO) of the UN in 1943 was when the concept of food security was first raised as a global issue. Then, food security was not only a need but a human right concern, following the Universal Declaration on Human Rights in 1948 (UN, 1949).

Following the Hot Springs Conference, some bilateral agencies spearheaded by the United States of America (USA) and Canada were established in the 1950s with the objective to channel agricultural surpluses of donor nations globally to food insecure countries, particularly those seriously affected by the global Wars (World War I and II). By the 1960s, there was a growing concern that food aid was actually demotivating countries' efforts to achieve food self-sufficiency. The concept of Food for Development was then institutionalised as the World Food Programme (WFP) in 1963. However, the food crises in 1972 - 1974 brought the era of food surplus of countries to an end. The fluctuating food supplies began to cause price hikes beyond the reach of certain group of people. And to mitigate that challenge, insurance schemes were developed and introduced to counter fluctuations in food supplies and guarantee food access, enhance coordination and monitoring among donor organisations and receiving countries (Napoli, 2011).

The concept of food security began to attract the attention of the global community soon after the world food crises of the 1970s, which then culminated in the 1974 World Food Conference. The goal of the conference was to ensure global "food supply and stability" because price hikes were threat to political stability of countries affected by food supply deficit. The main phrase for the definition of food security then, was " availability at all times to adequate supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices" (UN, 1975).

Following the Green Revolution in the 1960s, there was dramatic increase in global food production, but in the 1980s, famine and hunger were still witnessed among vulnerable groups across developing countries due to lack of purchasing power (Dasgupta, 1977; Napoli, 2011). This prompted stakeholders against world food crises to consider both the "economic and physical dimensions" of food security. The publication on 'hunger and poverty' by the World Bank in 1986 also drew the attention of the international community to look at the poverty aspect of food security. Also, the thesis title by Sen (1981) on poverty, famine and entitlement stated: "starvation is the characteristic of some people not having enough food to eat. It is not the characteristic of there not enough food to eat" reinforced the shift in thinking from the 1974 World Food Summit which stressed on "availability and stability of food at all times" to "adequate physical and economic access and stability to basic food supplies at all times" in the definition of the 1983 World Food Summit. Then, the concept of food security had three dimensions: to ensure production of adequate food supplies; maximizing stability in the flow of food supplies; and securing access to available supplies on the part of those who need them" (FAO, 1983).

Additionally, concerns whether the food consumed was efficiently utilized also shaped the aspect of "food quality" in the policy discourse in the 1996 world food summit. Utilization as a concept of food security reflects the nutritional quality and ability of individual body to absorb and metabolize food. The recognition of food preferences was later added to the definition to take care of the traditional and social acceptability of food type (Napoli, 2011).

The next food policy concern was on the distribution of food which emerged as a challenge not only at the national level but the household level as well. Additionally, improving global micronutrients deficiency such as iron, vitamin A and iodine was also identified as an important step towards minimising the threat to food security in the mid-1990s.

In sum, the various world food summits: spanning from hot springs conference in 1943 to the food availability (UN, 1975), to physical and economic access (FAO, 1983), to utilization (FAO, 1996) and stability at all dimension (FAO, 2009) crystallised into the globally accepted definition of food security as "when all people at all times have physical, economic and social access to safe nutritious food that meet their dietary needs and food preferences for healthy and active life" (FAO, 1996). This definition is multidimensional in concepts, where the absence of one or more of the dimensions at any level (global, regional, national, community, household and individual level) indicates food insecurity situation that demands attention at that level (FAO, 1996; Masset, 2011).

2.9 The Situation of Global Food Insecurity

Despite dramatic increases in per capita food production over the last half-century, chronic food insecurity, hunger and malnutrition persist in many parts of the world (FAO et al., 2020). Current statistics show that about 678.8 million people are food insecure, an increase of 10 million in just one year. In addition, malnutrition affect about 144 million children under five years, 47 million are wasted and over 38 million are overweight globally (FAO et al., 2020). While the population of malnourished in the developed world does not exceed 1.5%, Africa, Asia and Latin America have between 6% - 27% malnourished people (WHES, 2018).

The situation is projected to become worse, as the world's population currently at 7.2 billion would be reaching 9.6 billion by 2050. Agriculture is therefore under pressure to produce enough to feed an additional threshold of people even under persistent threat of changing climatic condition, affecting crops yield, particularly in less developed regions (Samir & Lutz, 2017). The corona virus diseases in 2019 (Covid-19) pandemic is also projected to further deteriorate the nutritional condition of more vulnerable people in developing countries globally (FAO et al., 2020).

2.9.1 The Concept of Food Insecurity in SSA

Poverty is the main determining factor of food insecurity in developing countries. Averagely, 43% of the population in SSA live below the $1.90 poverty line per day (The World Bank Group, 2016). And nearly one in every four people in sub-Saharan Africa suffer from severe food insecurity due to poverty (Conceição, Levine, Lipton, & Warren-Rodríguez, 2016; WHES, 2018). Food insecurity affects largely the marginalised rural folks including women and children less than 5 years of age (FAO et al., 2020). Food insecurity is the leading cause of underweight children with serious negative health implications in terms of the physical, social, economic growth and development (Black, Morris, & Bryce, 2003).

The rise in global temperature and inconsistent precipitations have largely affected agriculture production, particularly in sub-Saharan Africa (SSA) unlike other regions (Parajuli, Thoma, & Matlock, 2018). Unfortunately, majority of farmers in SSA who are mainly smallholder farmers' lack yield-boosting techniques such as greenhouse and irrigation technologies to overcome the challenges of climate change in order to improve agricultural productivity. Besides, varieties of crops which are usually self-bred by the continent's subsistent farmers have weak genetic diversity and resilience to withstand unfavourable weather condition compared to the industrialised crops which are purposely bred to contain such conditions (Amikuzuno & Hathie, 2013).

Additionally, the rising population, conflict, low agricultural productivity that characterise Africa's development also create food insecurity challenges (WHES, 2018). Currently, while the overall undernourished population worldwide is decreasing, the number in Africa, on the other hand, points to increasing trend from 196.5 million in 2004 to 239.6 million in 2019 (FAO et al., 2020). The vulnerable groups of people especially 21.3% of children under five years suffer from stunted growth, 5.6 million are underweight whiles 6.9% are malnourished due to lack of nutritious food and high incidence of diseases (FAO et al., 2020).

Food insecurity can cause conflict and threaten world peace, as happened in some countries in the past. The world food crisis of 1972-74, 2007/2008 and the most recent food price shocks of 2010/2011, for instance spontaneously sparked riots across countries largely from Africa. These disturbances occurred largely in urban towns in the West Africa sub-region than any other region in the world due to the continent's inability to produce the needed quantity of food to meet demand. The outcome did not only influence the political decisions of those countries but led to the overthrow of some governments like in Madagascar (Nyantakyi-Frimpong, 2014).

2.9.2 The Concept of Food Insecurity in Ghana

While some countries in Africa suffered instability due to food crises in the recent past, Ghana was spared this food-related violence due to relatively stable performance in the agriculture sector. Since the 1990s to date, Ghana has made progress in per capita food production resulting in a decline in average food insecurity among the citizenry (GSS, 2014). Ghana was among the best performers in sub-Saharan Africa in the Global Hunger Index (GHI) report by the International Food Policy Research Institute (IFPRI). The GHI reports the performance of all countries in terms of reduction in malnutrition, child wasting, stunting and mortality due to inadequate food supply (von Grebmer et al., 2017). Ghana's dramatic economic performance has also influenced peoples' access to other non-farm works, thus helped to reduce aggregate poverty and food insecurity levels in the country (World Bank, 2018).

The progress made in agricultural sector and the overall economy are the main drivers for poverty reduction in the country (Akobeng, 2016). Not until the occurrence of the global Covid-19 pandemic, Ghana's Gross Domestic Product (GDP) has been growing since the 1990s, averaging 7% between 2011 and 2019 and is one of the fastest growing economies in sub-Saharan Africa (MoF, 2019). The country halved the proportion of hungry people (Nyantakyi-Frimpong, 2014) and reduced poverty from 56.5% in 1992 to 23.4% in 2017 (GSS, 2019a) though with a steady drop in the share of agriculture contribution to GDP (from 29.5 in 2010 to 18.9% in 2016 and 19.7% in 2017). The agricultural sector however, remains the most important contributor to livelihood, employing over 40% of the economically active population (GSS, 2019a). These achievements among others are driven by durable political stability and enhanced domestic and foreign investments in the oil and services sectors of the economy (World Bank, 2018).

These notwithstanding, the economic achievements do not translate to the general welfare of the entire population of the country, because the inter-intra-regional level statistics show alarmingly high disparities and uneven geography of poverty and hunger among people in Ghana. Currently, with a population of about 30 million, close to 50% are living in rural area, and more than 82% of them directly or indirectly depend on agriculture for their livelihood (GSS, 2016, 2019a). However, productivity of farms is low, arising from poor investments, rudimentary agricultural practices, as well as drought, dry spells and floods, among others (ISSER, 2018).

Weather variability including drought, floods and extreme temperatures which characterised Ghana's agriculture, worsens poverty, food insecurity and affect the general livelihood of majority of people who depend on agriculture. The smallholder farmers who are the producers of food are often the poorest and food insecure section of the Ghanaian population. The report of the Ghana living standards survey round 7 (GLSS7) stated that close to 7 million Ghanaians are poor and more than 2.4 million are extremely poor. The five regions of the north account for over 40% of the poor in Ghana (GSS, 2019a). This means these extremely poor people cannot afford to consume the minimum calorie requirement of 2900 kcal per adult equivalent per day even if they were to spend their entire income on food. Many of these people are found in households where the heads are self-employed in the agricultural sector (GSS, 2019a).

Micronutrient's deficiency disorders (hidden hunger) in particular, are still a problem in Ghana. It is estimated that 92% of farm households suffer from malnutrition with stunting, underweight, wasting affecting 28%, 14%, 2% of children under five years, respectively (Christian, Marquis, Colecraft, Lartey, & Soueida, 2019). The situation is even worst in rural Northern Ghana, which contributes about 50% of the poverty incidence in Ghana (GSS, 2019a). About 20% of the vulnerable people in Northern Ghana either go to bed hungry each night or not know where their next meal may come from, and one in every nine children dies before attaining 5 years (Nyantakyi-Frimpong, 2014).

Unfortunately, the production of food in northern Ghana is characterised by uni-modal rainfall system which limits production to a short duration of less than four months. Empirical climate science studies in the region reveal a slight increase in total annual precipitation of 5% but at the same time, a significant decrease of about 70% precipitation in April, the usual month for the commencement of farming in Northern Ghana (Kunstmann & Jung, 2005), affect the food production of the people. The characteristics of climate variability with the accompanying extreme weather events such as flood and drought do not only reduce yields but reduces food availability and drives up prices (Springmann et al., 2016; Wiebe et al., 2015). FAO projects that, with a global temperature rise of 2-4% over pre-industrial level, crop yield will reduce by 50% in Africa and Asia (Nyantakyi-Frimpong, 2014).

2.10 Indicators and Measurements of Food Security

Given that the concept of food security is multidimensional nature, there is no single approach for measuring it. The approach for measuring food security depends on the objective and the level: that is either at the macro or global, regional, national level and micro or household and individual level (Masset, 2011). For example, the indicator for measuring the Prevalence of Undernourishment (PoU) relies on food balance sheet to estimate the availability and undernourishment at global, regional and national levels. The PoU was initiated by FAO in 1974 and since 1977, FAO gives annual publication on PoU (Cafiero, Melgar-Quiñonez, Ballard, & Kepple, 2014). The report estimates the availability per capita dietary food energy supply relative to the dietary energy requirement of individuals at global, regional and national levels. It categorises the number of undernourished people out of the total population (Ambagna, Dury, & Dop, 2019; Cafiero et al., 2014). The approach is less expensive and can be implemented in low income countries. Ambagna et al. (2019) applied it to determine the trends of food insecurity in Cameroun. However, the use of PoU suffers from poor data quality and does not also determine the extent to which food is utilised. The criticism against PoU is that it is dominated by assumptions, thus affecting reliability of findings.

The Global Hunger Index (GHI) indicator is conducted and published by the International Food Policy Research Institute (IFPRI) to track hunger at the global, regional and national levels.

The GHI measures the proportion of undernourished people including wasted, stunted, and mortality of children under 5 years of age (von Grebmer et al., 2017). This indicator subsumes several other indicators, thus minimises random errors associated with measurement. However, it reflects mainly on only child's health and nutrition, yet can be used to generalise the hunger situation of an entire population.

Closely related to GHI is the Global Food Security Index (GFSI); a multi-dimensional tool which measures three domains: affordability, availability, quality and safety of food at the national level. GFSI uses both qualitative and quantitative data. The index picks data from reliable sources such as governments, NGOs and international organizations like FAO, WFP but the qualitative scores are quite subjective, as such usually deviates from the way other national food insecurity indicators are generated (Jones, Ngure, Pelto, & Young, 2013).

At the household level, food security indicators are obtained using a number of varied measurement approaches. For example, Household Consumption and Expenditure Surveys (HCES) is an indicator obtained periodically at the national level to assess poverty and economic status and is used to calculate the consumer price index (Ambagna et al., 2019; Jones et al., 2013). Usually, HCES is done to identify households at risk of food insecurity and evaluate the impact of the implementation of programmes related to food nutrition and anti-poverty. It is less time-consuming and cheaper to conduct but only gives estimates on food acquisition but not consumption.

Household Dietary Diversity Score (HDDS) is another dietary diversity score often used by the United States Department of Agricultural Development (USDA) to assess household access to food based on the consumption of various food groups witin the past 24 hours prior to the survey (Leroy, Ruel, Frongillo, Harris, & Ballard, 2015; Swindale & Bilinsky, 2006). This indicator reflects the nutritional quality of diets at the household level. The process involves grouping food groups into 12 points-scale with each point denoting the response in the household consumption of a food group, which is summed up to give the household dietary diversity score (HDDS). A household or individual with low score correlates with food insecurity (McDonald et al., 2015; Wiesmann, Bassett, Benson, & Hoddinott, 2009) and a high score indicates the level of socio-economic status and food security (Kennedy, Ballard, & Dop, 2011). However, the absence of weight makes it appear as if all food groups have equal importance in terms of nutritional value. Additionally, the absence of explicit cut-off points gives room for the use of different cut-off points by researchers, thus making comparison quite difficult (Carletto, Zezza, & Banerjee, 2013).

Another Dietary Diversity (DD) measure commonly employed in most food security studies is Food Consumption Score (FCS) by the World Food Programme (WFP). FCS is a frequency-weighted dietary diversity score measured by taking into account the frequency with which a household consumes eight food groups- staples, pulses, vegetables, fruits, meat or fish or egg, milk, sugar and oils within a 7-day recall period prior to the date of the survey. It is an indicator which measures dietary quality.

The FCS is used to generate a composite score based on the frequency of food consumed and the relative nutritional importance of various food groups on the dietary mix (Perez-Escamilla, Gubert, Rogers, & Hromi-Fiedler, 2017). The frequencies within each food group are summed to obtain the food group score, which must not be higher than seven (7). Each food group score is then multiplied by its weight and the results aggregated to give the FCS, truncated between ranges 0 to 112. The food groups and weight include cereals = 2, roots and tuber = 2, pulses and nuts = 3, meat and fish = 4, dairy products = 4, vegetables and fruits =1, sugar = 0.5, oils = 0.5. The FCS has cut-off ranges which are used to classify the consumption levels of individuals and households into: (a) poor (0 – 28), (b) borderline (28.5 – 42) and (c) acceptable (above 42) levels (P. P. Acheampong et al., 2022; Jones et al., 2013; Maxwell, Coates, & Vaitla, 2013; Vaitla et al., 2017).

The challenge with FCS is that dietary patterns differ across regions and countries, for example between SSA and South Asia. There is also the issue of lack of consensus on the choice of food groups included in the FCS. It does not also differentiate between processed and unprocessed foods, which have implications on the utilization dimension of food security (Carletto et al., 2013).

Household food energy availability (per capita calories consumption) is one other indicator that measures the total quantity of food energy consumed in each household. Energy in food is necessary for the survival of mankind and for performance of physical activities. The sufficiency of energy available in food consumed by households and the ability of the households to access the food is measured by this indicator (Dary & Imhoff-Kunsch, 2010). This is done where the total household energy (kilocalories) = food quantity in grams per day ×edible portion × (food energy conversion factor × 1/100). The daily calorie available per adult equivalent for a household is then obtained by dividing total energy acquired per household per day by adult equivalent factor (Ibok, Osbahr, & Srinivasan, 2019). The International Food Policy Research Institute IFPRI (2000) and GSS (2007) applied this approach where an adult equivalent energy consumption threshold value of 2900kcal per person per day was adopted for Ghana.

There are also other food insecurity indicators that are used based on household, or individual's participatory adaptation. For instance, the Household Food Insecurity Access Scale (HFIAS) is an indicator that measures household's access to food using nine (9) questions that represent three domains: Anxiety, uncertainty and insufficient quality and quantity of food supply.

The Household Coping Strategies Index (HCSI) is another indicator designed to assess households' current food security situation as well as future vulnerability to food insecurity (Maxwell et al., 2013). The HCSI is calculated by multiplying the frequency of the household coping strategy by the weight of the strategy which ranges from 2 - 4. The coping strategies and weight include: Borrowing food or rely on friends or relatives (2), Limits the variety of food eaten (3), Reduce number of meals eaten a day (3), limits portion size at meal-times (4), Restricts consumption by adults in order for small children to eat (4), Have no food of any kind in the house (4), Sleep hungry at night because of no food (4) and not eating anything at both day and night (4).

There are no standardised guidelines on the interpretation of HCIS but a suggestion by Maxwell et al. (2013) was to group the score into food secure (0-2), mildly food insecure (3-12), moderately food insecure (13-40) and severely food insecure (above 40). This approach captures information on whether the food insecurity at a point in time is improving or deteriorating. Coping strategies index can be done to compare food insecurity situation across households within the same locality or community.

Also, how food is utilized is measured with the anthropometric indicators. Anthropometric measurement gives insight on how food is metabolised, absorbed and converted in the body. This indicator measures a child's anthropometrics like height-for-age, weight-for-height, stunting (chronic malnutrition), and wasting (acute malnutrition). Other outcome indicators include maternal caring practices and diseases control (UNICEF, 2009). Table 2.3 shows the empirical literature on food security studies and the effects of some socio-economic factors on household's food security status and the a priori expectation of the variables in the study areas.

Table 2. 3 Empirical Factors in literature Affecting Household Food Security

Factor	A priori	Location of study	Author (s)	Reasons
Age	+	Pakistan Ethiopia Nepal Senegal	(Abdullah et al., 2017) (Abate et al., 2019; Bogale & Shimelis, 2009; Gebru et al., 2019; Sisay & Edriss, 2013) (Joshi & Joshi, 2017) (Van den Broeck, Van Hoyweghen, & Maertens, 2018)	With increased age, household head develop experience that increases their wealth, and improve planning and managing food insecurity with relevant coping strategies
Gender	+	Tanzania Pakistan Nepal FAO (146 countries)	(Reincke et al., 2018) (Asghar & Muhammad, 2013) (Joshi & Joshi, 2017) (Broussard, 2019)	Male headed households are more food secure because of resources ownership, ability to diversity employment opportunities which reduces their income generation risk.
Educ. level	+	Pakistan Malawi Ethiopia Benin Tanzania	(Abdullah et al., 2017; Asghar & Muhammad, 2013) (Ragasa, Aberman, & Mingote, 2019) (Gebru et al., 2019; Kuma et al., 2019; Sisay & Edriss, 2013) (Adjimoti & Kwadzo, 2018) (Reincke et al., 2018)	Education as a social capital provides knowledge and awareness and increases the chance of securing a paid job which impacts household nutritional decisions. farmers are able to absorb new techniques of farming to improve productivity
Dependence ratio	–			Children and other elderly people outside certain age bracket are unable to work to increase household access to food.
Household size	-/+	Pakistan Tanzania Nepal Ethiopia	(Asghar & Muhammad, 2013) (Reincke et al., 2018) (Joshi & Joshi, 2017) (Bogale & Shimelis, 2009; Sisay & Edriss, 2013)	Large household size with limited productive agricultural land and other livelihood earnings means food supply may not match demand and that may lead to less calorie intake compared to small household size

Author's Literature Review, (2020)

Table 2. 3 Empirical Factor in literature Affecting Household Food Security Cont.

Household own food production	*	Ghana	(Kuwornu et al., 2013)	An increased own household production of food from the farm makes more food available and accessible to household members for consumption.
Ownership of livestock	+	Nepal Senegal Ethiopia	(Joshi & Joshi, 2017) (Van den Broeck et al., 2018) (Bogale & Shimelis, 2009)	Ownership of livestock acts as a hedge and an indicator of wealth which the household can fall on to mitigate the household during crop failures and other calamities. Manure can also be used to fertilizes land
Total off-farm income	+	Malawi, Pakistan, Ghana Ethiopia Tanzania Senegal	(Asghar & Muhammad, 2013) (Abdullah et al., 2017) (Kuwornu et al., 2013; Owusu et al., 2011; Tsiboe et al., 2016) (Bogale & Shimelis, 2009; Gebru et al., 2019; Sisay & Edriss, 2013) (Reincke et al., 2018) (Van den Broeck et al., 2018)	Off-farm income offers rural farm households escape route from poverty: Low-income households face food insecurity because of low purchasing power. Low income also affects the ability of households to access food and still meet other household obligations.
Income from vegetable	+	Ethiopia	(Gebru et al., 2019)	The income generated from high value crops like vegetables can be used to access more food for the household during lean season.
Credit access	+	Ghana Uganda Benin Ethiopia	(Kuwornu et al., 2013) (Twongyirwe et al., 2019) (Adjimoti & Kwadzo, 2018) (Bogale & Shimelis, 2009)	Credit smoothing household's consumption, build productive capacity through the purchase of inputs and enables households invest resources on agribusinesses and other non-farm activities to improve their food security status
Participant of agricultural programme	+	Bolivia	(Salazar, Aramburu, González-Flores, & Winters, 2016; Winters, Salazar, Gonza'les-Flores, & Aramburu, 2018)	Enhanced food access through improved household income. increased food availability via increased agricultural productivity and sales of produce
Access to irrigation	+	Ethiopia	(Bogale & Shimelis, 2009; Gebru et al., 2019)	Access to irrigation makes farmers participate in dry season irrigated farming including vegetable production and reduces the risks of crop losses, increases income and improve food access
Extension contacts	+	Malawi Benin Iran	(Ragasa et al., 2019) (Adjimoti & Kwadzo, 2018) (NOORHOSSEINI-NIYAKI & Allahyari, 2012)	Training is knowledge acquisition process which enables farmers access to better crop production techniques and incentives to improve farming for food and income

Author's Literature Review, (2020)

2.11 Summary and Conclusions on Literature Review

In conclusion, gaps were observed in the literature review on the technical efficiency of vegetable production and its implications on households' food security in the Upper East Region. Although studies on the challenges regarding vegetable yields in Ghana and the Upper East Region in particular, are well-documented, little is however known about the technical efficiency level of farmers who produce vegetables during the dry season and its effect on the value of output, and income and households' food security. This study intends to fill the knowledge gaps in the literature.

Indeed, countless number of researches on the contributions of cash cropping on food security have revealed mixed outcomes, globally. Although, anecdotal evidence exists on the positive contribution of dry season's vegetable income on households' food security, not enough empirical study is conducted to confirm or prove otherwise. This study fills this gap by focussing on the effect of dry season vegetable income on households' calorie availability and dietary diversity, especially in the irrigation districts in the Upper East Region of Ghana.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter covers the analytical framework underpinning the study. This is followed by a description of the methodology employed in the study. Finally, the methods of data collection continue to the sources of data, sampling procedure adopted in selecting the respondents' farmers and their households as well as a description of the study area.

3.2 Analytical Framework

The analytical framework of the study below in figure 3.1 presents the nexus between technical efficiency and food security of dry season vegetable farm households in the Upper East Region of Ghana. Vegetable cultivation during dry season is a major livelihood activity that provides income to farmers for purchasing food for farm households during the lean season in the region. The farmer's decision to cultivate vegetable during dry season depends on the resource endowment of the farm family, which may include natural (land, water), physical (capital: cash, implements, machinery) and human (physical labour, skill, education). These resources are employed to produce vegetable such as tomatoes, garden eggs, onions and pepper to generate income.

There are two significant pathways among others through which growth in the productivity of vegetable can be sustained: that is the efficient use of the existing technologies and technological change. The production efficiency of farm household which refers to the ability to produce possible maximum output using the available inputs is determined by many factors, namely the production inputs (ie. seed, fertilizer, agrochemicals, irrigation technology, labour), production risks and inefficiency factors (ie. Socio-economic, institutional, managerial factors). In view of that, addressing the inefficiency challenges and reducing the production risks through optimum utilization of the available technologies would result in increased output, which in turn would lead to improved annual dry season vegetable income or profit. The farm income is a major component of total household income most farm households in the study area use to sustain livelihoods. Therefore, farm households with improved income from dry season vegetables enhance the purchasing power for households' food. Consuming vegetables also removes any hidden hunger and improves the nutrition and health of household members. Additionally, the income gained from the sale of vegetables helps to further improve households' livelihood resource endowment: natural (land, water), physical (capital: cash, implements, machinery) human (physical labour, skill, education). These resources are employed to produce more vegetables, or invest to own household food to improve households' food availability.

However, the effects of technical inefficiency on food security are wide-ranging, owing to a diversity of factors among farm households. Exogenous nuances including climatic factors, pests and diseases, government subsidies, market conditions affect the technical efficiency and make the production inherently risky. While some of the inefficiency factors, to a certain degree, can be controlled by the farmer, the exogenous factors, on the other hand, cannot be controlled by the farmer. Therefore, having prior knowledge about the possible consequences of production risk also affect the behaviour of farmers who take decision on the level of inputs to use in the production process. Hence, farmers who are risk-averse may only be willing to invest less input resources to minimise losses. So, being risk averse may affect the choices of inputs which in turn may also affect the mean output and output variance and consequently income and household food security.

If the behaviour of the farmer affects the mean output and output variance, it would certainly affect the mean revenue streams and thereby the gross profit of the farmer. In the end, the farmer derives low income from the production of vegetable. Low income affects farm households' food security via two pathways. First, it reduces the food budget that can be used to purchase food items. Second, it also affects the budget that can be re-invested in acquiring inputs for the production of more vegetable.

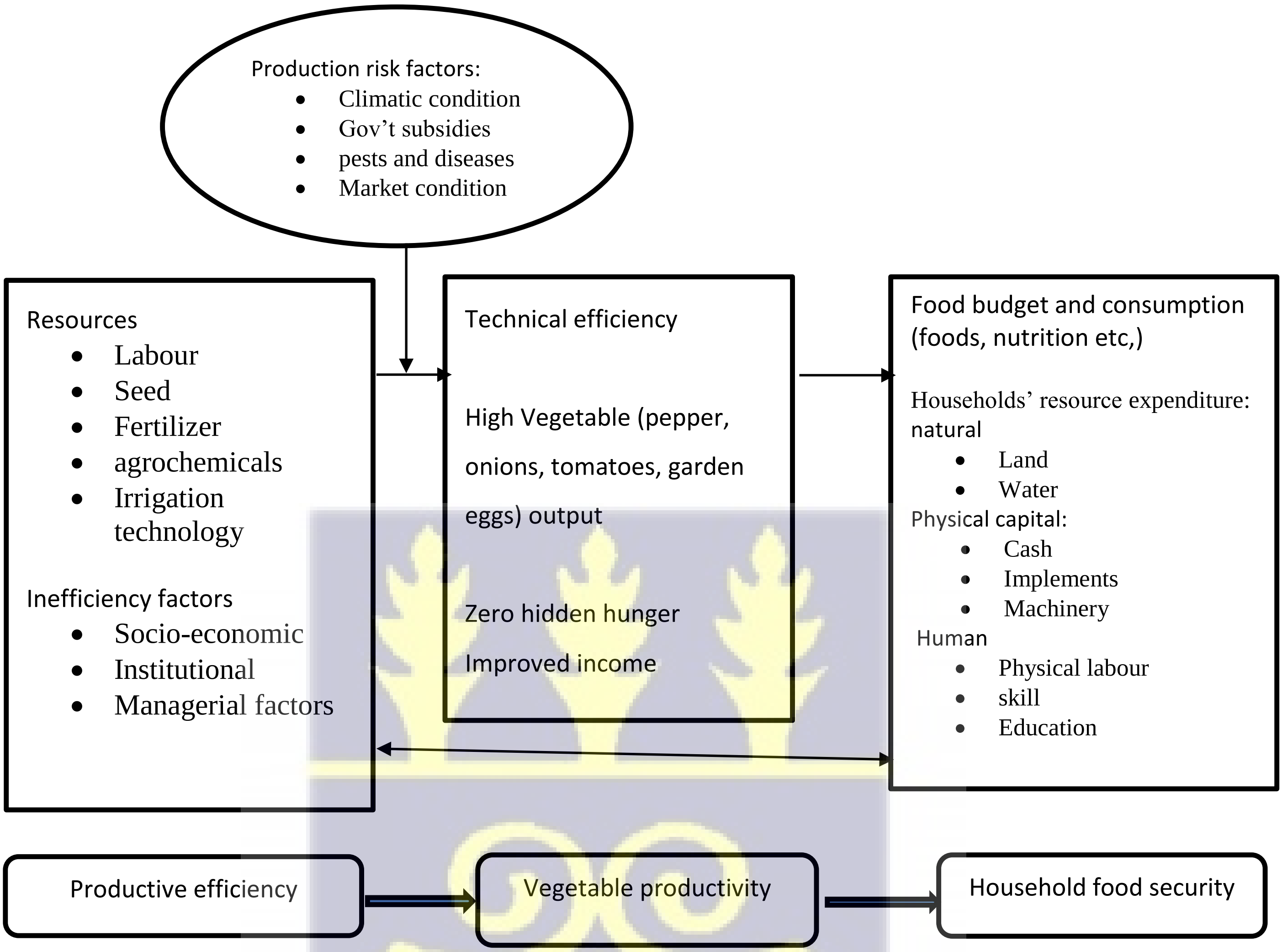

Fig. 3. 1: Analytical Framework of the study

Source: Adapted from Birhanu et al. (2021) with Author's modification

3.3 Theoretical Concepts of Stochastic Frontier Approach

Mathematically, a fully technically efficient farmer (without inefficiency) in a production process is given as $f(x_i\beta)$. However, because agricultural production is prone to risky climatic conditions and other shocks, the potential technical efficiency score of the farmer is often reduced. Output of farmers is therefore stochastic. This study employs the Stochastic Frontier Approach (SFA) instead of the Data Envelopment Approach (DEA), to assess the technical efficiency of dry season vegetable farmers in the Upper East Region of Ghana. Generally, the SFA function is given as:

$$Y_i = f(X_i; \beta) + \varepsilon_i \qquad (3.1)$$

Where the subscript i denotes the ith decision making unit (DMU), $i = 1,2,3, \ldots n$, Y_i is the value of output of the ith farmer in Ghana cedis, x_i is a vector of $k \times 1$ whose values are input costs and other explanatory variables of the ith farmer, β is the vector of fixed factor (technology) parameter, $f(.)$ is the best production frontier and ε_i is the error term decomposed into two independent variables u_i and v_i where $\varepsilon_i = v_i - u_i$. The v_i error component is symmetric and represents random error beyond the farmer's control. These factors may include weather, disease, luck, measurement errors, omitted variables and other noises. The random component is assumed to be identically and independently normally distributed, with zero mean and constant variance$[v_i \sim N(0, \sigma_v^2)]$. The inefficiency component (u_i,) on the other hand, is non-symmetric and assumes to be independently distributed with the random error (v_i) component as well as meets the conditions of $u_i \geq 0$. It also measures the deviation of the observed technical efficiency (Y_i) from the technical efficiency of the "best" performing farm on the production frontier $[f(x; \beta) + v]$.

The distribution of the $u_i s$ can take many forms, however, there is no established *a priori* that suggest the superiority of one distribution over another, although, each assumption produces different efficiency estimates. The inefficiency component accounts for inefficiencies of the farmer and may include factors such as farmer's specific knowledge and management skills, employee's effort, work stoppage, challenges of inputs and other disruptions in productions. There are four distributions of the $u_i s$ proposed by different authors namely, exponential form (Meeusen & van Den Broeck, 1977), half normal non-negative distribution, $[u_i \sim N^+(0, \sigma_u^2)]$

(Aigner et al., 1977), truncated normal distribution with constant mean and constant variance $[u_i \sim N(\mu, \sigma_u^2)]$ (Stevenson, 1980) and gamma density (Greene, 1980).

Technical efficiency refers to the distance from the ratio of the observed technical efficiency TE_i^* to the potential technical efficiency Y_i given as:

$$TE_i = \frac{Y_i^*}{Y_i^*} = \frac{f(x_i;\beta).\exp(v_i - u_i)}{f(x_i;\beta).\exp(v_i)} = \exp(-u) \quad (3.2)$$

The difference between Y_i and Y_i^*, which is $(-u)$ is the inefficiency, generally lies on $0 \leq TE \leq 1$ such that, if $u = 1$, the technical efficiency of the farmer lies on the production frontier and indicates full technical efficiency, but if $u < 0$, the observed technical efficiency of the farmer is below the production frontier and is technically inefficient. The effect of the technical inefficiency is defined as:

$$U_j = \alpha_0 + \sum \alpha_i z_i + \omega \quad (3.3)$$

Where z_i is a vector of the socio-economic (explanatory) characteristics attributed to technical inefficiencies of the farmer that affects the value of outputs in dry season vegetables farming j. The values of o and i, α_0 and α_i are vectors of unknown parameters to be estimated and ω is an observed random variable with zero mean and variance σ_u^2.

In the context of the stochastic frontier, the technical efficiency of the jth farm is defined as

$$TE_J = E[\exp(-U_j)] \; |\varepsilon_i = E\left[\exp(-\alpha_0 - \textstyle\sum_{i-1}^{n} \alpha_i z_i) \; |\varepsilon_i\right] \quad (3.4)$$

Where TE_j is the technical efficiency of the jth dry season vegetable farmer, which lies between 0 and 1 and inversely related to the inefficiency level, E is the probability operator, achieved by obtaining the expressions for the conditional expectations of U_j upon the observed values of ε_i. The sign of the parameters (z_i) indicates the effect on technical efficiency of the jth farmer. A negative sign suggests a positive effect on the U_j and vice versa.

3.3.1 Modelling Stochastic Frontier with Production Risk Function

The challenge in employing the stochastic frontier model in estimating technical efficiency in a production process is that it ignores the marginal effect of the farmer's behaviour regarding risk on the choice of inputs during the production process (Jaenicke and Lawson, 2001). In view of that, applying the conventional SFA does not adequately capture all the nuances associated with the production process, as such may lead to erroneous estimates (Lemessa et al., 2017). Just and Pope (1978), therefore, argued that the application of the conventional SFA model in several studies without deliberately including risk behaviour of farmers holds no *a priori* in any agriculture environment. This is because, in real life situations, farmers are often faced with numerous challenges regarding the decision concerning what level of inputs to use to minimise losses.

Although vegetables are high value products, its cultivation is highly prone to risk. Factors such as pests and diseases, perishability, etc, affect its production and marketing than farming staple cereal crops (Joosten et al., 2015). These uncertainties influence the decision of the farmer on what level of inputs to use to minimise losses, which then affect both the mean output and output variance. Most studies dealing with risks employs Just and Pope (1978). Their model adequately reflects all potential risk structures in the production process given as:

$$y = f(x;\beta) + \varepsilon = f(x;\beta) + g(z;\theta)v \tag{3.5}$$

Other researchers subsequently modified Pope and Just's model to accommodate both technical efficiency and production risk. For instance Battese and Broca (1997)added the inefficiency component to the risk function $[g(z;\theta)]$ stated as:

$$y = f(x;\beta) + g(z;\theta)\varepsilon \tag{3.6}$$

On the other hand, Kumbhakar (1993), combined both the production risk and technical efficiency models by multiplying them with the risk model in the production function, so as to make it more flexible to capture both the negative and positive marginal risk with respect to the inputs. Further, Kumbhakar (2002) employed both an additive and multiplicative effects to Just and Pope's model so as to make it furthermore flexible to account for both the production risk and technical inefficiency. These modifications, however, made the model consistent with the conventional stochastic frontier model of Aigner et al. (1977) and Meeusen and van Den Broeck (1977). In that case, the mean output and the output variance can be determined simultaneously to identify whether a given input in the production process is risk increasing, risk decreasing or risk neutral.

This study employed the additive heteroskedastic error model structure of Battese, Rambaldi, and Wan (1997) and Kumbhakar (2002), to achieve the objective of examining the technical efficiency score of dry season vegetable farmers in the Upper East Region of Ghana. The model conforms to the Just and Pope (1978) model which incorporates production risk in the production process.

A generalised flexible and production risk incorporated SFA function is specified as:

$$Y = f(x;\beta) + g(z;\theta)v - q(w;\delta)u. \qquad (3.7)$$

Where: $f(x;\beta)$ is mean output, $g(x;\theta)v$ is production risk and $q(w;\delta)u$ is an inefficiency function. The inefficiency function captures the relationship between the technical efficiency of the vegetable farmers and different demographic, socio-economic, farm attributes, institutional and managerial characteristics of the farmers, where the w is vector of inefficiency factors and δ is the parameter to be estimated. The equation (3.7) is synonymous to the general conventional SFA model, which exhibits heteroskedasticity where $\delta_v^2 = \exp(z;\theta)$ and $\delta_u^2 = \exp(w;\delta)$ represent v and u, respectively (Kumbhakar, 2002).

From the estimates of the inputs, the extent of inefficiency effects, the mean output of the ith farmer is given by:

$$E(\frac{\pi}{x,u}) = f(x;\beta) - g(w;\theta)u \qquad (3.8)$$

The inefficient dry season vegetable farmers are those with positive deviations which lie below the frontier while the efficient farmers are those with zero deviations which lie on the production frontier (Bachewe, 2009). The technical efficiency (TE) is therefore, defined as the ratio of the observed technical efficiency of a given vegetable farmer to the technical efficiency of a fully efficient vegetable farmer with the same input vectors (Coelli et al., 2005) given as:

$$TE = \frac{E(\pi/x,u}{E(\pi)/x,u-0} = \frac{f(x;\beta)-g(z;\theta)u}{f(x;\beta)} \qquad (3.9)$$

Hence, $TE = 1 - \frac{g(z;\theta)u}{f(x;\beta)}$, but since technical inefficiency $(TI) = \frac{g(z;\theta)u}{f(x;\beta)}$, then

$$TE = 1 - TI \qquad (3.10)$$

Since $E(TE) = f(x;\beta)$ and $V(y) = g^2(z;\theta)$, then, the marginal technical efficiency (production risk) is a partial derivative of the risk function with respect to the inputs (x_i) given as;

$$\frac{\partial Var\,(\pi)}{\partial x_i} = 2g(z;\theta)\frac{\partial g}{\partial x_i} \qquad (3.11)$$

In that case, where $2g(z;\theta)\frac{\partial g}{\partial x_i} > 0$, such an input is a risk increasing, if $2g(z;\theta)\frac{\partial g}{\partial x_i} < 0$, the input is risk decreasing and if $2g(z;\theta)\frac{\partial g}{\partial x_i} = 0$, the input is risk neutral. The marginal production risk, therefore has directional sign that can be positive, negative or zero to represent risk increasing, risk decreasing, and risk neutral, respectively. Therefore a risk averse farmer will allocate more resources to less risky income sources than a risk neutral farmer (Kumbhakar, 2002).

Following the work of Yang, Mugera, and Zhang (2016), the parameter estimates of equation (3.8) through the optimisation of the log-likelihood function using a single maximum likelihood (ML) procedure is presented as:

$$lnL = constant - \frac{1}{2}\sum_i \ln[\exp(w;\delta) + \exp(x;\theta)] + \sum_i ln\emptyset \frac{-\varepsilon\lambda}{\sqrt{\exp(w;\delta)+\exp(x;\theta)}} - \frac{1}{2}\sum_i \frac{\varepsilon i^2}{\exp(w;\delta)+\exp(x;\theta)} \quad (3.12)$$

where: $\varepsilon i = v - u$ and represents $\lambda \frac{\sqrt{\exp(w;\delta)}}{\sqrt{\exp(x;\theta)}}$; $\emptyset$ is the standard normal distribution. The inefficiency of each farmer can be estimated using the standard normal distribution of u given ε.

3.3.2 Specification of Stochastic Frontier Functional Form

In estimating stochastic frontiers, it is vital to situate it in the context of theoretical consistency, flexibility as well as identify and choose the appropriate production functional form (Sauer, Frohberg, & Hockmann, 2006). In literature, two functional forms are commonly applied in technical efficiency studies; the Cobb-Douglas (C-D) and transcendental logarithmic (trans-log) functional forms. The superiority of either of these two functional forms lies in the data set, the simplicity and ease of computation. Usually, the data is tested on which functional form appropriately fits the estimates of the data. Several studies (Lemessa et al., 2017; Tiedemann & Latacz-Lohmann, 2013) have used the (Cobb-Douglas and Trans-log) functional forms to estimate technical efficiency in agriculture and related fields.

However, Kopp and Smith (1980) opined that there is no significant effect on the choice of the functional form in the estimation of technical efficiency. Nevertheless, each of the functional forms has certain strengths and weaknesses in efficiency analysis. The Cobb-Douglas functional form, for example, is simple, self-dual, robust, easy to compute and interpret, as such, is widely applied in many technical efficiency studies in agricultural production (Amoah et al., 2014; Mal, Manjunatha, Bauer, & Ahmed, 2011). However, it also imposes some restrictions on the technologies of the farm by assuming constant elasticities and equating the elasticities of inputs substitution to one makes it not the best (Wilson, Hadley, Ramsden, & Kaltsas, 1998). The general Cobb-Douglas functional form for cross sectional data is given as:

$$lnY_i = \beta_0 + \sum_{j=1}^{n} \beta_j \, lnX_{ji} + \sum_{k=1}^{m} \beta_k D_{ki} + V_i - U_i \qquad (3.13)$$

Where lnY_i represents natural logarithm of value of vegetable in the ith farm area ($i = 1,2, \dots n$), X_i is a vector of inputs, D_k is vector of dummy variables and V_i and U_i are the random and inefficiency errors as previously defined.

The trans-log functional form, on the other hand, cures the restrictive nature of the cobb-Douglas functional form to allow for the combination of squared and cross product terms of the explanatory variables, thus gives the goodness of fit of the model. However, trans-log usually suffers from multicollinearity problems (Dawson, Lingard, & Woodford, 1991). The general trans-log functional form is defined as:

$$lnY_i = \beta_0 + \sum_{j=1}^{n} \beta_j \, lnX_{ji} + 0.5 \sum_{j=1}^{n} \sum_{k=1}^{n} \beta_{jk} lnX_{ji} + \sum_{k=1}^{m} \beta_k \, D_{ki} + V_i - U_i \qquad (3.14)$$

Where each of the variables remains the same as previously defined.

3.3.3 Empirical Model Specification of Technical Efficiency

Although the Cobb-Douglas functional form and the trans-log functional are commonly employed in most technical efficiency studies, the choice of a functional form is not discretionary. Rather, it is based on the one that appropriately fit the data set. To ascertain whether the Cobb-Douglas or Trans-log functional form is appropriate for the data, a log likelihood ratio test is performed on the null hypothesis that, the Cobb-Douglas functional form is appropriate for the data against the alternative hypothesis that the trans-log functional best fit the data. The generalised log likelihood ratio test statistic is given as:

$$\boldsymbol{\lambda = 2(lnL_{Cobb-Douglass\ functional\ form} - lnL_{Translog\ functional\ form})} \qquad (3.15)$$

Where λ is distributed as Chi-square with a degree of freedom equal to the number of independent variables including the constant. The test results reject the Cobb-Douglass functional form in favour of the trans-log if the test statistic (λ) is greater than the appropriate Chi-square critical value. In other words, a hypothesis test was conducted on whether $\beta_{jk} = 0$. The test found the trans-log functional form best suited for the study of the stochastic functional analysis of technical efficiency of dry season vegetable farmers in the Upper East region of Ghana.

The trans-log functional form is given as:

$$lnTE_i = \beta_0 + \sum_{j=1}^{5} \beta_j\, lnx_{ji} + 0.5 \sum_{j=1}^{5} \sum_{k=1}^{5} \beta_{jk}\, lnx_{ji} lnx_{ki} + v_i - u_i \qquad (3.16)$$

Where TE_i is defined as the value of vegetables (GHS) produced by the farmer in the ith area, which is log transformed for $i = 1,2,..322$, x_{ji} denotes the vector of cost (GHS) of different production inputs j used by the ith vegetable farmer. All inputs and outputs were evaluated at per hectare basis, where x_1 represents the cost of labour (GHS), x_2 denotes the cost of seed (GHS), x_3 denotes cost of fertilizer (GHS), x_4 denotes the cost of agrochemicals, x_5 denotes the average cost of irrigations (water levy, running and maintenance cost of pump or cost of digging wells and machinery depreciation). The cost of inputs is estimated separately for each vegetable cultivated on a farm and summed for all crops for the farmer. The explanatory variables identified are among the most critical hampering smallholder irrigated vegetable cultivation in Sub-Saharan Africa (Akamin et al., 2017; Drechsel & Keraita, 2014; Rajendran et al., 2015). Typical of smallholder farmers in SSA, dry season vegetable farmers in the study cultivated more than one type of vegetable in the season. The value of each vegetable was obtained by multiplying the quantity of the vegetable by the respective price and summing it up to arrive at the total output value. Although crop yield per hectare is the appropriate measure of productivity, this study employs the value of production for the following reasons. First, the study focussed on the farm as the main production unit as opposed to the plot level per type of crop. Secondly, famers prefer the cultivation of multiple crops on the same piece of land. In view of these, it is difficult to attribute the returns to land or labour to individual crops (Aragon, Restuccia, & Rud, 2022).

Several studies (Akamin et al., 2017; Xu et al., 2018) have employed similar units of measurement to estimate technical efficiency of farmers in vegetable production. Technical efficiency studies on the products of whole farm, rather than specific product usually apply monetary value of output instead of the physical quantities (Akamin et al., 2017; Bozoğlu & Ceyhan, 2007; Bravo- Ureta & Pinheiro, 1997; Habiyaremye et al., 2019; Rajendran et al., 2015). Similar analysis was employed in this study by aggregating the value of outputs of all the vegetables produced by the farmer.

3.3.4 Estimation of Elasticities

With the trans-log functional form, the elasticities with respect to the cost of the various inputs were normalised with land (ha) and scaled by the respective sample means according to Battese and Broca (1997), which is given as:

$$\frac{\partial LnE(Y_i)}{\partial Lnx_{ji}} = \left\{ \beta_j + \beta_{ji} Lnx_{ji} + \sum_{k \neq j} \beta_{jk} Lnx_{ki} \right\} \quad (3.17)$$

In such a situation, the first order coefficients were expressed as the elasticities of the technical efficiency with respect to the corresponding inputs cost specification. The sum of the coefficient of the inputs variables is the scale elasticities (ρ), which measures the return to scale for the dry season vegetable industry in the Upper East region. It determines the percentage change in technical efficiency as a result of a 1% change in all costs of input variables. The return to scale is increasing return to scale (IRS) if ($\rho > 1$), decreasing return to scale (DRS) if ($\rho < 1$), or constant return to scale (CRS) if ($\rho = 1$).

3.3.5 Description of the variables in the mean technical efficiency function

Technical efficiency ($\boldsymbol{Y_i}$) represents the value of output of the vegetables (pepper, onions, tomatoes, garden eggs) harvested from the ith farmer (GHS) per ha during the 2018/2019 dry season. Similar approached was adopted by Akamin et al. (2017) and Habiyaremye et al. (2019).

Labour cost ($\boldsymbol{\beta_1}$) denotes the cost of labour (family and hired labour) per ha in GHS used for vegetable cultivation by the farmer in the 2018/2019 dry season. Vegetable cultivation is labour demanding and requires a continuous gruelling work. This study adopts the measurement of labour in wages per day contrary to man-days adopted by Onumah et al. (2018), where one adult male, one adult female and one child ($\leq 18\, years$) who worked a day (8 hours) is equivalent to 1, 0.75, and 0.50 man days, respectively. This is because the study estimated all dependent and explanatory variables using monetary values hence labour alone in man-days would affect the analysis (Akamin et al., 2017). Labour is expected to have a positive effect on the quantity of vegetables produced per ha (Akamin et al., 2017; Bozoğlu & Ceyhan, 2007; Habiyaremye et al., 2019).

Seed cost ($\boldsymbol{\beta_2}$) represents the value of own or purchased vegetable seeds per ha in GHS used to establish the nursery and subsequent transplanting onto the field in the 2018/2019 dry season. All things being equal, the quality of seed applied on the farm is reflected in the cost of the seed. Thus, it is expected that, the cost of the seed would impact positively the value of vegetables harvested because improved and high yielding seeds cost more but yield better than less quality and own recycled seeds (Habiyaremye et al., 2019).

Fertilizer cost ($\boldsymbol{\beta_3}$) denotes the value of fertilizer (GHS) per ha applied on the farm in the 2018/2019 production. Given that the price of fertilizer stable and is currently subsidised for farmers in the country, increasing the quantity of fertilizer applied onto the farm is expected to impact positively on the output of vegetables (Habiyaremye et al., 2019; Khan, 2015) since providing appropriate quantity of nutrients would enhance the growth and development of the plants for bulbs/fruits formation.

Cost of agrochemicals $\boldsymbol{\beta_4}$ represents the amount (GHS) invested in acquiring agrochemical inputs such as herbicides and pesticides for the production of vegetables. Diseases and pests infestations have been a major problem hindering vegetable production in the Upper East Region, as it reduces the yields and sometimes causes total crop failure (Tanzubil & Boatbil, 2014). Given that the price of agrochemicals remains stable, increasing the amount invested on agrochemicals to overcome the challenges of pests and diseases at the right time would positively lead to high yields and ultimately more profit for the farmers.

Cost of irrigation $\boldsymbol{\beta_5}$ represents the total amount of money (GHS) invested in the appropriate irrigation technology on the vegetable farms. The irrigation technology available in the study area includes manual irrigation, motorised pump irrigation or gravity-fed irrigation. The investment covers fuelling, maintenance of equipment, depreciation of irrigating (watering) machinery etc. Adopting the appropriate irrigation technology, all things being equal, would reflect on the timeliness and the right quantity of water for the crops to grow and develop, which in turn would reflect on high farm productivity and high gross profit. The frequency of irrigation and quantity of water supplied to the crops varies with the technology, soil type, climatic condition and age of the crop. Ideally, it is appropriate to irrigate between 4-5 days interval for the first month in a light soil and gradually changes to 5-7 days interval until maturity (Olani & Fikre, 2010). Note that the study assumes equal rates for water levy (in GHC) per ha irrespective of the type of crop grown across farms in the study region. So, all things being equal, the higher the rate of payment the higher the quantity of water applied to farms. Providing the appropriate quantity of water at the right time, all things being equal, is expected to positively impact on the quantity and profitability of vegetables per ha.

Table 3. 1 Description of variables in the mean Technical Efficiency Function

Variable	Measurement	Symbol	Description	Expected sign
Output Value	Ghana cedi	Y_1	Output Value per ha	
Labour cost	Ghana cedi	β_1	labour per ha	+
Seed cost	Ghana cedi	β_2	seed per ha	+
Fertilizer cost	Ghana cedi	β_3	fertilizer per ha	+
Agrochem. cost	Ghana cedi	β_4	agrochem. per ha	+
Irrigation cost	Ghana cedi	β_5	irrigations per ha	+

Author's Construct, 2020

3.3.6 Estimation of Marginal Production Risk

To be able to appropriately determine the effect of the decision of the farmer on the choice of inputs on the mean output and output variance, the random error term $\varepsilon = v - u$ was parameterised to include production risk $g(z_i;\varphi)v_i$ and inefficiency $q(w;\delta)u$ such that:

$$\varepsilon = g(z_i;\varphi)v_i - q(w_i;\delta)u_i. \quad (3.18)$$

The production risk function was linearized as:

$$g(z_i;\varphi)v_i = \varphi_0 + \sum_{m=i}^{5} \varphi_m x_{mi} \quad (3.19)$$

Where, φ_0 represents the intercept, x_m denotes the input variables, and φ_m signifies the risk parameters to be determined, where if the estimate is positive, such input is risk increasing, negative estimate indicates a risk decreasing and zero means a risk neutral input or such input does not have any effect on the production risk of dry season vegetable farms in the study area (Just & Pope, 1978; Lemessa et al., 2017).

Table 3. 2 Description of Variables Used in the Production Risk Function

Variable	Measurement	Symbol	Description	Expected sign
Labour cost	Ghana cedi	ψ_1	Labour per ha	-
Seed cost	Ghana cedi	ψ_2	Seed per ha	-
Fertilizer cost	Ghana cedi	ψ_3	Fertilizer per ha	+
Agrochem. cost	Ghana cedi	ψ_4	Agrochem. per ha	-
Irrigation cost	Ghana cedi	ψ_5	Irrigations per ha	+

Author's construct, (2020)

The study expects all inputs in the model to increase the output value of vegetables, some inputs may reduce the level of output value of vegetables whereas others may increase it. For instance, human labour is expected to be the most important input given the intensive nature of vegetable farming and lack of machinery in the region (Guttormsen & Roll, 2014; Oppong et al., 2016). Increasing the use of labour is expected to have risk decreasing effect, as more labour will be required to maintain the quality of the farm by weeding, controlling pests and disease, applying water (irrigation), agrochemicals, fertilizers etc. Also, agrochemical is expected to reduce output variability in the model, as the use of more agrochemicals would improve vegetables health and fruiting (Lemessa et al., 2017). As expected, the use of fertilizer may increase output variability. This is because, as the concentration of fertilizer increases, crops develop better up to some point, after which further increase in the use of fertilizer may lead to crop poisoning and a reduction in yield. Many farmers in developing countries are uneducated and lack the skills to determine the appropriate quantities of fertilizer to apply on crops to avoid poisoning them (Guttormsen & Roll, 2014). Seed costs are expected to reduce production risk since the use of commercial seeds would result in less output variability in quantity and quality of vegetables, as compared to relying on own recycled seeds which is often the case in the area (Guttormsen & Roll, 2014; Oppong et al., 2016). Own seeds may not be viable. Also, relying on manual method of irrigating vegetable farms increases the cost of production and increases output variability of vegetables in the study area.

3.3.6 Inefficiency Model Specification

The technical inefficiency model gives an insight into the variables, which affects the efficiency of the farmer. Given the functional specifications in equation (3.20), the effects of the inefficiency variables(u) hypothesised in literature (Battese & Coelli, 1995) explains the variation in technical inefficiency given as:

$$q(w_n;\delta)u = \delta_0 + \sum_{j=1}^{19} w_{ni}\,\delta_n + \alpha_i D_{ki} \qquad (3.20)$$

Where δ_0 denotes the intercept, $\delta_n's\ (n = 1,2,3,\dots,19)$ are the unknown inefficiency parameters to be estimated. The $w's$ are the specific continuous variables while the $D's$ are dummy variables that explain the inefficiencies. These variables are defined and measured with their a priori expected signs listed in table 3.3. They include demographic factors and socio-economic variables (age, age squared, gender, family size, education), farmer attributes (experience, number of irrigations, irrigation technology), institutional variables (credit, extension contacts) and controlled by the type of vegetable the farmer cultivated in the year in question. It must be stated that model 3.20 only becomes relevant if the inefficiency effect is stochastic and follows particular distributional properties (Coelli et al., 2005). A negative sign of the variable suggests a positive effect on the technical inefficiency (TE) and vice versa (Brümmer, 2001).

3.3.7 Description of the Technical Inefficiency Variables

Age is a continuous variable and represents the number of years of the responding vegetable farmer. The sign on the coefficient of age is expected to have a positive effect on the technical inefficiency of vegetable farmers. The age of the farm decision maker can have an influence on the choice and adoption of technology, which impacts negatively or positively on the mean output of the farm depending on the effectiveness of the technology. For example, Abate et al.

(2019) found a positive relationship between age and technical inefficiency of red pepper production in Ethiopia.

Age^2 denotes the number of years of the decision maker squared and is used to determine the monotonicity of the age variable on vegetable production. The sign of age squared is expected to be negative. This is because older farmers may not be willing to embrace innovative ideas and technology that have the potential to reduce technical inefficiencies, thus will have negative effect on the technical inefficiency of the farmer. For instance, Akamin et al. (2017), Asravor et al. (2016) and (Bozoğlu & Ceyhan, 2007) all found an inverse relationship between age and technical efficiency among vegetable farmers.

Gender is a dummy and represents the sex of the decision maker. It takes the value of 1, if the farmer is a male, and 0, if the farmer is a female. The sign for gender is expected to be negative. The cultivation of vegetables is labour intensive and male dominated activity in the Upper East Region of Ghana. Besides, the triple roles of women would most likely increase the technical inefficiencies of female than their male counterparts as reported by Assibey-Mensah (1998).

Household size is a continuous variable and represents the number of members within the household of the vegetable farmer. The presence of a large household size may present an opportunity to access available family labour for use in production activities which may impact positively on farm yields and revenue as revealed by Ugbabe, Abdoulaye, Kamara, Mbaval, and Oyinbo (2017) and Ali et al. (2019). Household size is therefore expected to impact positively on technical efficiency of vegetable farmers.

Education represents a dummy for the level of education (no education, basic, SHS/Tech/Voc, Tertiary) of the farm decision maker. Education is a proxy for human capital, which influences a farmer comprehension on innovative techniques of farming, vital for improved production and farm management including marketing, as indicated in the findings of Abate et al. (2019), Akamin et al. (2017), Yang et al. (2016). The coefficient of education is, thus, expected to be negative (ie. Decrease the technical inefficiency) of vegetable farmers in the study area.

Table 3. 3 Description of Inefficiency Variables that Influence of Vegetable Production

Variable	Measurement		Symbol	Description	Sign
Irrigations	Number		w_1	Frequency of irrigating farm	+
Household size	Number		w_2	Household members	+
Experience	Years		w_3	Years of farming	+
Farmer's age	Years		w_4	Age of farmer	+
Age squared	Years		w_5	Age squared	-
Extension visits	Number		w_6	Number of visits	+
Gender	Yes = 1	No = 0	w_7	Gender of farmer	+
Credit access	Yes = 1	No = 0	w_8	Farmer received credit	+
Irrigation Tech					
Manual	Yes = 1	No = 0	w_9	Manual irrigation of farm	+
Gravity fed	Yes = 1	No = 0	w_{10}	Gravity fed irrigation of farm	-
Water pump	Yes = 1	No = 0	w_{11}	Pump irrigation of farm	-
Farmer's Edu.					
No formal edu.	Yes = 1	No = 0	w_{12}	Not attained formal education	-
Basic edu.	Yes = 1	No = 0	w_{13}	Attained basic level	+
SHS/Tech/Voc.	Yes = 1	No = 0	w_{14}	Attained SHS/Tech/Voc.	+
Tertiary edu.	Yes = 1	No = 0	w_{15}	Attained tertiary level	+
Crop Type					
Pepper	Yes = 1	No = 0	w_{16}	Cultivated pepper	-
Onions	Yes = 1	No = 0	w_{17}	Cultivated onions	-
Tomatoes	Yes = 1	No = 0	w_{18}	Cultivated tomatoes	-
Garden eggs	Yes = 1	No = 0	w_{19}	Cultivated garden eggs	-

Source: author's construct, (2020)

Extension visits represent the frequency of visits a farmer receives from an extension agent for the purposes of giving agricultural technology advice to vegetable farmers for the 2018/2019 season. The essence of extension education is to improve the knowledge-base of the farmer for more efficiency in farming activities. Yang et al. (2016) and Abate et al. (2019) report that education and training given to farmers make them acquire additional skills and become efficient in farming, which ultimately increases output. Based on this, the a priori expectation of extension visits would be negative to technically inefficiency.

Irrigation technology denotes the available irrigations technology for the farmer to lift water from the water source to the field for irrigating the vegetables. Farmers in the study area use various means including manual irrigation (fetching with buckets, watering cans, calabashes, basins etc), motorised water pumps, gravity fed technology to apply water from various sources (dams, dugouts, rivers, streams, etc) to irrigate their farms. An efficient irrigation technology would reduce the inefficiencies in irrigation and ultimately impact positively on the technical efficiency of the farmer.

Credit access denotes those farmers who had access to credit and have actually taken it to enhance their vegetable cultivation in the 2018/2019 season in the study area. The accessibility and availability of credit enable farmers to acquire the necessary farm inputs at the appropriate time for farm activities to increase output. Amoah et al. (2014), Yang et al. (2016), Ali et al. (2019) and Akamin et al. (2017) all reported positive effect of farm credit on farmers' technical efficiency. The study, therefore, expects a negative sign on technical inefficiency from the coefficient of credit access.

Irrigation is a continuous variable which represents the frequency of application of water to the vegetable field in the production season in 2018/2019. Studies show that investment in irrigation provides a potential avenue for reducing poverty through increases in income (Domenech, 2013; Nonvide, 2018). The number of times water is applied to the crops is influenced by the type of crop and soil (Olani & Fikre, 2010). Applying water, the right number of times on the vegetable field would impact positively the technical efficiency of vegetable farmers in the study area.

Experience is a continuous variable which denotes the number of years the farmer has been cultivating vegetables, a proxy for farmer experience. Given that a farmer is experienced, all things being equal, would result in an increased technical efficiency level of the farmer. It is therefore expected that the coefficient of experience will negatively affect technical inefficiency of vegetable farmers in the study area as reported by Ali et al. (2019).

Crop type denotes a dummy variable for the type of vegetable (pepper, onions, tomatoes or garden eggs the farmer cultivated in the dry season of 2018/2019. Depending on the farm yield and the price sold, the crop type will either have a positive or negative effect on the income and gross profit of the farmer.

3.3.8 Statement of Hypothesis

The null hypothesis (H_o) of no influence against alternative (H_A) of significant influence of explanatory variable on technical efficiency of dry-season vegetable farmers is stated as:

$H_o : \beta_1 = \beta_2 = \beta_3 + \cdots = \beta_{19} = 0$; farmer's age, age squared, extension visits, gender, education (no education, basic, SHS/Tech/Voc, Tertiary), household size, irrigation technology (manual, water pump, gravity-fed), frequency of irrigations, credit access, experience and type of vegetable crop have no influence on the technical efficiency of dry-season vegetable farmers in the Upper East region of Ghana.

$H_A : \beta_1 > \beta_2 > \beta_3 + \cdots > \beta_{19} > 0$; farmer's age, age squared, gender, education (no education, basic, SHS/Tech/Voc, Tertiary), extension visits, household size, irrigation technology (manual, water pump, gravity-fed), frequency of irrigations, credit access, experience and type of vegetable crop have significant positive influence on the technical efficiency of dry-season vegetable farmers in the Upper East region of Ghana.

3.3.10 Hypotheses Test of Model fitness

The following hypotheses were tested using the generalised likelihood ratio test to ascertain the best fit of the models specified; the relevance or otherwise of the risk component; the presence of technical inefficiency; and the importance or otherwise of each of the variables identified in the model.

1. The test for the functional form was given as H_0: $\beta_{ij} = 0$, the null hypothesis that the coefficient of the second order in the model is zero or otherwise. The test statistic determines which functional form is appropriate to adopt for the study, that is either the trans-log or the Cobb-Douglas functional form.
2. $H_0: \theta_1 = \theta_2 = \ldots \theta_5 = 0$. The null hypothesis states production risk relating to input factors do not explain the variability of vegetable output value.
3. $H_0: \lambda = 0$. The null hypothesis states that inefficiency effect is absent from the model at every level. That is, the variance of the technical inefficiency term is absent, meaning the exogenous factors should be incorporated into the mean output function and estimated as traditional average normal responses using Ordinary Least squire (OLS). However, if $\lambda > 0$, it means the inefficiency effects are present in the model, as such, the stochastic frontier model should be applied.
4. $H_0 : \delta_1 = \delta_2 = \ldots \delta_{19} = 0$. The null hypothesis specifies that farm specific exogenous factors do not jointly influence technical efficiency.
5. $H_0: \sum \beta_i = 1$. The hypothesis that the sum of the coefficients of the inputs variables is a constant return to scale (CRS).

3.3.9 Hypotheses Validation and Decision Criteria

The above hypotheses were tested using the generalized likelihood ratio statistic stated as:

$$\mathrm{LR} = \mathrm{n}[\ln(\mathrm{L}(\mathrm{H}_0) - \ln(\mathrm{H}_1)] \qquad (3.21)$$

Where: $L(H_0)$ and $L(H_1)$ are null hypothesis and alternative hypothesis, respectively. LR has a chi-square distribution if the given null hypothesis is true with a degree of freedom equal to the number of parameters assumed to be equal to zero in null hypothesis. The third hypothesis was examined with a mixed chi-square (Kodde & Palm, 1986). The fifth hypothesis is tested with probability (p-value). The effect of explanatory variables on technical inefficiencies of dry-season vegetable farmers was also tested with probability (P-value). STATA 15.1 software was employed for the data analysis.

3.4 The Profit Maximization Theory of Vegetable Production

The estimation of profit relies on the theory of profit maximization and the Return on Investment (ROI). Following the theory, as applied by Wongnaa et al. (2019), the study assumes that a dry season vegetable farmer chooses inputs and outputs bundle that maximizes profit (revenue minus cost) subject to technology constraints. A generalized production function is given as:

$$x\,(g, y, z) = 0 \tag{3.22}$$

Where g is the vector of vegetable outputs, y is the vector of variable inputs, z is the vector of fixed inputs and x is the technology required to achieve maximum production and profitability. Assuming that there is equal technology across all farms in the industry, a gross profit (proxy for income) function is specified as:

$$\text{Maximize } \; p.g = wy \; \text{ or } \; p.g - wy = 0 \tag{3.23}$$

$$\text{Subject to } \; x(g, y, z) = 0$$

Where p is the vector of output prices while w is the vector of input prices. Given a set of inputs and outputs, profit maximizing input demand (Y) and outputs supply (G) functions are expressed as:

$$Y = y(p, w, z) \tag{3.24}$$

$$G = g(p, w, z) \tag{3.25}$$

Substituting equations 3.24 and 3.25 into equation 3.26 gives rise to a gross profit function which is the maximum attainable profit for a given vegetable farmer. Now, given the prices of inputs and outputs, a profit function is expressed as:

$$\pi = p'.g(p, w, z) - w'y(p, w, z) \tag{3.26}$$

The study looked at four different types of vegetables (pepper, onions, tomatoes, garden eggs) aggregated into a single profit value and used to estimate the profitability of the farmer in the study area.

3.5 Measuring Food Security of Farm Households

In analysing the effect of vegetable profit (income) on farm households' food security, the study defines a farm household according to De Janvry and Sadoulet (2015) given as an "economic unit that makes production and consumption decisions". There is no single and universally established tool for measuring food security due to its complexities and multidimensional nature. However, all indicators for measuring food security are classified under two broad categories: objective (quantitative) and subjective (qualitative) measures. Although the objective measurement indicators (eg. Per capita consumption, anthropometric), give a more precise outcome, it is often difficult to implement due to cost, logistics, sometimes burdens the respondents and could be prone to measurement errors, affecting reliability. On the other hand, whiles the qualitative indicators measure the actual (rather than potential) number of times food is available and or accessible to the household, it fails to capture the utilization and thus, only meets the social science requirement of individual or household's welfare. It also ignores the fact that "a household could consume the same number of meals all-year round but the quality of meal eaten during a certain period (eg. Lean season) may be lower than those eaten during the rest of the year" (Dzanku, 2019).

Nevertheless, this study employed two qualitative food security outcome indicators to measure the status of food security among vegetable farm households. The first was households' calorie availability (HCA) as a proxy to capture daily quantity of food consumed per adult equivalent and the second was the World Food Programme (WFP) Food Consumption Score (FCS) as a proxy measure to determine the quality of food of households.

3.5.1 Measuring the Extent of Farm Households Food Insecurity Status

Several approaches are available for measuring the extent of food insecurity status at the household level but each approach is influenced by different interrelated socio-economic, environmental, political and cultural factors. The two common approaches used to establish household food insecurity status include: the Foster-Greer-Thorbecke (FGT) approach (Tsiboe et al., 2016; Zereyesus et al., 2017) and the Food Security Index (FSI) approach (Babatunde & Qaim, 2010; Kuwornu et al., 2013).

The FGT and FSI as proxies for household food security status. Both approaches use the Recommended Daily Allowance (RDA) of calories per male adult, constructed based on the household food security line. The construction of household calorie availability is done according to age, sex and activity level of household members (see Appendix I), as recommended by FAO and WHO (1985).

3.5.2 Estimating Household Calorie Availability (HCA)

Generally, the total household calorie intake (energy availability) is estimated by determining the absolute quantity of food the household consumes within a seven-day recall period prior to the survey. This follows a series of steps. Firstly, all non-standardized quantities of foods items are converted into standard units. That is, all household own produced or purchased and or gifts and transferred food items such as maize, millet, sorghum, rice, beans, bambara beans, soybeans, cowpea etc measured in local units (eg. “Olonka” or bowl, paint container, bucket, basin, bag, etc) were converted into kilogramme as indicated in Table 3.4.

Table 3. 4 Standardisation of Local Units

Local Unit	Conversion into kg
Olonka (Bowl)	2.5
Paint Container	7.5
Bucket	15
Basin	25

Source: Author’s scaling (2020)

Next, the quantities of food items (in kilogram) are converted into standard calorie values (kcal) using the calorie conversion factor for each food item. That is, the total quantity of each food item consumed is multiplied by the food energy (calorie) content and edible-portion as indicated in Table 3.5. That is, total consumption (kcal) equals total quantity of food item (kg)

Table 3. 5 Common Food Items, Energy Conversion Factor and Edible Portion

Food group	Food item	Energy (100g)	Edible portion
Cereals	Maize	359	1.00
	Millet	391	1.00
	Rice	352	1.00
	Sorghum	369	1.00
Legume	Cowpea	335	1.00
	Soy bean	397	1.00
	Bambara groundnut	371	1.00
	Groundnuts	528	1.00
Roots & tuber	Cassava	351	0.84
	Cocoyam	149	0.81
	Yam	128	0.81
	Sweet potato	117	0.84
	Plantain	149	0.65

Source: extract from Stadlmayr et al. (2010)

multiplied by energy conversion factor multiplied by edible portion. This procedure was adopted from Kuwornu et al. (2013), Ibok et al. (2019) and Marivoet, Becquey, and Van Campenhout (2019). The reasons for multiplying by the edible portion is to capture the losses as a result of processing. The calorie availability was computed for each food item and aggregated to obtain the net weekly household calorie availability.

Next, the net weekly calorie availability is divided by seven (7) to obtain the daily calorie intake. The family size of each household was converted into adult equivalent (AE) family size with consideration for age, sex and activity level of each member (see Appendix I). The daily calorie availability per adult equivalent of the household is obtained by dividing the net calorie consumption of the household by the adult equivalent family size. The calories per AE is preferred to the calories per capita to enable compare calories intake across households with different demographic compositions. It must be noted that more than two third of diets of developing countries, particularly from Africa including Ghana come from cereals and starchy roots, few animal products, may be high in fats, and sugars (Conceição et al., 2016).

3.5.3 Determining the Recommended Daily Household Calorie Requirement

To be able to estimate each households' calorie requirement, all household members are first classified based on age and sex since people of different ages and sexes require different thresholds of food energy consumption. World Health Organisation (WHO) developed the adult equivalence based on the age and sex. The daily calorie requirements of people of different ages and sexes in a household are converted into adult equivalent using the equivalent scales (Appendix 1). This is done by multiplying the adult equivalent scales by the conversion factor of the respective age and sex of household members to convert them to the adult equivalent (AE). For example, a female of age 11-14 years requires 0.76 of the adult equivalence while a male of the same age range requires 0.86 of the adult equivalence or RDA of calories

The total calorie requirement for each household is determined by multiplying the respective total adult equivalence in each household by the Recommended Daily Allowance (RDA) for an adult. The RDA is the minimum quantity of energy required so as to enable achieve about 97% -98% healthy status for every household member (Latham, 1997). In Ghana, a RDA value of 2900kcal for people aged between 19-51+ years old, as used by IFPRI (2000), GSS (2007) and GSS (2014) was adopted in this study. The energy requirements for all ages and sexes for each household were then aggregated to give the total energy requirement of the household.

3.5.3 Measuring the Extent of Farm Households Food Insecurity

The Food Security Status (FSI_i) for the ith household was determined based on the formula given as:

$$FSI_i = \frac{Y_i}{R_i} \tag{3.27}$$

Where Y_i is the absolute daily calorie availability of the ith household and R is the Recommended Daily calorie (energy) requirement per adult equivalent in the ith household. Households with FSI less than 1 are food insecure whereas households with FSI equal or greater than 1 are food secure

Based on the absolute daily calorie indicator, the study further estimated the household specific food energy deficiency. A household's consumption below the daily per AE consumption of 2900kcal, the recommended national food poverty line or threshold in Ghana is considered as undernourished (Fisher & Lewin, 2013). To this end, the study employs Foster-Greer-Thorbecke (Foster, Greer, & Thorbecke, 1984) as used by several previous studies (Abebaw, Admassie, Kassa, & Padoch, 2020; Kahsay, Reda, & Hailu, 2019; Mitiku, Fufa, & Tadese, 2012; Zereyesus et al., 2017) to determine the severity of food insecurity status in the study area.

The Foster-Greer-Thorbecke (FGT) model has three food insecurity indices namely the head count index/ratio, food insecurity gap index and severity of food insecurity. These indices are synonymous to poverty head count, poverty gap index and poverty severity often employed to determine the extent of inequality among the poor (Foster et al., 1984). Food insecurity head count here refers to the percentage of households whose per capita calories consumption falls below the predetermined food poverty line. Similarly, food poverty gap, also referred to as the food poverty depth, measures the extent to which those classified as food poor or insecure, fall below the food poverty line. Likewise, the severity of food poverty (insecurity) measures the level of inequality among the food insecure households by assigning a higher weight. The specification of FGT is given by:

$$FGT_\alpha = (1/m)\sum_{i=1}^{n}\left(\frac{p-y_i}{p}\right)^\alpha$$

(3.28)

Where p is the cut off line between food security and food insecurity (2900 calories per AE per day); y_i is the individual household's calories intake per AE per day; m is number of households in the sample; n is the number of food insecure households and α reflects the weight, example $\alpha = 0,1,2.$ attached to the severity of food insecurity. Following this formula, an expression within the summation is employed to evaluate a given household food insecurity status by setting α at 0, 1, or 2 to determine the extent of severity in that order. For instance, setting α at zero (0) in equation 3.28 is reduced to $FGT(\alpha = 0) = n/m$ to obtain head count ratio (or the percentage) of food insecure households. In other words, substituting $\alpha = 0$, classifies a household as food insecure. However, if $p - y_i \geq 0$, that household is considered as food secure (Hoddinott, 2001).

Similarly, food security gap is obtained when equal weight is attached to the severity of food insecurity among all food insecure, which means $FGT(\alpha = 1)$. Hence, summing $p - y_i$ gives the food insecurity gap, and further dividing by p is the index of food insecurity. This is given as:

$$\left(\frac{p-y_i}{p}\right)^\alpha \qquad (3.29)$$

Where p and y_i and α remain as previously defined and setting α at one and two, respectively.

The food insecurity gap/depth measures the quantity of resources that will be required to bring all the food insecure households to subsistence level. Also, as commonly applied to estimate poverty index, increasing the weight to the severity of food insecurity means that $\alpha > 1$. In this case, applying for example $FGT(\alpha = 2)$, yields the severely food insecure households among all food insecure groups. Thus, those households further away from the subsistence level.

Based on equation 3.28 and applying the weights in each case, the incidence, depth and severity of food insecurity among vegetable farm households in the study area were identified and classified.

3.5.4 Effect of Vegetable Production on Households' Food Security Status

To estimate the effect of dry-season vegetables production on household food security status, two groups of food security outcomes were employed as dependent variables. The first was to measure the average Household Calorie Availability (HCA), a proxy for the quantity of food consumed per capita and the second was the average household Food Consumption Score (FCS), the World Food Programme (WFP) indicator for determining dietary diversity to capture the average quality of food consumed by the dry season vegetable farm households. Several studies (Fongar, Gödecke, Aseta, & Qaim, 2019; Muthini et al., 2020; Verger, Ballard, Dop, & Martin-Prevel, 2019) have used FCS to estimate dietary diversity as a proxy for quality of food. A food consumption score measures "the number of unique foods consumed in a week prior to the survey" and is used to capture the quality of diet because it is associated with micronutrient intake and nutrition of households.

In determining the effect of dry season vegetable production on households' calorie (energy) availability, probit model was employed. A household calorie consumption (or daily energy availability) was first estimated based on Ghana Statistical Service (FAO, 2009; GSS, 2014; IFPRI, 2000) criteria of household energy consumption equivalent (AE) of 2900kcal per adult per day. These standards provide the basis for the categorization of farm households food security status. Hence, household's kcal per capita consumption equal or greater than the recommended subsistence threshold of 2900kcal was classified as food secure (coded 1) and households kcal consumption below the minimum recommended threshold as food insecure, (coded 0). Following Long (1997), a dichotomous dependent variable was constructed to represent households' daily calorie availability per capita. Probit model is specified as follows:

$$HCA_i^* = \beta_0 + \sum_{1=1}^{15} \beta X_i + \varepsilon_i \qquad \varepsilon_i \sim N(0,1)$$

(3.30)

Where HCA^* is latent dependent variable for households' calorie availability; HCA is the observed variable that represents the outcome of households' calorie availability; X is a vector of vegetable income (vegetable production) and other control demographic and socioeconomic characteristics explanatory variables determining households calorie availability; β are vector of unknown parameters to be determined; $i = 1,2, \ldots 322$ households; and ε are error term which is assumed to be normally distributed across observations.

3.5.5 Empirical Model Determining Households' Calorie Availability

Empirically, the Households' Calorie Availability (HCA), represented by the binary dependent variable was regressed with vegetable income and other socio-economic determinants of household food security status given as:

$$HCA_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} +, \ldots, + \beta_{15} X_{15i} + \varepsilon_i \qquad (3.31)$$

The definitions and *a priori* expectations of the dependent as well as the explanatory variables were based on literature, as indicated in Table 3.7 below

3.5.6 Estimation of Food Consumption Score (FCS)

Food consumption score is a dietary diversity scores indicator for measuring the quality of diets of people. The reason for this second estimation was due to the fact that there could be households whose level of calorie consumption or availability may reflect that they are food secure but the quality of food served may be less than the acceptable dietary standards for a healthy and active life.

FCS is a proxy indicator that was developed by Food and Nutrition Technical Assistance Project (FANTA) guidelines with funding from USAID. This was later adopted and promoted by the World Food Programme (WFP) long before 2000 for evaluating quality of diets of households (Leroy et al., 2015). This study adopts FCS as a dependent variable to analyse the variations in dietary composition among vegetable farm households in the study area. Several studies (Akuffo & Quagrainie, 2019; Jones et al., 2013; Nkomoki, Bavorová, & Banout, 2018) have used this outcome indicator to estimate dietary quality of households. The food consumption score for the ith households is aggregated based on the specification below:

$$FCS_i = a1b1 + a2b2 + \cdots a8b8 \qquad (3.32)$$

Where a is frequency of consumption within a one-week (7-day) recall period preceding the survey, $1 - 8$ represents the various food groups and b is the weight attached to the food group. The eight (8) categories of different food groups reflect the WFP's perception of the nutrient's density in each food items such that, groups rich in protein have the highest weight while food groups with few micronutrients have the least weight as indicated in Table 3.5 below.

The data on the type food items the household has eaten in the last 7 days prior to the survey were collected based on the WFP (2008) guidelines. FCS was measured by its weighted score based on frequency of food consumption and nutritional importance of eight (8) food groups. The household FCS was calculated by first summing all food cluster frequencies within each of the eight food groups. Secondly, truncate any of the food groups score above 7 to a maximum of 7. Thirdly, multiplying each of food groups frequency by weight. And finally, the weighted food group scores are summed up to give the composite FCS. Following WFP (2008), the FCS food consumption status of households were then recoded using the threshold of poor (0 – 28) borderline (28.5 – 42) (acceptable (above 42) (P. P. Acheampong et al., 2022) The FCS is truncated on the ranges of 0 – 112 (P. P. Acheampong et al., 2022; Jones et al., 2013; Maxwell et al., 2013; Vaitla et al., 2017). FCS vary across different countries with much higher thresholds for daily edible oil and sugar consumers.

Table 3. 6 World Food Programme (WFP) Food Groups and Weights

Example of food items	Food groups	Weights
Maize, maize porridge, rice, sorghum, millet, bread, other cereals	Cereals	2
Cassava, potatoes, sweet potatoes etc	Roots and tubers	2
Beans, peas, groundnuts, cashew nuts and other nuts	Pulses	3
Vegetables, leaves, and fruits	Vegetables and fruits	1
Red meat, poultry, eggs, fish	Meat, eggs and fish	4
Milk, yoghurt and other dairy products	Milk	4
Sugar and sugar products	Sugar	0.5
Oils, fats and butter	Oil	0.5

Source: World Food Programme (2008)

3.5.7 Modelling the Food Consumption Score for Farm Households

Following WFP (2008), the dependent variable was a categorical variable which takes values of 1 (poor dietary diversity score, 2 (borderline dietary diversity score) and 3 (acceptable dietary diversity score). Hence, food consumption score and dietary diversity score are used interchangeably but mean the same in this study. The categorisation of the food consumption score into three dietary diversity score was done to differentiate households which falls under poor dietary diversity score as worse off than the those under the borderline dietary diversity score, which is also less than households under acceptable dietary diversity score. In view of that, assigning a single variable for, say “poor” and the “borderline” score alone, for instance, can be misleading.

Being a categorical variable with a clear ranking of score, an ordered probit model was applied. Ordinal data in literature usually employ multinominal logit or probit model. However, the choice between the two models is usually a matter of convenience, ease of usage and the relevant area the model is commonly adopted in analysis (Islam, Alauddin, & Sarker, 2017; Long, 1997).

Let j denotes the number of discrete ordered dietary diversity values ($j = 1,2,3$). More formally, the relationship between the observed dietary diversity score DDS_i and latent dietary diversity score DDS_i^* is represented as:

$$FCS_i \begin{cases} 1 \Rightarrow \; poor\ status\ of\ dietary\ diversity\ if\ \mu_1 = -\infty \leq DDS_i^* < \mu_1) \\ 2 \Rightarrow \; boderline\ dietary\ diversity\ if\ \mu_2 \leq DDS_i^* < \mu_2) \\ 3 \; \Rightarrow acceptable\ dietary\ diversity\ if\ \mu_3 \leq DDS_i^* < \mu_3 = \infty) \end{cases}$$

The $u's$ represent the thresholds or cut-off points for DDS that classified household's dietary diversity into 1 for poor, 2 for borderline and 3 for acceptable level. It is worth noting that ordered probit regression does not contain constant, though the cut off points can be considered as such. Each of the various categories of dietary diversity scores is a discrete category of the dependent variable, which can be explained by the same set of explanatory variables.

The study employed the maximum likelihood estimation techniques in STATA 15.1 software to determine the unknown parameters (β, μ_1, μ_2). In line with the explanation given by Long (1997), the formulas for the determination of the probabilities with three observed outcomes for the ordered model are given by:

$$\begin{cases} \Pr(DDS_i = 1|x_i) = \emptyset(\mu_2 - \alpha - \beta x_i) \\ \Pr(DDS_I = 2|x_i) = \emptyset(\mu_2 - \alpha - \beta x_i) - \emptyset(\mu_1 - \alpha - \beta x_i\ ) \\ \Pr(DDS_I = 3|x_i) = \emptyset(\mu_3 - \alpha - \beta x_i) - \emptyset(\mu_2 - \alpha - \beta x_i) \end{cases}$$

It must be noted that it is quite ambiguous when interpreting ordered probit regression estimates using the coefficients since there are three categories of the dietary diversity variable while the model estimates a single unknown threshold parameter (Greene, 2012.). Due to the challenge, it is necessary to apply the partial change or marginal effect to elicit the effects of the independent variables on the probability of the three different categories of the dietary diversity among the households.

In that case, an average marginal effect is the estimated probability of an outcome k, for continuous variable, in the range between μ_{k-1} and μ_k for a change in an explanatory variable x_m at the mean value specified as:

$$\frac{\delta \Pr(FCS=k|\bar{x})}{\delta x_m} = \beta_m[f(\mu_{k-1} - \bar{x}\beta) - f(\mu_k - \bar{x}\beta)] \quad (3.33)$$

However, the change in the predicted probability for a discrete variable to a change in x_m from the x_a (initial value) to x_b (end value), in other words, a change from $x = 0$ to $x = 1$ is specified as:

$$\frac{\delta \Pr(FCS=k|\bar{x})}{\delta x_m} = \Pr(DDS = m|x, x_m = x_b) - \Pr(DDS = m|x, x_m = x_a) \quad (3.34)$$

Where $\Pr(DDS = m|x, x_m = x_b)$ states that, the probability of $DDS = m$ given x, for a given particular value of x_m. Therefore, when x_m changes from x_a (initial value) to x_b(end value), the predicted probability of the outcome, m changes by $\Delta\Pr(DDS = m|x)/\Delta x_m$, holding all other explanatory variables at x.

The major challenges confronting the application of the ordered probit model in estimating a single crossing outcome is the linearity of the single index formulation. Additionally, the model sometimes becomes too restrictive by the constant threshold assumption and the distributional assumption (Boes & Winkelmann, 2006). Besides, the model is deficient in addressing the individual heterogeneity that often arises in estimations involving micro data such as household level. These limitations, notwithstanding, Davidson and MacKinnon (2004) opined that the ordered probit model is the most common model for ordered response data thus, was adopted in this study whiles acknowledging these challenges.

3.5.8 Empirical Model Determining Food Consumption Score (FCS)

The empirical model was used to identify the determinants of Food Consumption Score, a proxy for dietary diversity score of vegetable farm households in the study area is specified as:

$$FCS_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} +, \dots, + \beta_{15} X_{15i} + \varepsilon_i \quad (3.35)$$

The definitions and *a priori* expectations of the explanatory variables determining households' food consumption score are the same as those included in determining the households' calorie availability presented in table 3.7 below.

3.5.9 Treatment and Control Variables Influencing Food Security Status

In this study, a household is considered as a dry-season vegetable farm household if it has at least one member (eg. Spouse or any bread winner) who cultivates vegetables during dry-season using either conventional or any of the emerging irrigation systems for the purpose of generating income to support the household livelihood including food provision. As stated above, the main task of the study was to identify the impact of dry-season vegetable production on each of the two food security indicators (HCA and FCS) at the household level. The income (profit) from vegetable production and the efficiency level of the farmers are key treatment variables, expected to have positive effect on the food security status of farm households (Balana et al., 2020). This is based on the fact that households in the study area spend a larger proportion (about 66%) of their income on food consumption (Zereyesus, Ross, Amanor-Boadu, & Dalton, 2014). Similar empirical studies on the association between vegetable income and food security in Ethiopia (Gebru et al., 2019), in South Africa (Modi, 2015), in Bangladesh (Schreinemachers et al., 2015) as well as in most African countries (Joosten et al., 2015).

The task of the analysis, however, is not a straight forward activity, as there are other control variables which affect household food security apart from vegetable cultivation. In view of that, empirical literature was reviewed to identify other control determinants of households' food security in the study area. The variables identified included experience, household size, gender, dependency ratio, educational level, farm size, agricultural programme (eg. Planting for food and Jobs Programme), crop diversification, credit access, non-farm employment, ownership of livestock, own food production and farm to district market distance. These variables as specified in Table 3.7 can influence households' calorie availability as well as dietary diversity score of vegetable farm households.

The income from vegetable production was measured as a proportion of vegetable income that the farmer spends on acquiring food for the household in 2018/2019 farming year since vegetable production constitutes a major livelihood activity for households' food security in the Upper East Region. Previous studies (Abate et al., 2019; Joosten et al., 2015; Keatinge et al., 2011) have documented the positive correlation between vegetable cultivation and income and food security. The a priori expectation was that vegetable income would have negative effect on farm households' food insecurity in the study area.

Household size is a continuous variable representing the total number of members who lived and eat with household for at least six months (Mota, Lachore, & Handiso, 2019). A large household with limited livelihood earnings would have less income spent on food thus, gives rise to low households' calorie availability for consumption (Ajuruchukwu & Sanelise, 2016). Conversely, high household size may mean more labour available for other economic income generating activities for with high income to improve household food security (Owusu et al., 2011). Therefore, the impact of household could either be positive or negative to the household food insecurity status.

Table 3. 7 Description of Selected Variables in Food Security Models

Variable	Measurement	Description	Expected sign
Dependent variable			
Per capita calorie availability	Continuous	Daily calorie per adult equivalent	
Food consumption score	Continuous	Frequency of different food groups consumed	
Households Calorie Availability (HCA)	Dichotomous	1 if HCA = or > 2900kcal, 0 otherwise	
Food Consumption Score (FCS)	Discrete	1 if Poor, 2 if Borderline, 3 if Acceptable dietary diversity	
Explanatory variable			
(Log)Vegetable income (GHS)	Proportion	Proportion of vegetable income spent on food	+
Household size	Number	Number of household members	-/+
Experience	Years	Number of years of farmer	+
Gender	Dummy	1 if male and 0 if female	+
Dependency ratio	Ratio	Proportion of working to non-working household members	-
No education	Years	1 if farmer does not attain any formal education otherwise 0	+
Basic education	Years	1 if farmer attained basic level education, otherwise 0	+
SHS/Tech/Voc	Years	1 if farmer attained SHS/Tech/Voc. Education, otherwise 0	+
Tertiary education	Years	1 if farmer attained tertiary level education, otherwise 0	+
Non-farm employment	Dummy	1 if farmer has non-farm employment, 0 otherwise	+
District market distance	Kilometres	Number of kilometres from farm to district market	+
Beneficiary of PFJ prog.	Dummy	1 if farmer benefited from PFJ subsidy, 0 otherwise	+
Credit access	Dummy	1 if farmer received credit, 0 otherwise	+
Vegetables farm size	Hectare	Total farm size under vegetable production	+
Crop diversification	Number	0 if 1 crop, 1 if 2 crops, 2 if 3 crops, 3 if 4 crops planted	+
Value of livestock holding	TLUs	Total household livestock holdings	+
(Log) Food production	Kilogramme	Log of total household food produced in the year	+
Technical efficiency	TE	Technical efficiency scores of dry season vegetable farmers	+

Author's construct, (2020)

The experience of a household head, which represents the number of years a farmer has practiced vegetable farming is a continuous variable. The experience of the farmer is expected to have negative impact on household food insecurity (Villacis et al., 2022). Experience is hypothesised to mean accumulation of wealth and knowledge on how to plan appropriate coping strategies to increase vegetable income in order to enable purchase more food for the household to reduce food insecurity (Abdullah et al., 2017; P. P. Acheampong et al., 2022; Gebru et al., 2019).

Gender (sex) of a household head is a dummy variable that takes a value of 1 if male household head and 0, otherwise. Gender captures the sex role in food provisioning. Male household heads in northern Ghana are in a better position to command more labour force and fertile land for the cultivation of crops than female household heads (Lambrecht, Schuster, Asare, & Pelleriaux, 2017). Therefore, it is expected that male headed households would have negative impact on households food insecurity than female headed households due to their ability to engage in other income generating activities besides agriculture which could improve their chances for high income and food security (Broussard, 2019).

Dependency ratio is a continuous variable. Usually, it is assumed that children and the elderly outside certain age brackets are dependents (Anderman et al., 2014). However, the limitation against such economic interpretation is that, not all people within the supposed active working class are employed while some people within the assumed dependency age bracket may be working instead. In Ghana, for example, statistics on the state of employment revealed that, 24.9% of age group 15-19 and 44.3% of age above 65 are employed (GSS, 2016). In view of this, the study considered dependency ratio as a proportion of household members who are working to members who are not working. Accordingly, households with high non-working members (dependents) are hypothesised to be food insecure. Therefore, dependency ratio was expected to positively impact on household food insecurity.

Educational level of household heads was categorised into: No formal education, Basic, Senior High/Technical/Vocational education, and Tertiary education, each representing a specific a dummy variable. That is, No formal education 1 otherwise 0, basic level 1 otherwise 0, SH/Tech/Voc level 1 otherwise 0, and tertiary level 1 otherwise 0. Being a social capital, the educational level of the farmer, all things being equal, would enable an individual to secure paid up job either in the formal or informal sectors improve the household food security status. Education also represents the ability of the farmers to easily comprehend new techniques of farming (agriculture modernisation), which enhances productivity and income level compared to no education at all (Kuma et al., 2019). It is therefore expected that educated farmers would negatively impact household food insecurity.

Non-farm employment offers households with additional coping strategies to escape from poverty and food insecurity (Owusu et al., 2011; Zereyesus et al., 2017). The income from non-agricultural activities enables households to overcome economic shocks such as farm failures during bad year. It is expected that, a farmer or any household member who engages on non-farm employment including commerce, services, and cottage manufacturing industry, etc, would have a negative impact on household food insecurity (Owusu et al., 2011; Tsiboe et al., 2016; Zereyesus et al., 2017).

The farm to district market distance is a continuous variable, which represents the distance (km) from the vegetable farm to the nearest district market that the vegetables can be sold. The proximity of one's vegetable farm to the district market enhances the farmer's ability to generate more income, thus negatively impact on their household food insecurity than farmers whose farms are far away from the market (Mango et al., 2015; Sinyolo, 2020). This is based on the premise that vegetables are perishable, hence the closeness of one's farm to the market reduces the travelling time, minimises the risk of postharvest losses as such raises more income from the sale of fresh dry season vegetables.

Access to institutional resources is very important for increasing farm production and productivity and therefore enhances households' food availability and access. The government's programme "Planting for Food and Jobs" (PFJs) is captured as a dummy variable. The PFJs is an input subsidy programme that was introduced in 2017 for farmers to access farm inputs. Subsidy is meant to reduce the cost of production and increase profit (MoSDI, 2020). Similar outcome was obtained by Harou (2018) in Malawi. Farmers who were part of the programme have benefitted from farm incentives and subsidies such as improved seeds, fertilizers and extension services. The programme has improved food production and productivity, increased farm income and food security in the country (Akoto, 2019). Hence, it is expected that being a beneficiary of PFJ would impact negatively on households' food insecurity.

Credit is captured as a dummy variable and represents "1" if the farmer obtains credit, otherwise "0" if the farmer did not have access. Credit smoothens household's consumption and supports investments in agribusinesses and other non-farm sectors that can accumulate wealth. The inclusion of the credit variable is to capture its constraining effects on vegetable cultivation and by extension, its impact on household food security in the area. It is expected that access to credit would impact negatively on household food insecurity as argued by Bidisha, Khan, Imran, Khondker, and Suhrawardy (2017), Adjimoti and Kwadzo (2018) and Twongyirwe et al. (2019).

Irrigated vegetable farm size represents the size of the field that the farmer uses for the cultivation of vegetables. Irrigation is a system that de-links agricultural production from the challenges of erratic rainfall and allows for the production of crops all year round. As an agricultural intensification method, irrigation plays an important role in agriculture production and productivity (Balana et al., 2019). Hence, the field size could affect the output which in turn, affects the income of the farmer. A large farm size may not necessarily lead to high output of vegetables since the farmer may not be able to maintain the farm to harvest more. On the other hand, farmers who have enough resources to cultivate and maintain large fields, all things being equal, would lead to high output and income (Joshi & Joshi, 2017). The effect of vegetable farm size is therefore expected to impact negatively on household food insecurity.

Crop diversification represents a continuous variable and explains the number of different vegetables cultivated by farmers in the study area. Crop diversification may act as a risk reducing strategy especially when disaster affects yield or when there is market failure. Diversification also improves soil fertility, if crops with varied nutrient demands are alternated by farmers. Bellon, Kotu, Azzarri, and Caracciolo (2020) and Ecker (2018) found positive relationship between crop diversification and food security in Ghana. Several studies in other jurisdiction have found similar evidence linking crop diversification and nutrition/food security (Asfaw, Scognamillo, Di Caprera, Sitko, & Ignaciuk, 2019; Bellon, Gotor, & Caracciolo, 2015; Birhanu et al., 2021; Dillon, McGee, & Oseni, 2015). The a priori expectation is that crop diversification would have negative impact on household food insecurity

Ownership of livestock is an indication of household's wealth from draft power (Tefaye & Beshir, 2014). Manure can also be hedged against food insecurity, a form of savings and investment and a source of cash income which could be used to purchase food when household food stocks deplete (Joshi & Joshi, 2017; Kahsay et al., 2019). To adequately capture the actual value of livestock owned by households, the value of all livestock was standardised based on the conversion factor of various types of livestock (Appendix 2) in Tropical Livestock Units

(TLUs). A total Tropical Livestock Units (TLU) is defined as the number of livestock owned by a household and is measured in Tropical Livestock Units (TLU). A TLU is equivalent to one head of cattle of 250kg live weight. The International Livestock Research Institute (ILRI) values: 1.0 for cow and ox, 1.10 for horse, 0.7 for donkey, 0.13 for sheep and goat, 0.2 for pig, 0.013 for poultry bird (Benson & Mugarura, 2013; Jahnke, Tacher, Kiel, & Rojat, 1988; Kahsay et al., 2019; Storck & Doppler, 1991; Yikii, Turyahabwe, & Bashaasha, 2017). It is a continuous variable and so, the more livestock a household owns, the wealthier and more capable a household is, and can therefore invest in food purchases when the need arises (Getaneh, Alemu, Ganewo, & Haile, 2022). Empirical studies by Herrero et al. (2013) and Desta et al. (2020) opined that livestock contributes to food security by providing cash income from the sales, which can be utilised to purchase food in times of food deficit or through direct access to animal source of food. Therefore, it is hypothesised that ownership of livestock would negatively affect household food insecurity in farm households.

Household own food production is a continuous variable representing the quantity of food (kg) that is accumulated from own family farms for consumption within the year. Generally, increasing household own food production, *ceteris paribus*, would result in increased household food security (Galeana-Pizaña, Couturier, Figueroa, & Jiménez, 2021). Hence, own household food production is expected to negatively impact on household food insecurity in the Upper East Region (Kuwornu et al., 2013).

Technical efficiency represents the efficiency scores of individual dry season vegetable farmers in the study area. One critical factor that can help to raise vegetable production is when there is sustained productivity through increased technical efficiency (Villacis et al., 2022). A study by Wongnaa and Awunyo-Vitor (2018) in Ghana concluded that increasing the technical efficiency of farmers improves the productivity which in turn enhances the food security of households. Also, Oyetunde-Usman and Olagunju (2019) examined the effect of technical efficiency of farmers on household food security and concluded that technical efficient households were food secure in Nigeria. On the basis of these empirical studies, it is hypothesised that technical efficient dry season vegetable farm household would be food secure in the study area.

3.5.10 Statement of Hypotheses of the Food Security Status

The null hypothesis (Ho) of no influence against the alternative (Ha) of significant influence of the explanatory variables on the dry-season vegetable farmers' household food security status stated as:

1. $H_o: \beta_1 = \beta_2 = \beta_3 + \cdots = \beta_{15} = 0$; experience, gender, education, household size, dependency ratio, livestock holdings, farm size, own food production, vegetable income, district market distance, crop diversification, non-farm employment, credit access and planting for food and jobs programme and technical efficiency score of farmers have no significant influence on calorie availability (HCA) of vegetable farm households.

   $H_A: \beta_1 > \beta_2 > \beta_3 + \cdots > \beta_{15} > 0$; experience, gender, education, household size, dependency ratio, livestock holdings, farm size, own food production, vegetable income, district market distance, crop diversification, non-farm employment, credit access and planting for food and jobs programme and technical efficiency score of the farmers have significant positive influence on calorie availability (HCA) of vegetable farm households.

2. $H_o: \beta_1 = \beta_2 = \beta_3 + \cdots = \beta_{15} = 0$; experience, gender, education, household size, dependency ratio, livestock holdings, farm size, own food production, vegetable income, district market distance, crop diversification, non-farm employment, credit access and planting for food and jobs programme and technical efficiency score of the farmers have no significant influence on Food Consumption Score (FCS) of vegetable farm households.

$H_A: \beta_1 > \beta_2 > \beta_3 + \cdots > \beta_{15} > 0$; experience, gender, education, household size, dependency ratio, livestock holdings, farm size, own food production, vegetable income, district market distance, crop diversification, non-farm employment, credit access and planting for food and jobs programme and technical efficiency score of the farmers have significant positive influence on Food Consumption Score (FCS) of vegetable farm households.

The effect of each of the explanatory variables on the Household Calorie Availability (HCA) and Dietary Diversity Score (DDS) was tested with probability (P-value). STATA verse 15.0 software was employed for the analysis.

3.5.11 Robustness Test of Model Specification

Variance inflation factor (VIF) was employed to measure the linear relationship among continuous variables explanatory variables according to (Gujarati, Porter, & Gunasekar, 2012) given as: $VIF(x_j) = \frac{1}{1+Rj^2}$ (3.36)

Where $x_j =$ the jth quantitative variable regressed on the other quantitative independent variables. Rj^2 = the coefficient of the determination when the variable is regressed on the other independent variables. The rule of thumb is that if the VIF of a variable is greater than 10, that variable is highly collinear, as such multicollinearity is a problem (Gujarati et al., 2012).

3.5.12 Effects of the Vegetable Production Variables on Households' Food Security Status.

The study employed T-test statistics to compare the effect of technical efficiency of vegetable farmers and other production variables on household food security status of vegetable farm households in the study area. T- test given as:

$$t = \frac{x_1 - x_2}{\sqrt{s^2(\frac{1}{n1}+\frac{1}{n2})}} \quad (3.37)$$

Where t is the t-value, x1 and x2 are the means of the two groups being compared, s2 is the pooled standard error of the two groups, and n1 and n2 are the number of observations in each group

3.6 Description of the Study Area

Typical of countries within West Africa sub-region, Ghana covers six agro-ecological zones and located between latitudes 4.5°N and 11.5°N and longitudes 3.5°W and 1.5°E. Before 2018, Ghana had 10 administrative regions, but has recently divided it further into 16 regions following a constitutional amendment by an act of parliament. These regions contain 175 metropolitans, municipals and districts assemblies. Ghana's annual rainfall ranges between 800mm and 2400mm with increasing aridity as one move from south to north wards of the country. The population is about 30 million with a growth rate of 2.3%, (GSS, 2019b).

The Ghanaian economy survives on a share of GDP of 46.3% from the services, 34.0% from the industrial and 19.7% from the agriculture sector (ISSER, 2018). Until recently, the agriculture sector was the single largest contributor to GDP. It however, remains the highest employer of averagely 40% of the economically active labour force but produces mainly primary products for export (GSS, 2016). The export earnings from cocoa, timber and recently, oil drive the economy. The fruits and vegetable sub-sector constitute one of the non-traditional export earnings that contribute to the GDP. For instance, the non-traditional export (NTE) sub-sector, including vegetables earned about 441 million US$ to the economy in 2017 (GEPA, 2019).

Future predictions on the characteristics of the country's climate show that, the annual temperatures would rise by 2.0^{o}C and 3.9^{o}C while rainfall would decline by 10.9% and 18.6% by 2050 and 2080, respectively. The effects of changing climate and its consequences on temperature and rainfall are expected to reduce growing seasons and decrease crop yields between 20-50% by 2050 in Africa including Ghana (Connolly-Boutin & Smit, 2016; Seini, Botchie, & Damnyag, 2004). The rise in temperature coupled with reduced rainfall increases evaporation and lessen water availability for meaningful agriculture activities and food security. In Ghana, the effect of climate variability is particularly severe in the five regions of the north namely, Northern, Savannah, North East, Upper East and Upper West Regions.

The focus of this study is the Upper East Region of Ghana. It is bordered to the north by Burkina Faso, the east by the Republic of Togo, the west by Sissala district in Upper West Region and south by the North East Region. The region has 3 municipalities (Bolgatanga, Kasena Nankana East, Bawku East) and 11 districts (Bolga East, Tongo, Nabdam, Bongo, Bawku West, Binduri, Pusiga, Garu, Tempane, Kasena Nankana West and Sandema) where agriculture constitutes about 83% of the livelihood of the people (GSS, 2019a).

The region has a total area of about 8,842km^2 representing about 3.7% of the total land mass, inhabited by 1,046,545 people with population density of 118 persons/km^2 relative to 35 persons/km^2 in the northern region (Northern, Savannah and North East Regions) and 38 persons/km^2 in Upper West Region (GSS, 2016). The entire Northern Ghana experience unimodal rainfall season with annual rainfall range between 700mm and 1010mm, with peak rainfall occurring in late August and ending in September. The annual evapotranspiration is higher than precipitation, making water storage reservoirs critical source for supply of water for agricultural activities during the dry season. The long spell of dry season from November to mid-May is accompanied by dry cold and dusty "harmattan" winds from November to February. The months of March to April are, however, characterised by dry hot temperature, sometimes above 40^{o}c. The natural vegetation is the savannah woodland with scattered drought-resistant trees and grasses (Mdemu, Rodgers, Vlek, & Borgadi, 2009).

Like most parts of the country, small holder agriculture with per capita land size of averagely less than 2 hectares dominates livelihood activities. The main types of soils are sandy clays, clay loamy, and sandy loam. The crops grown in the Upper East Region include millet, guinea corn, maize, groundnut, beans, and sorghum. Rice is however, grown in both rainy and dry season, though on a small scale during the dry season along with vegetables like tomatoes, pepper, onions, garden eggs, cabbage, aleafy, bitter leaf, on irrigation sites.

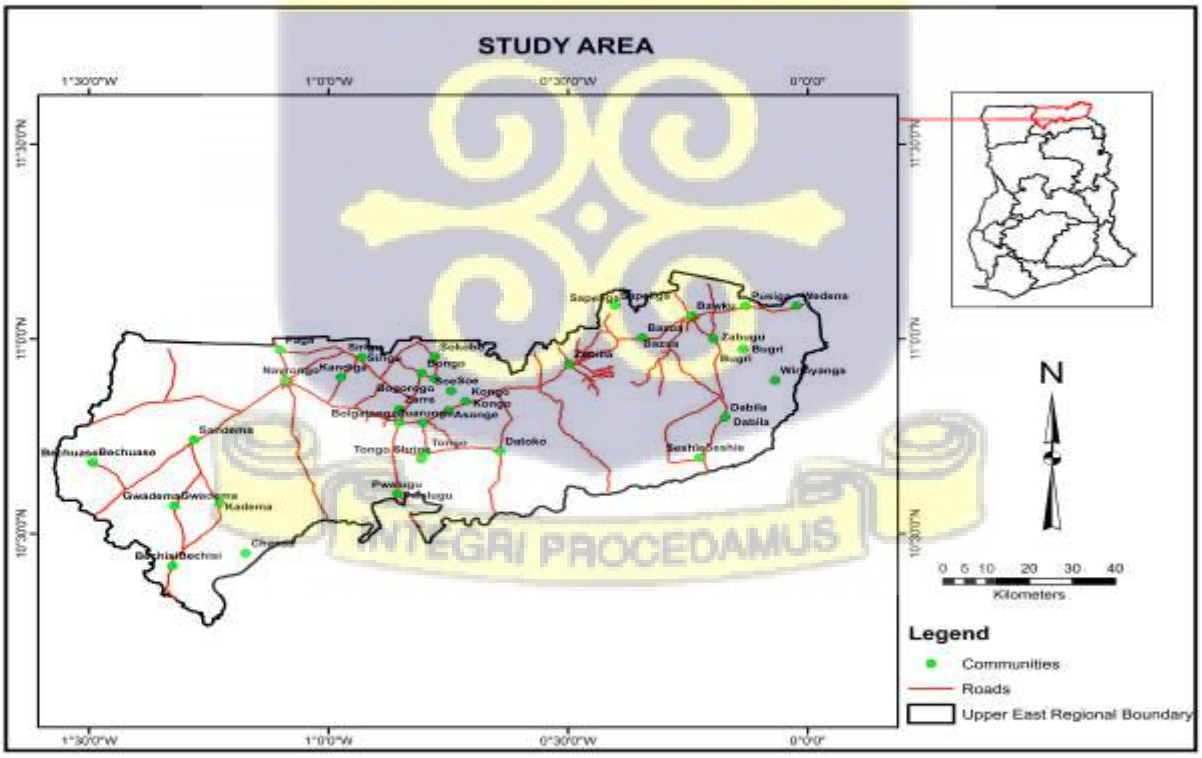

Fig. 3. 2 Map of Ghana indicating the Upper East Region

Given the prospects for dry season agriculture to reduce poverty and increase food security, the Upper East Region continues to attract the attention of successive governments who establish dams and dugouts to boost all year-round farming. Two large irrigation dams, the Tono and Vea dams, as well as a cross section of small dams, dugouts are constructed in the region.

Additionally, natural water bodies such as rivers and streams are wide spread in the region. The White Volta, in particular drains several water bodies in the northern part of the country, flowing southward. The White Volta river basin also has its connection from the Bagre dam in Burkina Faso (Mdemu et al., 2009). Annually, managers of the Bagre dam in Burkina Faso spills excess water in September-October, often causing flood and damaging livelihoods and putting lives at risks in northern Ghana with the Upper East Region largely affected (WFP, 2012). The abundance of grassland support livestock like cattle, goats, sheep and pigs under semi-intensive system. Poultry such as fowls and guinea fowls are also reared on a small scale.

3.7 Method of Data Collection

3.7.1 Sources of Data

Both primary and secondary data were used for the study. The primary data was obtained from vegetable farmers and their respective farm households while secondary data was obtained from the districts offices of Ministry of Food and Agriculture (MOFA) and the Irrigation Company of Upper Region (ICOUR). The questionnaire for the primary data was first pretested and revised, incorporating feedback from enumerators and pre-test participants, before deploying on the wider scale. The survey instrument recorded data about the composition and socio-economic characteristics of dry season vegetable farmers and their households. Respondent farmers were asked to provide in details, the production inputs, outputs, prices, costs of production and returns of vegetables as well as the acquisitions of household food and consumption in the region. The common vegetables cultivated are onions, pepper, tomatoes, okra, garden eggs, and leafy vegetables. However, data was sought for only pepper, onions, tomatoes, and garden eggs, because they are the most dominant crops commercially cultivated by the farmers during dry season. The rest of the household information included own food production, livestock holdings, non-farm employment, remittances, and other earning and pensions.

Food security data was elicited from respondent households, particularly from the persons who prepare food for the entire households, in the presence of other household members. The data covered quantities of food consumed including food from own production and purchases from the market. For an annual data to be comprehensive, it should cover all calendar months to avoid seasonality bias, but the accuracy of food consumption data is negatively associated with the length of the recall period (Bouis, 1994). In view of that, a seven-day recall period was employed in the survey to minimise inaccuracies.

The survey was conducted in the period when the main staples were being harvested, during which the household consumption is often above the annual average. In that case, the prevalence of food insecurity derived from the data might have been understated. This was not a serious issue at all on grounds that, since the focus of the study was on determining the implications of dry season vegetable production on household food security, it was equally possible that vegetable income helps to better smoothen food intake over the year and reduces the consumption shortfall during the lean season. Based on that, the data might understate the effect of vegetable income on food security for the entire year. This concern was noted when interpreting the results.

3.7.2 Data Sampling and Sample Size

The study employed data from a comprehensive survey of dry season vegetable farmers and their households in the Upper East Region. The survey was conducted between May and November 2019. The Upper East Region was chosen because dry season vegetable farming constitutes one of the main livelihood activities of the people. The Ghana Statistical Service (GSS) Labour Force Report in 2015 revealed that, 83% out of the over 1 million people in the region are farmers (GSS, 2016). They produce mainly cereals in the rainy (major) cropping season. Commercial vegetable farming during dry season is, however, adopted since farming in the rainy season has become unreliable hence unable to meet the food security requirements of households in the region (MOFA et al., 2020).

A multi-stage sampling design was applied to sample dry season vegetable farmers and their respective households for the study. Beaman and Dillon (2012) definition of a household was adopted for the study. Here, a household is “a group of people who are generally bound together by ties, kinship or joint financial decision, who live together in same dwelling space, commonly work together on at least one income-generating activity, are answerable to one person as the head and share at least one eating arrangement”. Accordingly, a household also referred to as a vegetable farm household, is where either the head and or the spouse of the household head cultivates any of the vegetables (pepper, onions, tomatoes, garden eggs) considered in the study during dry season in the study area.

The sampling techniques adopted was meant to ensure proportional representation of all dry season vegetable farming districts in the study. In the first stage, seven (7) out of the fifteen (15) districts and municipals where vegetables are cultivated in the region were purposively selected and zoned into three to constitute the Primary Sampling Unit (PSU). That is, the PSU comprises the Central zone (Bolga municipal, Talensi and Bongo districts), Eastern zone (Bawku Municipal, Binduri and Zebilla districts) and Western zone (Navrongo Municipal).

The purposive sampling of the districts was based on those with similar characteristics like the major type of vegetables grown, sources of irrigation water use and proximity. For instance, while the districts in the eastern zone grow mainly onions, those in the central cultivate tomatoes and the western zone districts zone grow mainly pepper. The sources of irrigation water used for vegetable cultivation also vary across the zones. The western zone covered only Navrongo Municipal though has the largest reservoir used by many dry season farmers for cultivating vegetables than the rest of districts in the region.

In the second stage, eight (8) communities per farming zone were randomly selected across the three (3) zones, making up 24 communities. A complete list of vegetable farmers from the sampled communities, provided by each respective districts MOFA officer constituted the Secondary Sampling Unit (SSU).

Then, Cochran's sample size formula (Cochran, 1977) was employed to determine the number of dry season vegetable farmers and their households for the study. The generalised Cochran formula is given as:

$$n_o = \frac{Z^2pq}{e^2} \quad (3.38)$$

Where e (desired precision) = 0.05, at 95% confidence interval (z = 1.96), p = 0.5 (proportion of the population size), q = 1 – p. This gave a Cochran's sample size value (n_0) of 385. Now, adjusting with a population sample of 6410 farmers in the formula in eq (3.3) obtained a sample size of 366 farmers for the study.

$$n = \frac{n_0}{1+\frac{(n_0-1)}{N}} \quad (3.39)$$

With the support of the respective districts Agricultural Extension Agents (AEAs), the aspirational sampling target of 366 farmers in table 3.8 were systematically sampled. Sampling was based on proportion-to-population sampling design using systematic random sampling method. Systematic random sampling method involves selecting sample units at specific intervals. Similar sampling method was employed by the Ghana Statistical Service for the Ghana Living Standard Surveys (GSS, 2019a) and adopted by Tesfay, Grmay, and Yohannes (2020) for the study of household food security in Ethiopia.

Table 3. 8 Sample Size Distribution of Dry-Season Vegetable Farmers

Zone	District	Community	Farmer Pop.	Sampled size	Completed questionnaire	% Completed
Central	Bolga	Yikene	354	20	19	
		Zaare/yorogo	313	18	15	
		Sumbrungu/Dindubisi	123	7	8	
		Bolga-Nyariga	339	19	18	
	Bongo	Bongo-Nyariga	241	14	13	
		Gowrie/Vea	302	17	14	
	Talensi	Pwalugu	215	12	10	
		Baare/Yinduri	187	11	9	
Total			**2,074**	**118**	**106**	33.00
Eastern	Zebilla	Kamega/Teshie	168	10	9	
		Timonde/Yarigu	241	14	13	
		Saka/Ampalug	263	15	12	
	Binduri	Kumpalgoga	205	12	10	
		Binguri	320	18	17	
		Azum Sapelga	560	32	30	
	Bawku	Kpalwega	285	16	15	
		Modnori	283	16	16	
Total			**2,325**	**133**	**122**	38.00
Western	Navrongo	Biu	325	18	16	
		Gaani	217	12	8	
		Korania	244	14	12	
		Yoobgannia	321	18	15	
		Bonia	274	16	13	
		Wuru	230	13	10	
		Yigbwannia	219	12	9	
		Chuchuliga	208	12	11	
Total			**2,011**	**115**	**94**	29.00
Grand total			**6,410**	**366**	**322**	100

Source: MoFA and ICOUR, Upper East Region, (2020).

Under the direct supervision of the researcher, data was collected by a team of enumerators recruited and trained on the use of smartphone technology for the data collection prior to the survey. Data were collected via face-to-face personal interviews of vegetable farmers, usually in the presence of other household members, especially for the food security data, using tablets. The Open Data Kit (ODK) platform was used and data uploaded daily.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents and discusses the results of the study. The first section contains the socio-economic profile of the respondent vegetable farmers. The next section covers the explanatory variables used in the frontier model, the hypotheses test results, the maximum likelihood estimates of the technical efficiency of farmers and the elasticities of inputs. This is followed by the section that presents analyses of the profitability of vegetable production. The final section contains an assessment of the food security status, the extent of food insecurity and effects of socio-economic factors affecting vegetable farm households' food security status.

4.2 Socio-Economic Profile of Vegetable Farmers

Table 4.1 indicates the summary of the frequency distribution of the socio-economic profile of the respondents. About 322 (88.0%) out of the aspirational target of 366 farmers answered the questionnaires appropriately after cleaning the data. The remaining 12.0% (44) responses were either not completed or were outliers as such were therefore eliminated from the data. About 33.0% (106) of the data was obtained from the central zone, 38.0% (122) from the eastern zone while 29.0% (94) was obtained from the western zone.

Majority (90.4%) of the farmers were males while only 9.6% of them were females. This was expected given the patriarchal dominance in dry season commercial vegetable farming in the study area. Men control majority of the irrigable lands. The gruelling work involved in vegetable cultivation, perhaps limits women in dry season vegetable production in the area. Majority (64.3%) of the farmers were within 15-35 years, 31.0% were within 36-60 years, while a few 4.7% were above 60 years old. Majority of the farmers in the youthful age bracket is indicative of the interest of the youth in dry season vegetable cultivation, perhaps, due to their desire to raise income to meet their livelihood.

Table 4. 1 Distribution of Socio-Economic Characteristics of Respondents

Variable	Freq.	%
Farm location		
Central (Bolga, Tongo, Bongo) zone	106	33.00
Eastern (Bawku, Binduri, Zebilla) zone	122	38.00
Western (Navrongo) zone	94	29.00
Total	**322**	**100.00**
Farmer's gender		
Male	291	90.40
Female	31	9.60
Farmer's age group (years)		
15-35	207	64.30
36-60	100	31.00
Above 60	15	4.70
Total	**322**	**100.00**
Farmer's edu. Level	322	100.00
No education	121	37.60
Basic education	133	41.30
SHS/Tech/Voc.	45	14.00
Tertiary (college, polytechnic, university)	23	7.10
Total	**322**	**100.00**
Access to extension service		
Yes	284	88.20
No	38	11.80
Total	**322**	**100.00**
Farm size		
Between 0.1 – 0.5ha	195	60.60
Above 0.5ha	127	39.40
Total	**322**	**100.00**
Crop diversification		
Planted 3 or more veg.	17	5.30
Planted 2 veg.	68	21.10
Planted a single veg.	237	73.60
Total	**322**	**100.00**
Irrigation water source		
Large dam	102	31.70
Small dam/dug out	79	24.50
Perennial rivers/streams	124	38.50
Temporal wells	16	5.00
Bore holes	1	0.30
Total	**322**	**100.00**
Irrigation technology		
Manual irrigation	54	16.80
Gravity fed	60	18.60
Motorised water pump	208	64.60
Total	**322**	**100.00**
Credit received		
Yes	58	18.00
No	264	82.00
Total	**322**	**100.00**

Source: Survey results, (2020).

Generally, access to education and training enhance acquisition of knowledge and skills for improved productive capacity of farmers. Majority (41.3%) of the farmers had acquired basic education (ie. Primary and Junior High School) while 37.0% of the farmers had no formal education. About 14.0% of the farmers have reached SH/Tech/Voc level while a few (7.1%) had education up to the tertiary level. This suggests that many people in the region drop out of school after basic level or do not attend school at all, which could have negative effect on the ability to be effective in the farming. In terms of extension education, a total of 284 (88.2%) farmers had access to extension service while 38 (11.8) had no access to extension services in the region. The extensive coverage of extension education can be explained on the fact that, unlike raining season, farming during dry season under irrigation, is limited to some few farmers, hence, the extension officers are able cover many irrigators.

About 60.6% farmers had land size ranging between 0.1 and 0.5ha, an indication of dominance of small holders in dry season vegetable production in the region. About 39.4% of the farmers cultivate on land size greater than 0.5ha. A few of the farmers have adopted crop diversification as a strategy for various reasons including mitigating production and price risks (Manjunatha et al., 2013). However, majority (73.6%) practice sole cropping, that is cultivating either pepper, onions or tomatoes. The rest (about 21.1%), produced two types of vegetables whiles only 5.3% cultivate either three or all four types of crops, although on different pieces of plots in the same area or at different locations but in the same district. The least cultivated crop in the area was garden eggs.

Perennial rivers and streams (38.5%), large reservoirs or dams (31.7%), small dams/dugouts (24.5%) constitute the main sources of water for vegetable cultivation in the study area. Only a few (5%) farmers, mainly from the eastern zone (Bawku enclave) obtain water from temporal wells that were dug on their farms. It must be noted that temporal wells are seasonal wells, which are usually abandoned or covered up when the season' production is over and the land has to be prepared for planting staples (maize, millet, sorghum, groundnuts, etc) when the rain starts for the main cropping reason.

Motorised diesel/petrol water pumps connected with water hoses (64.6%) form the majority of irrigation technology adopted by farmers to lift water from the source to irrigate the fields. Laube et al. (2012) and Namara et al. (2014) obtained similar outcomes in their studies on irrigation technologies in Ghana. A few (18.6 percent) utilise gravity fed technology while the manual system involving the use of buckets and watering cans etc constitute about 16.8 percent. The motorised water pumps technology has been a challenge for farmers considering the rising cost for fuel and the operating and maintenance for using the machinery. Access to credit was a hindrance to vegetable cultivation since few (18%) of the farmers had access to credit while 82% never obtained credit not because they did not ask for it but the opportunities were not available to them. The farmers had to rely on equity capital to fund their farming activities. This, perhaps, could have limited the ability of these farmers from purchasing modern inputs to expand and maintain their farms for increased productivity.

4.3 Explanatory Variables Used in Stochastic Frontier and inefficiency Models

Table 4.2 describes the averages of the variables used in the stochastic frontier model. A bulk of the cost of production went into labour and irrigation which accounted for averagely GHS4,182.00 and GHS807.00 per ha, respectively. The average output value of vegetables harvested was GHS8,449.86. Ideally, the estimations for irrigations should have been based on the quantity of irrigated water (volume) but data was a major challenge. The study therefore relied on the frequency of irrigations (watering) per season, which revealed that, a farmer requires between 10 – 40 times per month to irrigate the crops, depending on the type of soil structure, the age of the crops and the irrigation technology the farmer adopts. This gives the average number of times a farmer irrigates (apply water) to be 51 times, for the entire 3 months period of farming activities.

Table 4. 2: Summary of Selected Variables in Frontier and Inefficiency Models

Frontier var.	**Measurement**	**Mean**	**Std.**	**Min.**	**Max.**
Veg. value	GhS/ha	8449.86	8172.00	105.00	39100.00
Labour cost	GhS/ha	4182.00	2951.00	321.00	19958.00
Seed cost	GhS/ha	245.00	248.00	10.00	2400.00
Fertilizer cost	GhS/ha	359.00	292.00	10.00	2120.00
Agrochem. Cost	GhS/ha	271.00	267.00	1.00	1600.00
Irrigation cost	GhS/ha	807.00	807.00	40.00	6120.00
Inefficiency var.					
Irrigations	Watering no.	51	42	10	255
Household size	Number	7	3	1	35
Experience	Years	9	7	1	45
Farmer's age	Years	41	11	16	86
Age squared	Years	1872	1006	256	7396
Extension visits	Number	2	2	0	7
Dummy var.	**Measurement**			**% of farmers with 1**	**% of farmers with 0**
Irrigation tech					
Manual	Yes = 1	No = 0		16.80	83.20
Gravity fed	Yes = 1	No = 0		18.60	81.60
Water pump	Yes = 1	No = 0		64.60	35.40
Gender	Yes = 1	No = 0		90.30	9.70
Credit access	Yes = 1	No = 0		18.00	82.00
Farmer's edu.					
No formal edu.	Yes = 1	No = 0		37.60	62.40
Primary/JHS	Yes = 1	No = 0		41.30	58.30
SHS/Tech/Voc.	Yes = 1	No = 0		14.00	86.00
Tertiary	Yes = 1	No = 0		7.10	92.90
Crop type					
Pepper	Yes = 1	No = 0		68.00	32.00
Onions	Yes = 1	No = 0		25.78	74.22
Tomatoes	Yes = 1	No = 0		13.66	86.34
Garden eggs	Yes = 1	No = 0		8.07	91.93

Source: Survey results, (2020)

For instance, farmers who used motorised pump and gravity-fed, irrigate once after every third-day, while those who use the manual system irrigate twice daily (morning and evening) for every other day. The reasons for the differences in the frequency of irrigation (watering) is that, high volume of water is applied to crops at a time using the water pump of gravity-fed system of technologies. A small volume of water is however, applied to the crops at a time with the manual system, hence it has to be frequent enough to avoid the effects of drought. Besides, the high temperature (sometimes above 40^{o}c) usually experienced during the day in the study area encourages high evapotranspiration and wilting of the crops, as such requires frequent replenishment to maintain the required soil moisture content for the crops to flourish. While farmers using the motorised pump system of irrigation spend a bulk of their resources on the running cost of the machines, including fuelling and repairs, others farmers particularly those from the Bawku enclave (eastern zone) relied on temporal wells that they dug on their farms as their source of irrigation water. As such they spend extra money on labour for digging the wells aside having to manually water the crop frequently.

The average age of the farmers was 41 years with 9 years' experience in the cultivation of vegetables. This means, the farmers are matured and well-experienced in dry season vegetable farming. Similar results were obtained by Donkoh et al. (2013) in the study of tomato farmers at the Tono irrigation site in Navrongo in the Upper East region of Ghana. Averagely, each farm household has 7 members, an indication that family labour may have been available for farm activities. Each farmer had an average of 2 extension visits for the entire three months farming season. Other inefficiency dummy variables included were type of irrigation technology, educational level of farmers, credit access, gender and the type of crops cultivated by the farmers.

4.3.1 Hypotheses Test Results

Table 4.3 presents the results of the maximum likelihood ratio tests of relevant hypotheses in the stochastic frontier analysis. The first test was the null hypothesis that the coefficient of the second – order (β_{ij}) variables in the translog model was zero. In other words, the test that the Cobb-Douglas model is appropriate for the data was rejected in favour of the translog model, because the likelihood ratio test statistic is greater than the tabulated (critical) value. The trans-log model was, therefore chosen as the best model for the data set, thus was employed to derive the estimates.

The second hypothesis test that the production risk in the inputs choices does not exist in the production process was also rejected since the calculated statistic value is greater than the critical Chi-square value. This implied that production risk associated with input choices is present in the data.

Table 4. 3: Hypothesis Test for Model Specification and Statistical Assumptions

Null hypothesis	Test statistic (λ)	Critical value	Decision rule	Conclusion
$H_{0:}\ \beta_{ij} = 0$	52.03	30.58[a]	Rejected	Trans-log is appropriate
$H_0: \theta_1 = \theta_2 = \ldots \theta_5 = 0.$	123.14	15.09[a]	Rejected	Production risk explain output variability
$H_0: \lambda = 0.$	169.48	9.50[b]	Rejected	Presence of Inefficiencies
$H_0 : \delta_1 = \delta_2 = \ldots\ \delta_{20} = 0$	98.74	34.81[a]	Rejected	Exogenous variables affect variation
$Ho: \sum Bi = 1;$ $Hi: \sum Bi \neq 1$		0.00[c]	$Ho = 0$ rejected	Not CRS

Source: Model result, (2020). $x^2\ 0.001^a\ mixed 0.001^b, p - value^c$ Chi-square critical values are sig. at 1%

The third hypothesis that the inefficiency effect is not present, and that the inefficiency effects are indeed not stochastic was also rejected since the likelihood test statistic is greater than the critical value from the mixed square distribution table (Kodde & Palm, 1986). This meant that employing the traditional average response function was inappropriate representation for the data. Rather, the data favours the stochastic frontier and inefficiency models.

The fourth null hypothesis which states that all coefficients of the exogenous variables in the model explaining the inefficiency effects are zero was also rejected. This implied that the combined effect of the technical inefficiency variables are important determinants explaining the output variability in dry season vegetable production in the region. This does not mean, individually, the variables may not be significant.

The fifth hypothesis which states that the sum of the coefficients of the elasticities are equal to constant was rejected. This implied that the sum of the coefficients of elasticities could either be at the range of Decreasing Return to Scale (DRS) or Increasing Return to Scale (IRS).

4.3.2 Maximum Likelihood Estimates of Technical Efficiency of Dry Season Farmers

Table 4.4 indicates the maximum-likelihood estimates for the stochastic translog model. The results show the mean output value function (upper rows), production risk function (middle rows), the variance parameter as well as the multicollinearity and heteroskedasticity test results (lower rows).

The Diagnostic Statistics of Model Fitness reveals a lambda ($\lambda = \sigma u/\sigma v$) of 1.904 in the function is highly greater than zero, implying that the model and its distributional assumptions were chosen appropriately. The positive lambda equally indicates that the variation in the observed output values from the frontier are due to both technical inefficiency and stochastic noise components, as such, the data cannot be estimated with the use of ordinary least square model. The results however, reveal that the deviation from the frontier attributed to technical inefficiency ($\sigma u = 0.456$) is relatively higher than the deviation due to the idiosyncratic disturbance effects ($\sigma v = 0.239$), which is accounted by measurement errors, adverse weather conditions, diseases and pests' infestations, etc. The gamma (γ) value of 0.78 implies that 78% of the total variations in output value of vegetables are attributed to technical inefficiencies in the study area.

The Wald chi-square statistic (4871.390) is highly significant (1%), indicating the presence of a joint significance of the stochastic frontier model. The small value of the Variance Inflation Factor (VIF) of 1.630 reveals that the model is free from multicollinearity (Edriss, 2003). Lastly, the outcome of the Breusch Pagan (BP) statistic test of 0.944 not being significant reveals the absence of heteroskedasticity.

The results of the maximum likelihood estimates show that the signs of all the variables included in the parameter estimates of the stochastic frontier trans-log model are in line with theory. It is worth noting that, the various inputs cost were normalised with land (ha) and scaled by their respective sample means according to (Battese & Broca, 1997). Therefore, the first order coefficients are considered as elasticities of the output value of the vegetables with respect to the different inputs cost. In that case, the coefficients of each input cost are therefore, interpreted as elasticity. The coefficient of labour, seed, fertilizer, agrochemical, and irrigation

Table 4. 4: Maximum Likelihood Estimates of Trans-log Mean Stochastic Function

Variable	Par.	Coeff.	Standard error
Constant	β_0	0.184***	0.042
Lnlabour cost	β1	0.434***	0.042
Lnseed cost	β2	0.099***	0.038
Lnfertilizer cost	β3	0.383***	0.048
Lnagrochemical cost	β4	0.321***	0.031
Lnlrrigation cost	β5	0.105***	0.032
0.5Ln(labour cost)^2	β6	0.195	0.120
0.5Ln(seed cost)^2	β7	-0.156	0.102
0.5Ln(fertilizer cost)^2	β8	-0.086	0.095
0.5Ln(agrochemical cost)^2	β9	0.055	0.035
0.5Ln(lrrigation cost)^2	β10	0.383***	0.076
Lnlabour cost * Lnseed cost	β11	-0.114	0.074
Lnlabour cost* Lnfertilizer cost	β12	0.009	0.094
Lnlabour cost* Lnagrochemical cost	β13	-0.040	0.052
Lnlabour cost* Lnirrigation cost	β14	-0.238***	0.068
Lnseedcost * Lnfertilizer cost	β15	0.275***	0.068
Lnseed cost* Lnagrochemical cost	β16	0.046	0.053
Lnseed cost* Lnirrigation cost	β17	-0.140**	0.063
Lnfertilizer cost* agrochemical cost	β18	0.052	0.056
Lnfertilizer cost* Lnlrrigation cost	β19	-0.071	0.061
Lnagrochemical cost* Lnlrrigation cost	β20	-0.035	0.041
Production Risk variables	**Par.**	**Coefficient**	**Standard error**
Lnlabour cost	ψ_1	-0.002***	0.001
Lnseed cost	ψ_2	-0.001	0.002
Lnfertilizer cost	ψ_3	0.003**	0.001
Lnagrochemical	ψ_4	-0.003**	0.001
Lnlrrigation cost	ψ_5	0.001	0.002
Model diagnostics			
σu		0. 456	
σv		0. 239	
Lambda ($\lambda = \sigma u/\sigma v$)		1.908	
$\sigma^2 = \sigma_u^2 + \sigma_v^2$		0.265	
Gamma (γ) = $\sigma_u^2/\sigma_u^2 + \sigma_v^2$		0.784	
Wald chi2		4871.390***	
Mean VIF (multicollinearity)		1.630	
Breusch-Pagan test (heteroskedasticity)		0.944	
Log likelihood function		-90.165	
Mean technical efficiency		0.730	
Maximum TE		0.990	
Minimum TE		0.070	
Number of observations		322	

Source: Model results, (2020). Note: *** p<0.01, ** p<0.05, * p<0.1

costs are positively related to the output value of vegetables and highly significant $(p < 0.01)$, indicating that all the inputs have reasserting influence on vegetable production in the region. This implies that a 1% increase in costs of investment on labour, fertilizer, agrochemical, irrigation and seed increases the output value of vegetables per hectare by 0.434%, 0.383%, 0.321%, 0.105%, 0.099%, respectively.

The results further reveal that labour has the most important effect on the output value of vegetable production. This implies that investing more on labour yields higher returns, perhaps due to the fact that vegetable production is labour intensive. Indeed, the agronomic practices (eg weeding, application of water, pesticides control, harvesting etc) required for maintaining the quality of vegetable farms are quite labour demanding that result in more fruiting and higher gross profit. The finding is consistent with the study by Bozoğlu and Ceyhan (2007) of vegetable farms in Samsun Province in Turkey and Habiyaremye et al. (2019) research on vegetable-poultry integration in rural Tanzania. The next important yield-booting inputs were fertilizer and agrochemical, irrigation and seed, which all show significant positive relationship with the output value of vegetable production in the study region.

The results of the marginal production risks estimates show that the signs of the coefficients of the production risk function all met the *a priori* expectation and in line with theory. The findings reveal information on the input factors causing output variability as a result of the production risk decisions that were taken prior to the production. Whiles some inputs may be risks minimising, others may be risks maximising, as such provide useful guide to stabilise vegetable output in the study area.

The study shows that all variables in the production risk function influence vegetables production significantly. The estimates show that labour, seed and agrochemical decrease the variability of output value of vegetables. The risk-decreasing effect of seed cost confirms the apriori expectation that obtaining good quality seed from accredited dealers may result in less variation in quantity and quality of vegetables produced similar to the conclusion by Guttormsen and Roll (2014) in Tanzania. Fertilizer cost and irrigation costs increase the output variability of vegetables in the study location. This explain why risk-averse farmers may decline to apply more fertilizer even though they are aware that using more fertilizer appropriately is more profitable. Also, inefficiencies in the utilization of available irrigation technologies may be causing wastage of water, thus resulting in increases in output variability of vegetables in the study area.

The findings imply that a risk-averse vegetable farmer who intends to reduce the cost of production may opt to increase the usage of more labour, apply more seed and agrochemical, which may in turn, affect the efficiency of vegetable production. However, that same farmer who may want to reduce losses due to production risk, would be expected to use less fertilizer as well as reduce the costs of investments on irrigation, which might have negative implications on vegetable output and eventually reduce the profitability for such a farmer. This finding lends credence to the fact that vegetable cultivation is a labour-intensive industry, as such labour plays a critical role in farm maintenance (weeding, monitoring outbreak of diseases and pests and control, irrigations etc). For instance, a vegetable like pepper being a perennial crop requires constant weeding, application of fertilizer, agrochemicals, and irrigations for continues fruiting, as such, requires more investments of capital and labour resources.

4.3.3 Elasticities of Inputs

Table 4.5 indicates the elasticities of various inputs employed on vegetable production in the study area. Total elasticity measures the Return to Scale (RTS) which is obtained by adding all the inputs elasticities of the production. Hence, the sum of elasticities equalled 1.34 points. This implies that on the average, dry season vegetables farmers are operating at an increasing rate of return to scale in the Upper East region. In other words, when all the inputs cost are jointly increased by 1%, the output value of vegetable farmers will increase by 1.34%.

Table 4. 5: Elasticity and Return to Scale

Variable	Parameter	Elasticity
lSNlabour cost	B_1	0.434***
lSNseed cost	B_2	0.099***
lSNfertilizer cost	B_3	0.384***
lSNagrochemical cost	B_4	0.321***
lSNirrigation cost	B_5	0.105***
Return to scale (RTS)		1.340

Source: Model results, (2020). *** p<0.01, ** p<0.05, * p<0.1

Again, vegetable farms in the Upper East Region are operating on the first stage of the production function. For this reason, farmers could take advantage to expand their farms to enjoy the advantage of economies of scale. However, expanding vegetable farms will also be associated with increasing expenditure on cost of irrigation since water is a scarce resource during dry season in the study region. The challenges of getting water for vegetable production during dry season limit vegetables farm expansion in the study area.

4.3.3 Technical Efficiency Estimates

The distribution of the technical efficiencies of dry season vegetable farms in the Upper East Region of Ghana is reported in Fig.4.1. The results depict the distribution of the technical efficiencies ranges between a minimum and maximum technical efficiency score. The graph shows that, 188 out of the 322 farmers recorded technical efficiency scores below 80% while 134 farmers obtained technical efficiency scores between 81% and 99%. The modal technical efficiency scores show that 133 observations operate within the efficiency scores of 81% and 100%. The overall predicted mean technical efficiency score was 0.73 points. This means that on the average, dry season vegetable farmers produce about 73% of their potential (stochastic) frontier output value, given the current level of technology and inputs use. The implication is that about 27% of the farm's potential output is unaccounted for due to technical inefficiency.

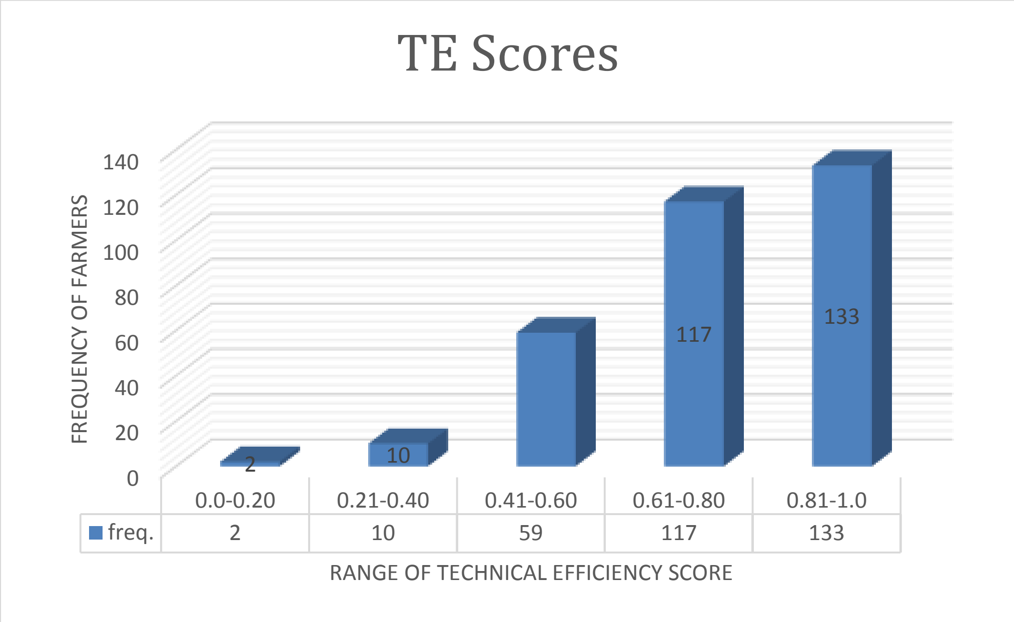

Fig. 4. 1: Distribution of Technical Efficiency Scores of Vegetable Farmers.

This, therefore means that there is the possibility of increasing vegetable productivity in Ghana by an average of 27% within the shortest possible time with the same disposable resources by adopting the practices of the best farm.

4.3.4 Determinants of Technical Inefficiency of Dry Season Vegetable Farmers

The results in Table 4.6 show the effects of the exogenous variables on technical inefficiency of dry season vegetable farmers. Most of the variables associated with technical inefficiency, had the expected signs, though some relationships were weak. The findings indicate that variables which had significant coefficients included household size, extension visits, use of motorised water pump system, use of gravity-fed irrigation system, and years of experience. Contrary to the a priori expectation, the coefficient of household size is estimated to be negative and significant at 1% level. This implies that farm families with relatively larger household sizes are relatively less efficient than those with smaller household size. Asravor et al. (2016), also obtained similar findings in their study of technical efficiency and its determinants of chilli farms in the Volta region of Ghana. A summary statistic of the data shows that about 61% of the sampled dry season vegetable farms are less than 0.5ha. Hence, depending on the skills of the family labour to be deployed on the farm, too much labour inputs on a small vegetable land to work could also lead to diminishing marginal returns on labour. Besides, the results also lend credence to some findings which argued that larger household size may not provide labour to improve technical efficiency since large household size may be composed of many children who are always in school (Effiong, 2005; Idiong, 2006).

Table 4. 6: Sources of Technical Inefficiency of Vegetable Farmers

Variable	Parameter	Coefficient	Standard error
Constant	δ0	-2.212	1.503
Age	δ1	0.018	0.060
Age squared	δ2	0.000	0.001
Gender	δ3	0.623	0.428
Household size	δ4	0.0945***	0.033
Farmer's Edu. level			
No education			
Basic education	δ5	0.118	0.280
SHS/Tech/Voc. education	δ6	0.182	0.413
Tertiary education	δ7	-0.815	0.496
Extension visits	δ8	-0.117*	0.068
Irrigation Technology			
Motorized Pump	δ9	-0.872**	0.369
Gravity-fed	δ10	-1.415***	0.510
Number of irrigations (watering)	δ11	0.001	0.004
Experience	δ12	-0.076***	0.019
Credit access	δ13	-0.180	0.319
Crop type			
Pepper	δ14	-0.398	0.285
Onions	δ15	-0.179	0.328
Tomatoes	δ16	0.450	0.328
Garden eggs	δ17	-0.178	0.483

Source: Model results, (2020). Note: *** p<0.01, ** p<0.05, * p<0.1

Consistent with the results of Yang et al. (2016), the number of extension visits positively influence the technical efficiency at 10% significant level. This implies that farmers who had access to regular extension education are more technically efficient than those with small or no access to extension education. This is premised on the fact that improved technologies, knowledge, skills and inputs developed by scientists get to farmers only via agricultural extension agents (AEAs). The implication is that farmers who have access to extension services become technologically abreast with modern skills which can help improve yields and with optmum selling prices, will achieve high output returns (profit).

The coefficients of motorised water pump ($p < 0.05$) and gravity fed ($p < 0.01$) irrigation systems adopted by farmers were positive and significantly associated to the technical efficiency of dry season vegetable production. This means that farmers who use motorised water pumps or gravity-fed irrigation technology are more technically efficient relative to farmers who adopt a manual system of irrigation. The findings however, have implication on the cost of irrigation as corroborated by Gadanakis, Bennett, Park, and Areal (2015). The motorised pump in particular, is the commonest system that farmers adopt for irrigating vegetable fields in the study area. However, its running cost has been a challenge to farmers, in terms of operation and maintenance (eg. purchase of fuel), thus, makes irrigating vegetable fields very expensive for farmers in the study area (Bawakyillenuo & Kpieta, 2013).

The coefficient of experience had positive and significant relationship with technical efficiency of dry season vegetable production. The implication is that vegetable farming is highly dependent on years of accumulated experience, which gives better managerial skills for high performance and higher yields. This finding concurs with the results of Bozoğlu and Ceyhan (2007), and Ali et al. (2019) but contradicts with the finding of Asravor et al. (2016). The analysis of the study was controlled by the type of vegetable crops (pepper, onions, tomatoes, and garden eggs) cultivated in the analysis.

4.4 Profitability Analysis of Vegetable Production

Table 4.7 presents the yields, variable costs, gross profits as well as the return on investment per hectare of vegetables (pepper, onions, tomatoes and garden eggs) farms in the Upper East

Region of Ghana. Generally, gross profit was used as an indicator of farm income in the discussions. The average yield of harvested pepper was 3052kg ha $^{-1}$ (or 3.052tons ha^{-1}) contrary to Van Asselt et al. (2018) who found 7.3tons ha^{-1} in Ghana. Based on an average price of GHS6.60 kg^{-1} of pepper, an average total revenue of GHS20,143.20 ha^{-1} was realised from the farms. The average variable cost incurred for cultivating pepper was GHS8,292.00 ha^{-1} which led to an average gross profit of GHS11,851.20 ha^{-1}. The implications are that the Return on Investment (ROI) was 143%, on the average. This means that for every one Ghana cedi (GHS 1.00) spent on the cultivation of pepper in the region, GHS 1.43 was received in return as income. Majority of the farmers cultivate scotch bonnet variety of pepper while a few cultivate other varieties including the bird eye, Legon 18 and sweet pepper.

The study revealed a considerable decline in the yields of onions. However, the Bawku enclave remains the onions production hub in Ghana although the average yield has declined to 1,658.78kg ha^{-1} (1.658tons ha^{-1}) from the 11ton ha^{-1} found by DFID-MADE (2014) some years back. An average total revenue of GHS9,289.15 ha^{-1} was obtained from the onions field with an output price of GHS5.60 kg^{-1} of onions harvested. An onion farmer incurs, on the average, a total variable cost of GHS5,058.60 ha^{-1}, which results in gross profit of GHS4,230.55 ha^{-1} and Return on Investment (ROI) of 84% on the average. The findings indicate that for every one (1.00) Ghana cedi invested on onions cultivation in the region, eighty-four (84) Ghana pesewas was realised as average income. Majority of the farmers cultivate the “Bawku red” whiles a few of the farmers grow the Nigerien “Galmi” variety.

Farmers in the Bawku enclave continue to cultivate the “Bawku red” even though they are relatively smaller in sizes compared with the “Galmi” variety. They are however, characterised by sharp peppery spicy flavour and also stay longer on storage while the Nigerian Galmi variety is quite bigger but less spicy. Other varieties were rarely seen in the study area. The study also found that the average yield of tomatoes was 2,947.90kg ha^{-1} (2.947ton ha^{-1}), far lower than the 15ton ha^{-1} found by Robinson and Kolavalli (2010) in the past under irrigation in Upper East Region.

Table 4. 7: Cost and Revenue of Vegetables Production in the Upper East of Ghana

Item (Cost/Revenue)	Quantity of input/outputs (GHS)	Unit price of inputs/outputs (GHS)	Total cost/revenue (GHS)	Cost (%)	ROI %
Pepper yield (kg/ha) (n = 226)	3052.00	6.60	20143.20		
Variable cost					
Seed (kg/ha)	0.36		448.00	5.40	
Fertilizer (kg/ha)	302.00	2.00	1004.00	12.10	
Agrochemicals (litres/ha)	9.80	94.00	921.00	11.10	
Labour (Man days/ha)	185.00	23.00	4255.00	51.30	
Irrigations (cost/ha)			1664.00	20.10	
Total variable cost			8292.00	100	
Gross profit			**11851.20**		
Return on investment (ROI)					143.00
Onion yield (kg/ha) (n = 83	1658.78	5.60	9289.15		
Variable cost					
Seed (kg/ha)	0.55		323.00	6.40	
Fertilizer (kg/ha)	304.00	1.85	562.60	11.10	
Agrochemicals (litres/ha)	3.60	79.10	285.00	5.60	
Labour (Man days/ha)	106.00	25.00	2650.00	52.40	
Irrigations (cost/ha)			1238.00	24.50	
Total variable cost			5058.60	100.00	
Gross profit			**4230.55**		
Return on investment (ROI)					84.00
Tomato yield (kg/ha) (n = 44)	2947.90	3.20	9602.00		
Variable cost					
Seed (kg/ha)	0.31		399.00	6.90	
Fertilizer (kg/ha)	298.40	2.10	627.00	10.90	
Agrochemicals (litres/ha)	5.70	66.60	379.62	6.60	
Labour (Man days/ha)	117.00	25.00	2925.00	50.90	
Irrigation's cost			1421.00	24.70	
Total variable (cost/ha)			5752.00	100.00	
Gross profit			**3850.30**		
Return on investment (ROI)					67.00
Garden egg yield (kg/ha) (n = 20)	4926.48	1.21	5961.00		
Variable cost					
Seed (kg/ha)	0.43		450.00	9.21	
Fertilizer (kg/ha)	267.00	2.07	552.69	11.31	
Agrochemicals (litres/ha)	7.70	29.35	226.00	4.62	
Labour (Man days/ha)	153	15.00	2295.00	46.96	
Irrigation's cost			1363.00	27.90	
Total variable (cost/ha)			4886.69	100.00	
Gross profit			**1074.31**		
Return on investment (ROI)					22.00
BEST TWO GROSS PROFIT					
Pepper and onions					
Total value/ revenue (per ha)			14716.18		
Variable cost					
Seed (kg/ ha)			385.50	5.80	
Fertilizer (kg/ha)			783.30	11.73	
Agrochemical (litres/ha)			603.00	9.03	
Labour (man days/ha)			3452.50	51.72	
Irrigation (cost/ha)			1451.00	21.74	
Total variable cost			6675.30	100.00	
Average gross profit			**8040.88**		
Return on Investment (ROI)					**120.00**

Source: Survey results (2020). Note: $1.0 = GHS5.60

This confirms that there has been a drastic decline in the productivity of tomatoes over the years in the Upper East Region of Ghana. In all, an average total revenue of GHS9,602.00 was calculated using an average output price of GHS3.20 kg^{-1} of harvested tomatoes. The average total variable cost was GHS5,752.00 ha^{-1}, resulted in a gross profit of GHS3,850.30 ha^{-1} with a Return on Investment (ROI) of 67% from tomatoes production. This implies that for every one (1.00) Ghana cedi spent on tomatoes production in the dry season in the Upper East Region of Ghana, sixty-seven Ghana pesewas (67Gp) was realised as income. The most common varieties cultivated in the study area are Pectomech and "No name", similar to the variety cultivated by Burkina Faso farmers. The "No name" variety has characteristics, similar to the Pectomech variety. The pectomech and "no name" are known to be high yielding with high shelf- life.

Additionally, the study estimated the average yield of garden eggs to be 4,926.48 kg ha^{-1} or 4.926tons ha^{-1} sold at an average price of GHS1.21kg $^{-1}$, which gave rise to an average total revenue of GHS5,961.00 ha^{-1}. On the average, about GHS1,074.31 $ha^{-1}$was realised as the gross profit with a Return on Investment (ROI) of 22% from garden eggs cultivation. Few farmers cultivate garden eggs in the study area but could not identify the varieties that they grow.

Generally, the findings reveal a decline in average productivity for all four vegetables relative to the country's previous records. Besides, the cultivation of vegetables during the dry season in Northern Ghana is highly seasonal. Usually, the period for transplanting most of the vegetables (tomatoes, pepper, garden eggs) is from late October to early January and some farmers start harvesting. Usually, farmers who plant and harvest early or late in the season attract premium price due to less market supply at the time against demand. In view of this, huge returns are sometimes enjoyed by farmers who stagger their production to take advantage of the good prices.

However, as harvesting peaks, prices of vegetables begin to fall, somewhere around mid-March to early April and starts to pick up again until June. From June to December, the entire country including northern Ghana harvest vegetables (except onions). At that period, the prices usually fall low (Van Asselt et al., 2018). Harvesting of onions in the north begins in January/February, but peaks in March when farmers start to experience a glut. The price begins to rise again from April/May every year. So, farmers who are able to store onions up to such period usually enjoy high prices. Due to the perishability of tomatoes, pepper and garden eggs, most farmers do experience high post-harvest losses. The cultivation of vegetables during the dry season in the north can therefore be considered both as a reward and a curse. However, the vegetable sector in the north still has the potential to reduce poverty and enhance households' food security in the region, if managed properly.

The study revealed that, pepper and onions were the optimal cropping mix that gives higher return in the study area. This finding confirms Balana et al. (2019) who stated that pepper, onions and tomatoes were the best cropping mix in their study on flood recession agriculture for food security in Northern Ghana. An average total revenue of GHS14,716.18 ha^{-1} was obtained from the production of pepper and onions against an average total variable cost of GHS6,675.30 ha^{-1} for producing the two crops. This results in an average gross profit of GHS8,040.88 ha^{-1}.

The key variables which drive up the cost of vegetable production include irrigation, labour and other inputs (fertilizer, pesticide, fungicides). The findings reveal that over 50% and 20% of the cost of vegetable cultivation are attributable to labour and irrigation, respectively. Clearly, this indicates how important roles labour and irrigation play in dry season vegetable cultivation in Ghana (Robinson & Kolavalli, 2010). Similar findings were obtained by Huong et al. (2013) in Vietnam and Woltering, Ibrahim, Pasternak, and Ndjeunga (2011) who analysed the economics of drip irrigation and hand watering for vegetable production in the Sahel regions.

4.5 Food Security Status of Vegetable Farm Households

Table 4.8 reveals the food security status of dry-season vegetable farm households in the Upper East Region of Ghana. The results confirmed that food security remains a challenge for most households in the region (MOFA et al., 2020). Indeed, when the household average daily calorie intake per capita available was compared with the recommended minimum calorie requirement of 2900cal per adult equivalent per day in Ghana (GSS, 2014; IFPRI, 2000), it was revealed that 175 (54.3%) households out of the total sampled households of 322 were food secure whereas 147 (46.7%) were food insecure. The average kcal intake for the food secured households were 2,958 per capita whereas the food insecure households were found with a means kcal intake of averagely 1,670 per capita which is far below the average daily per capita calorie requirement of 2,423kcal. However, since the food security data was taken soon after the main harvest season, these interpretations are done cautiously.

Table 4. 8: Food Security Status of Vegetable Farming Households

	FS (n =175)		**FI (n =147)**		**t-value**	**Total (n =322)**	
Food Security Indicator	Mean	SD	Mean	SD		Mean	SD
Food Availability (kcal)	2958	675.65	1670	474.32	18.61***	2421	949.28
Calorie allowance (kcal)	-	-	-	-	-	2423	256.40
Food Security Index (FSI)	1.215	0.241	0.690	0.186	20.58***	1.001	0.376

Source: Model results (2020). Note: Food secure (FS), Food insecure (FI), *** is significant at 1% prob.

Additional evidence was sought to illustrate the food security status of vegetable farm households using the Food Security Index (FSI) in the study area. As indicated, the mean food security indices of 1.2 for the food secure households and 0.69 for the food insecure households concurs with the findings of Kuwornu et al. (2013) who obtained 1.42 for food secure households and 0.69 for food insecure households in forest communities in the central region of Ghana. Similar outcome was also arrived at by Abu and Soom (2016) in the rural and urban area of Benue state in Nigeria.

Food insecurity is more pronounced in households during dry season, just before the onset of rains for the main cropping season (lean season) in the study area. This coincides with the period during which farmers cultivate vegetables to raise income. The implications, therefore are that food insecure vegetable farm households will continue to experience challenges of food security unless issues relating to the efficiency of the farmers are addressed. Overcoming the challenges of farm productivity will increase the output of vegetables for the farmers to generate enough income to improve livelihood including the provision of food.

4.5.1 The Extent and Severity of Food Insecurity

Table 4.9 depicts the extent of food insecurity among vegetable farm households in the study region. The three FGT measures: head count ratio, food insecurity gap and severity of food insecurity reflect the incidence, depth/gap and severity of the food insecurity among vegetable farm households, respectively. The mean head count ratio or incidence of food insecurity of 0.3333 implies that 33.33% of the sampled farmers' households do not meet their daily recommended calories intake. The findings revealed that the incidence of food insecurity in the region is, however greater among households in the eastern zone (51%), followed by the western zone (28%) and the central zone (21%), in that order. This means that any intervention intended to address food insecurity among dry season farm households in the Upper East Region must target more vegetable farmers in the eastern zone (Bawku Municipal, Zebilla and Binduri Districts).

The food insecurity gap, otherwise termed food poverty gap estimates the extent to which the food insecure households' fall below the recommended daily caloric requirement. The indicator provides a clue on how to estimate the resources necessary to eliminate food insecurity through appropriate targeting. The findings of the study revealed a mean food insecurity gap of 31.20% across the three vegetable farming zones. This implies that if resources for dry season vegetable farming (including irrigation water, agrochemical, fertilizer) could be mobilised to increase farm income to achieve 31.20% of calorie intake requirement level among food insecure vegetable farm households, then theoretically food insecurity can be eliminated in the study region.

Table 4. 9 Measures: Extent and Severity Food Insecurity in Vegetable Farming Zones

	Headcount (p = 0)		FI Gap/Depth (p = 1)		Severity of FI (p = 2)	
Zone	Percent	Rank	Percent	Rank	Percent	Rank
Central (Bolga, Talensi, Bongo)	21	3	31.0	2	13.0	2
Eastern (Bawku, Zebilla, Binduri)	51	1	32.0	1	14.0	1
Western (Navrongo)	28	2	30.6	3	11.9	3
Total	**33.33**		**31.20**		**12.97**	

Source: Models results (2020)

The study also revealed the extent of inequality among food insecure households in the study area. The findings showed a mean severity of food insecurity of 12.97% across the three zones in the study. These results were in line with the findings of Kuwornu et al. (2013) study on food security among farming households in the forest belt in the central region of Ghana. Similar findings were also obtained by Mitiku et al. (2012) in southern Ethiopia. The severity of food insecurity was however higher in the eastern zone, followed by central and western zone, in that order.

4.5.2 Description of Factors Influencing Households Food Security

Table 4.10 describes the socio-economic variables employed in both model 3.31 to determine factors influencing the food security status (calorie availability) and model 3.35 to estimate the factors affecting the food consumption score (dietary diversity score) of vegetable farm households in the study area. The data shows that averagely, dry season vegetable farmers in the region had about 9 years' experience in vegetable farming, implying that the experience acquired over the years in vegetable farming could positively influence his/her ability raise more income from vegetable farming and improve household food security. The dependency ratio was averagely 2.5 (1:2.5) household members in an average household size of 7 members. This implies that, an average working person in the household feeds averagely more than two people in addition to him/her self. This certainly would be a burden for low-income working people, as such might lower the food security status of those households in the study area. Averagely, a vegetable farmer cultivates 0.6ha and received about 2 extension agent's visits in 2018 (the year of the survey).

Cultivation of crops and rearing of animals constitute the main economic activities of most farmers to meet their households' food and other needs in the study area. Similar report was stated by GSS (2019a), which states that grains and flour constitute 84.3% of the food consumed by households in the study area. The data of the study confirmed that households accumulate averagely 1373kg of grains and rear animals valued at about 2.6 tropical livestock units (TLUs) in the area. These findings corroborate that of the comprehensive food security and vulnerability survey which found that poor households in northern Ghana keep farm animals valued at about 2.5 TLUs in their homes (WFP, 2012). The common livestock kept by farmers in the area includes cattle, sheep, goats, pigs, and poultry among others. Each tropical livestock unit is equivalent to one head of a cattle of 250kg of live weight (Benson & Mugarura, 2013; Yikii et al., 2017).

The data also revealed that dry season vegetable farmers spend averagely 49% of their gross profit (income) to purchase food for their households' consumption. Indeed, the food consumption expenditure from vegetable production could be higher if the analysis was limited to net profit instead. This agrees with similar findings by the GSS (2019a) which stated that food expenditure accounts for 44.8% of the total expenditure of households in the Upper East region.

Table 4. 10: Descriptive Statistics of Determinants of Household Food Security Status

Continuous Var.	Measurement	Mean	Std.	Min.	Max.
Vegetable income	Ratio	0.488	0.295	0.027	0.996
Experience	Years in farming	9	7.8	1	45
Household size	No. of members	7	4.2	1	35
Dependency ratio	Working to non-working	2.5	2.0	0	10
Extension visits	Number	2.3	1.8	0	7
Hh. food prodtn	Kilogramme	1,373	4,764	0	80,000
Livestock value	TLUs	2.6	4.9	0	48.6
Veg. farm size	Hectare	0.61	0.51	0.04	6.9
Farm to mkt. dist.	Kilometre	4.5	3.9	0.1	20
Crop diversification	1 crop = 0. 2 crops =1. 3 crops =2. 4 crops =3.	0.3	0.5	0	3

Dichotomous var.	Measurement		% With 1	% With 0
Non-farm emplymt	Yes = 1	No = 0	59.90	40.10
Credit access	Yes = 1	No = 0	5.59	94.41
PFJs prog.	Yes = 1	No = 0	41.00	59.00
Gender	Male =1	Female = 0	90.00	10.00
Level of edu.				
No. formal edu	Yes = 1	No = 0	37.60	62.40
Pri/JHS edu	Yes = 1	No = 0	41.30	58.70
SHS/Tech/Voc.edu	Yes = 1	No = 0	14.00	86.00
Tertiary edu.	Yes = 1	No = 0	7.10	92.90

Source: author's computation, (2020)

The average distance from the farmer's vegetable field to the nearest district's local market is 4.5 km. A simplified method of crop diversification was employed in the analysis. Since the study was based on 4 vegetable crops, the diversification ranged between 0 – 3, where farmers who cultivated only one crop did not diversify, coded 0, while farmers who cultivated all 4 crops were the highly diversified farmers, coded 3. Based on these classifications, the mean crop diversification was 0.3 among the vegetable farmers. The variables: gender, educational level. Credit access, non-farm employment, planting for food and jobs remain the same as defined previously.

As earlier explained, men dominated the distribution of vegetable farmers with 90% whiles only 10% were headed by female. About 60% of the household heads were engaged in non-farm employment to generate additional income to supplement their daily livelihood including food for household consumption. Few (6%) of the vegetable farmers had access to credit support for farming activities. In view of the challenges of accessing credit, the introduction of the government's Planting for Food and Jobs (PFJs) programme was a great relief to some farmers, especially those who cultivate maize, the main crop supported by the programme in 2018. Hence, about 41% of the farmers benefitted from the programme against 59% who did not. Perhaps, those farmers do not cultivate maize as one of the staples in the main cropping seasons.

4.5.3 Effects of Vegetable Production Variables on Households' Food Security Status

Table 4.11 depicts the effects of the vegetable production variables on households' food security status in the Upper East Region. The discussions are centred on differences that are statistically significant. The aggregate distribution of the factors shows that farmers with relatively higher technical efficiency score (averagely 80%) are food secure where as those with lower technical efficiency score (averagely 64%) are food insecure. This implies that if the technical efficiencies of the farmers are improved, the productivity of the farms would be improved which would increase income and improve household food security in the study area. Similar finding was obtained by Wongnaa and Awunyo-Vitor (2018) in Ghana and Birhanu et al. (2021) in Ethiopia.

Farmers in food secure households used more intensive inputs such as fertilizer, and agrochemicals (herbicides and pesticides). They also cultivated on larger farm size, adopted the use of improved seeds, and invested more on labour to maintain their farms (Wongnaa & Awunyo-Vitor, 2018). Intensified cultivation of vegetables resulted in higher output value, higher profit (income), which allowed those households to spend more on household food security than food insecure households.

Table 4. 11: Summary of the Effects of Production Variables on Food Secure and Insecure Farm Households

Variable definition	Measurement		Food secure Households	Food insecure Households	T-test
Continuous var.					
Age of farmer	Years		42.84	40.61	-1.810*
Household size	Number of members		7.00	8.00	1.624
Fertilizer	Kg/Ha		189.52	156.63	-2.727**
Agrochemical	Litters/Ha		4.40	3.46	-2.675**
Labour	Cost/Ha		1,326.09	925.68	-3.979***
Veg. farm size	Ha		0. 70	0.55	-1.96**
Output value	GHS/Ha		9,818.46	6,820.57	-3.330***
Vegetable's income (profit)	GHS/Ha		8,132.15	5,484.01	-3.075***
Veg. income spent on food	GHS/Ha		3,759.82	3,489.05	-3.036***
Technical efficiency	TE Score		0.80	0.64	-13.046***
Extension visits	Number		2.28	2.24	-0.194
Dummy var.	**Measurement**				
Gender	Male = 1	Female = 0	0.88	0.92	1.195
Non-farm income	Yes = 1	No = 0	0.66	0.60	1.003
Used improved seed	Yes = 1	No = 0	0.60	0.45	-2.687***
Type of irrigation tech.					
Manual irrigation tech.	Yes = 1	No = 0	0.29	0.27	-0.374
Water pump irrigation. tech.	Yes = 1	No = 0	0.70	0.61	-1.419*
Gravity fed irrigation. tech.	Yes = 1	No = 0	0.14	0.23	2.0503**
Level of farmer edu.					
No edu.	Yes = 1	No = 0	0.47	0.54	1.235
Basic edu.	Yes = 1	No = 0	0.57	0.48	-1.556
SHS/Tech/Voc. edu.	Yes = 1	No = 0	0.48	0.52	0.546
Tertiary edu.	Yes = 1	No = 0	0.50	0.52	0.158

Source: Author's computations, (2020)

Similar conclusions were found on the effects of vegetable production on income, and food security in Kenya (Muriithi & Matz, 2015), in Ethiopia (Gebru et al., 2019) and in Nepal (Rai et al., 2019). Holding all other things constant, one may therefore deduce that improving technical efficiency of farmers could enhance productivity, increases income and contributes to reducing food security among vegetable farm households in the Upper East Region (Tsiboe et al., 2019).

The study found that farmers in food secure households adopt gravity fed and motorised water pump irrigation technologies of irrigation where as farmers in food insecure households adopt the manual system of irrigation. Adopting the appropriate type of irrigation technology, all things being equal, positively influences the technical efficiency of the farmers which enhances the productivity and profitability of vegetable production. This would improve the food security of vegetable farm households in the study area.

The age of vegetable farmers in food secure households is averagely higher than farmers in food insecure households. This implies that older farmers have a higher level of experience which help them to increase households' income from vegetable cultivation hence improves their food security.

4.5.4 Factors Influencing Household Calorie Availability

Table 4.12 shows the estimates of binary probit model identifying the factors influencing Households' Calorie Availability (HCA) among dry season vegetable farm households in the study area. The households' calorie availability (HCA) is a proxy for the quantity of households' calorie (energy) availability. The model is satisfactory given its statistical significance (1% level) of the pseudo R^2 of 0.194 and log likelihood value of -173.283. The sensitivity and specificity test results of the data were 91% and 62%, respectively.

It was noticed that among the fifteen variables hypothesised to influence food security in the study area, six were found to be significant in determining the food security of farm household in the study area. The empirical results of the study show that vegetable income, land size and households' own (subsistence) food production significantly increase the probability of households' food security in the study area. In otherwards these variables positively increase the probability of the households' calorie availability above the 2900kcal threshold.

However, gender, household size, and the value of livestock holdings had negative effects on the food security of vegetable farm households in the study area. The negative effect of gender implies that female-headed households are more likely to consume more calories of food than male headed-households in the study area. This can be explained that women are more inclined to spend their resources on the up-keep of the home including food provisioning than men. Similar results were obtained by Goshu, Kassa, and Ketema (2013) in Ethiopia and Sinyolo and Mudhara (2018) in South Africa. This implies that strategies intended to improve the food security of dry season vegetable farm households in the study region should target more women than men.

The results however, contradicts the study of Meludu, Ifie, Akinbile, and Adekoya (1999) in Nigeria and Lam et al. (2017) in northern Ghana who all concluded that female farmers have limited access to resources such as land, education, credit and extension, and are largely engaged in unpaid care work such as fetching water, collecting fire wood, child bearing and care, which limit their time to effectively manage their farms to raise enough income for the household needs including food. The findings also affirm the dominance of men (90%) relative to women (10%) in commercialised agriculture in northern Ghana (Lambrecht et al., 2017).

In terms of the household size, an increase in household size decreases the calorie availability for the households to consume. This was expected because an increase in household size means more household members are expected to be fed even though few of them may be contributing to the "bread basket". Large household size therefore tends to increase the burden on the few household members who produce food, thereby negatively affecting the availability of calories for the household members (Ajuruchukwu & Sanelise, 2016). Similar outcome was reported by Sinyolo (2020) on a study on the relationship between technology adoption and food security among rural households in South Africa. Also Oyetunde-Usman and Olagunju (2019) made the same conclusion in Nigeria..

Table 4. 12: Binary Probit Regression Estimates

Dependent Variable: HCA **Variables**	**Parameter (Robust Standard Error)**	**Marginal effects ($\delta y/\delta x$)**
Vegetable Income	1.123 (0.175 **	0.420***
Household Size	-0.027 (0 .019) *	-0.010*
Experience	-0.004 (0.011)	-0.002
Vegetables Land Size	0.394 (0.237) *	0.147*
Gender	-0.724 (0.328) **	-0.271**
Dependency Ratio	0.066 (0.042)	0.026
Educational level	0.016 (0.014)	0.006
Non-Farm Employment	0.103 (0.168)	0.038
Planting for Food & Jobs	0.004 (0.171)	0.001
Farm Distance to Market	-0.031 (0.022)	-0.011
Value of Livestock Holding	-0.036 (0.020) *	-0.014*
Credit Access	0.199 (0.214)	0.075
Crop Diversification	-0.040 (0.146)	-0.015
Own Food Production	0.046 (0.027) *	0.017*
Technical Efficiency	1.260 (0.534) **	0.470**
N	322	
Log likelihood	-173.283	
Pseudo R^2	0.194	
P-Value	0.000	
VIF	1.190	
Sensitivity	91%	
Specificity	62%	

Source: Model results, 2020, Note: Food Secure Household (1) Food Insecure Household (0). Statistical significance is indicated by ***p < 0.01, **p < 0.05, *p < 0.10, figure in parentheses standard errors.

The vegetable land size had a positive influence on the food security status of vegetable farm households. This explains that households who have more irrigated vegetable farm land, all things being equal, generate more income which improve households' food security status and enhance their calorie availability than farmers with small land size. The outcome of this study confirms the findings of Balana et al. (2019) in northern Ghana. Similar conclusion was drawn by Joshi and Joshi (2017) in Eastern region of Nepal and Getaneh et al. (2022) in north-Eastern riff valley of Ethiopia.

Contrary to the hypothesis of the thesis and the findings by Getaneh et al. (2022) and Desta et al. (2020) in Ethiopia, the study revealed a negative relationship between the value of animal holdings and food security in the Upper East Region of Ghana. Perhaps, the farm households may only be keeping the animals as a stock of wealth but do not sell them to raise income for the households' welfare including meeting their food security needs.

The evidence from the study revealed that technical efficiency of dry season vegetable farmers is positively associated with households' food security in the study area. Indeed, the technical efficiency of vegetable farmers has a direct positive effect for vegetable farm households. This finding is in line with empirical literature on the link between technical efficiency and food security of smallholders (Wongnaa & Awunyo-Vitor, 2018). The implication is that farmers who are technically efficient are more productive, hence generate much profit which they can use to improve the food security of their households than less technically efficient famers.

Regarding the marginal effects, for instance, a 10% increase in vegetable income, land size, technical efficiency and own food production of farmers had a 4.20%, 1.47% and 4.7% and 0.017% more likely to improve the availability of calories among vegetable farm households, respectively.

In terms of the effect of gender, female headed vegetable farm households are 7.1% more likely to have available calories than male headed households in the study area. On the other hand, the household size and the value of animal holdings are l 0.10% and 0.14% less likely to enhance the food security of vegetable farm households, respectively. Surprisingly, the value of animal farm households is associated with a reduction in food security of households but was positive in a similar study by Getaneh et al. (2022) in Ethiopia.

Regarding the magnitude, the most important factor that increases the probability of higher calorie availability of food for consumption among respondent households in the region is vegetable income. This implies that dry season vegetable income plays a critical role in reducing households' food insecurity in the study area. Similar results were found by Gebru et al. (2019) in Ethiopia, Balana et al. (2019) and Balana et al. (2020) in northern Ghana. Therefore, improving the technical efficiency of dry season vegetable farmers can be an effective strategy to improve productivity, generate income, reduce poverty as well as improve households' food security in the study area.

4.5.5 Determinants of Household Food Consumption Score

Table 4.13 displays the results of the food consumption score for dry season vegetable farm households in the study area. Food consumption score (FCS) is a proxy for the quality of food consumed the households, which were categorised into poor dietary diversity score, borderline dietary score and acceptable dietary score. On the whole, the outcome of the model appears well fit given its high significance of $p < 0.000$ with pseudo R^2 of 0.5360 and log likelihood of -144.376. A close observation on the results revealed the nuance perspective on the factors which directly affect households' food quality in the Upper East Region. Note that, the interpretation of the ordered probit results was based on only the marginal effects ($\delta y/\delta x$) due to the ambiguity in the use of coefficients.

The variables affecting the food consumption score are similar to those affecting the household calorie availability discussed above. Variables such as vegetable income, non-farm employment, educational level and technical efficiency of farmers are positively and significantly related to poor dietary diversity of vegetable farm households. Specifically, a

Table 4. 13: Ordered Probit Regression Estimates

Variables		Marginal effect ($\delta y/\delta x$)		
	Coef. (Std. Err)	**Poor (0-28)**	**Borderline (28.5 – 42)**	**Acceptable (above 42)**
Vegetable Income	-5.256 (0.594) ***	1.713***	-1.556***	-0.159***
Household Size	-0.033(0.026)	0.011	-0.011	-0.001
Experience	-0.011 (0.012)	0.004	-0.003	-0.001
Vegetable Land Size	0.260 (0.191)	-0.085	0.077	0.008
Gender	0.415 (0.296)	-0.120	0.110	0.009
Dependency Ratio	0.086 (0.045) *	-0.028	0.026*	0.003
Educational level	-0.040) (0.016) ***	0.013**	-0.012**	-0.001*
Non-farm Employment	-0.845 (0.211) ***	0.284***	-0.250***	-0.034**
Planting for Food & Jobs	0.280 (0.188)	-0.093	0.084	0.009
Value of Livestock Holding	-0.013 (0.020)	0.004	-0.004	-0.001
Farm Distance to Market	0.065 (0.023) ***	-0.021**	0.019**	0.002*
Credit Access	0.203 (0.257)	-0.069	0.062	0.007
Land Fragmentation	0.107 (0.162)	-0.035	0.029	0.003
Own Food Production	0.108 (0.035) ***	-0.035**	0.032***	0.003**
Technical Efficiency	-1.215 (0.576) **	0.396**	-0.060**	-0.036*
N	322			
Log likelihood	-144.376			
Pseudo R^2	0.5360			
P-Value	0.000			

Source, model results (2020) Note: Dependent variables are Poor (1), Borderline (2) and Acceptable (3), ***P < 0.01, **p < 0.05, *p < 0.10, figure in parentheses are standard errors.

10% increase in vegetable income has a 17.13% more likely to improve on the poor dietary diversity score of households but 15.56% and 15.90% less likely to improve on the borderline and acceptable dietary diversity scores, respectively. This was expected because unlike households who experience poor dietary diversity score, those dry season vegetable farm households who are relatively better off, in terms of their food security status, all things being equal, would instead, invest the additional income from dry season vegetable farms on other livelihood needs other than on food. The findings of the study confirm the studies of Balana et al. (2019) in northern Ghana, Abate et al. (2019) in Ethiopia, who all contended that vegetable income was crucial in uplifting the livelihood of poor households including improving their food security. Keatinge et al. (2011) had similar findings in sub-Sahara Africa (SSA) including Ghana and South Africa. This means that improving dry season vegetable production to raise more income can be an important conduit to reduce the high level of food insecurity in the Upper East Region of Ghana.

Education is a social capital that affords an individual the capacity to adopt improve technology, secure a paid job, which could help to improve the person's livelihood including food provision. Accordingly, household heads who have attained high level of education are 0.13% more likely to improve on their poor dietary diversity score. Similar findings was arrived at by Sisha (2020) in South Africa. However, being educated would be 0.12% and 0.01% less likely to improve the dietary diversity of households who are on the borderline and acceptable dietary diversity scores, respectively. The results confirm similar outcome on the effect of education on food security in Ghana (Setsoafia, Ma, & Renwick, 2022), implying that policy makers wanting to improve the poor dietary diversity among dry season vegetable households should place emphasis on educating and training dry season vegetable farmers in the Upper East Region to enable them improve on their farming to raise more income.

Also, farmers who engage on non-farm employment are 2.84% more likely to improve on their poor dietary diversity status, while those on the borderline and acceptable dietary diversity are 2.50% and 0.34% less likely to improve on their food security status, respectively. Additional income from non-farm activities eliminates credit constraints, allow farmers to invest on innovative technologies to improve farm performance which enable them to raise more income and help achieve food security (Setsoafia et al., 2022). The finding concurs previous studies (Owusu et al., 2011; Tsiboe et al., 2016; Zereyesus et al., 2017) in northern Ghana.

Regarding farm to district market distance, the study revealed that households which are farthest away from the district market are 0.21% points lower probability of improving on their poor dietary diversity status. This was expected because given the poor road conditions in farming communities, vegetable farmers who are far away from the market may not get their produce to the market in good time and condition to obtain good price compared with farmers closer to the market. This may affect the income of the farmers far away from the market and thus their ability to purchase the needed food to achieve household food security. On the other hand, households which are far away from the market are 0.19% and 0.02% more chance to be on the borderline and acceptable dietary diversity status, respectively. Similar effect about farm distance to market was concluded by Sinyolo (2020) at KwaZulu Natal in South Africa.

In Ghana like many developing countries, own food production from smallholder farms constitute a major component of the food basket of rural households (Ecker, 2018). This is evident from the findings of the study where farmer's own food production is 0.32% and 0.03 more likely to improve on the dietary diversity of the borderline and acceptable vegetable farm households in the study area. On the contrary own food production is 3.96% less likely to improve on the dietary diversity score of dry season vegetable farm households. This is because perhaps, most poor vegetable farm households lack the required resources to produce their own food, sufficient enough to sustain their household members food intake. Even if they do, they often sell their produce at harvest to acquire other needs but later purchase food at exorbitant prices during lean season, which affect their food security status (Quaye, 2008). In view of that these farmers usually rely on dry season vegetable production and non-farm activities to raise income to purchase food for the households (Owusu et al., 2011).

The study found a positive and statistically significant relationship between technical efficiency and dietary diversity among vegetable farm households in the study area (Wongnaa & Awunyo-Vitor, 2018). The results show that technical efficient dry season vegetable farmers are 3.96% more likely to improve on their poor dietary diversity status. The implication is that improving technical efficiency of dry season vegetable farmers in the study area has food insecurity reduction effect among households who are in the poor dietary diversity bracket. This is premised on the fact that farmers who are technically efficient are able to produce more vegetable and achieve high productivity which lead to higher income through the sale of the produce and therefore afford them to access diversified food for their households. Similar findings was obtained by Villacis et al. (2022) in Nigeria

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The previous chapters covered the theoretical and methodological background of the thesis, followed by presentations of results, analysis and discussions. This chapter presents the summary of the key findings and conclusions of the entire study as well as provides policy recommendations.

5.2 Summary of Key Findings of the Study

This thesis assessed the technical efficiency of dry season vegetable farmers and its implications on households' food security in the Upper East Region of Ghana. Specifically, the study sought to: examine the technical efficiency of dry season vegetable farmers; estimate the gross profit (income) from dry season vegetable production; determine the extent of food insecurity among the farm households, and determine the effect of technical efficiency and profitability of vegetable production on households' food security status in the study region. The key findings of the study are as follows:

- The study reveals that all inputs, namely labour, seed, fertilizer, agrochemicals and irrigations exert positive influence on dry season vegetable productivity in the Upper East Region (UER). The most important yield-boosting inputs in dry-season vegetable production is labour, followed by fertilizer and agrochemicals.
- The mean elasticity was 1.34, which implies that dry season vegetable farms in the region exhibit Increasing Return to Scale (RTS).
- Regarding the distribution of technical efficiency scores, it revealed that the farmers operate at a minimum technical efficiency score of 7% and a maximum technical efficiency score of 99%. The overall mean technical efficiency score of dry season

vegetable production was 73%, which means the farmers were unable to account for about 27% of the production due to technical inefficiency and production risks.

- The analysis of the production risk shows that, costs associated with labour, seed and agrochemical decrease production risks hence reduce the variability of output value of vegetables while fertilizer and irrigation costs increase production risks hence increase the variability of output value of vegetable in the study location.
- Experience, extension visits, water pumps and gravity-fed irrigation technologies reduce technical inefficiency (TI) of dry season vegetable farming in the study region.
- The results of the gross profit analysis present some evidence that shows that dry season vegetable farming is profitable but the yield/ha are too low (pepper 3MT/Ha, onions 1.65MT/Ha, tomatoes 2.9MT/Ha and garden egg 4.9MT/Ha), far below the country's average yield potentials.
- A Return on Investment (ROI) of 143% was obtained from pepper, 84% from onions 67% from tomatoes and 22% from garden eggs. This could be higher if the yields of farmers increased.
- The analysis of the households' calorie availability shows that, 54.3% were food secure (FS) and consume averagely 2958kcal per capita daily while 46.7% of the sampled farm households are food insecure (FI) and consume about 1670kcal per capita daily, far below the recommended daily calorie per capita of 2900kcal in Ghana.
- An analysis of the extent of food insecurity reveals a mean head count index of 0.3333, which implies that, 33.33% of the sampled farmers' households are unable to meet their daily calorie requirements. The results also show a mean food insecurity gap of 31.20% and a mean severity of food insecurity of 12.97% in the three vegetable farming zones in the region.

- The farmers with higher average technical efficiency score of 80% are food secure whereas those with averagely lower technical efficiency score of 64% are food insecure.
- Technical efficiency, vegetable income, non-farm employment and own food production have positive marginal effect on households' calorie availability. Those factors also improve food quality of households in the poor dietary diversity brackets in the region
- Dry season vegetable farmers who adopt gravity-fed and motorised water pump irrigation technologies are food secure whereas farmers who adopt the manual system of irrigation are food insecure.
- The use of more intensive inputs such as fertilizer and agrochemicals (herbicides and pesticides), cultivate on relatively larger farm sizes, use improved seeds, and more labour obtain higher productivity, higher profit (income) resulting in food security of households.
- Technically efficient dry season vegetable farmers who produce on large irrigated farm size, obtain higher vegetable income as such are able to improve on their households' food security status.
- Farmers whose vegetable farms are located closer to the district market are move likely to improve on their poor dietary diversity status compared with vegetable farms far away from the district local market.

5.2 Conclusions of the Study

Dry season vegetable production is a major economic activity for the people in northern Ghana, and the Upper East Region in particular but low productivity of the farms remains a drawback to farmers ability to sustain their livelihoods. Even though vegetable farmers lack production resources to increase outputs, inefficiency in the utilisation of the existing resources has also been a challenge to farmers, affecting productivity and income and affecting households' food security.

Drawing from the empirical findings, this study has the following conclusions:

- Vegetable farmers are about 27% technically inefficient in their production operations. The technical efficiency of these farmers could be improved by adopting the best production practices while reducing production risks.
- Dry season vegetable farmers in the Upper East Region who are technically efficient obtain higher vegetable output which give them higher income and therefore afford them the opportunity to access food to be food secure relative to the technically inefficient farmers.
- The dry season farmers are operating at an increasing return to scale, implying they have not yet reached the profit maximizing level. In other words, the farmers operate in the first stage of the production function, hence they have the potential to expand to take advantage of the economies of scale. This could be achieved with more labour, agrochemicals and the use of improved seeds so as to improve the productivity of the vegetable farms.
- Investment cost associated with labour, seed and agrochemical decrease production risks hence increases output value of vegetables while costs attributed to fertilizer and irrigations increase production risks as such decrease output value of vegetable in the study location.
- Investing in the cultivation of pepper and onions have the potential to increase the income of farmers and reduce food insecurity among vegetable farm households than investing in tomato and garden eggs. This is because pepper and onions yield more profit than tomato and garden eggs.

5.3 Policy Recommendations of the Study

Based on the findings, the study distils the following policy recommendations to improve income and food security status of dry vegetable farm households in the study region:

- To improve the technical efficiency and productivity of vegetable production in order to increase income of dry season vegetable farmers, the Irrigation Development Authority (IDA) should initiate interventions to provide farmers with farm inputs, water pumps as well as rehabilitate the existing deplorable irrigation infrastructure in the region.
- Since agrochemicals decrease production risks of dry season vegetable farmers, the current PfJ fertilizer and seeds subsidy programme provided by MoFA should include agrochemicals to improve the technical efficiency and enhance the productivity of vegetable production.
- Also, since fertilizer and irrigation costs increase production risks, vegetable farmers in the region should consider reducing fertilizer and replacing it with organic manure to improve yields while reducing costs to increase farm profit.
- The IDA should also put in place a mechanism to supply dry season farmers with efficient alternative irrigation equipment and kits (eg. efficient water pumps, sprinklers, drip, etc) at subsidised prices to dry season farmers to reduce irrigation cost but still efficiently irrigate their fields to increase productivity and income of the farmers.
- Experience, extension visits, water pumps and gravity-fed irrigation technologies reduce TI of dry season vegetable farming. For this reason, financial institutions (eg banks, NGOs etc) should assist dry season vegetable farmers with credit at subsidized interest rate to acquire inputs (improved seeds, agrochemicals, water pumps etc).
- Also, the IDA should take steps to enhance the capacity of Agricultural extension agents (AEAs), make them accessible to farmers, rehabilitate the existing gravity-fed

irrigations systems for farmers to increase their scale of operations and improve their TE in order to increase the productivity of vegetable farms for more profit.

- The government through MoFA should consider supporting experienced dry season vegetable farmers to mentor the young inexperienced ones to improve their knowledge and skills in order for them to fully take dry season vegetable farming as an occupation since it is profitable. This will help reduce the unemployment rate in the country.
- The road network to all vegetable growing communities in the region should be improved by the government to enable farmers' access marketing centres in time to increase profit (income) and improve farm households' food security status.

5.4 Contributions of the Thesis Research to Policy

This study is important to Ghana and the Upper East Region in particular for the following reason:

- Improving the technical efficiency of dry season vegetable farmers has higher poverty reduction and food security effect among dry season vegetable farm farmers. Therefore, identifying and addressing the causes of technical inefficiencies should be at the heart of policy makers that aim to improve vegetable outputs, reduce poverty and enhance households' food security in the northern Ghana.
- For the above reason, the government of Ghana and NGOs working on the vegetable sub-sector should have policies and interventions that include subsidy programme to incentivise farmers to adopt the use of modern production inputs (improved seeds, agrochemicals, fertilizer), efficient irrigation machinery (water pumps, drip irrigation system). This will increase vegetable farm yields and income and help the country to achieve the SDGs of no poverty and zero hunger by 2030.

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APPENDIXES

Appendix I: Recommended Average Energy Intake per Person per Day.

Category	Age (years)	Energy allowance per day	Equivalent scales
Infants	0 – 0.5	650	0.22
	0.5 – 1.0	850	0.29
Children	1 – 3.	1300	0.45
	4 – 6	1800	0.62
	7 – 10	2000	0.69
Males	11 – 14	2500	0.86
	15 – 18	3000	1.03
	19 – 25	2900	1.00
	25 – 50	2900	1.00
	51+	2900	0.79
Females	11 – 14	2200	0.76
	15 – 18	2200	0.76
	19 – 25	2200	0.76
	25 – 50	2200	0.76
	51+	1900	0.66

Recommended Dietary Allowances 10th edition (Washington D.C): National Academy press (1989), adopted by GSS, (2000) and (2010) and (2014).

Appendix II: Conversion Factor of Various Categories of Livestock to TLU

Animal unit	Tropical livestock unit (TLU)
Calf	0.25
Donkey (young)	0.35
Weaned calf	0.34
Camel	1.25
Heifer	0.75
Goat/sheep (adult)	0.13
Cow and ox	1.0
Goats/sheep (young)	0.06
Horse	1.10
Donkey (adult)	0.70
Chicken	0.013

Source: (Storck & Doppler, 1991)

Appendix III Questionnaire
University of Ghana

Department of Agricultural Economics and Agribusiness

Survey Questionnaire

Purpose of the survey

This questionnaire has been purposely designed to collect data relating to address the topic "**technical efficiencies of dry season vegetable farmers and its implications on household food security in the Upper East region of Ghana.**" It is prepared by James Anaba Akolgo as part of a PhD research at the Department of Agricultural Economics and Agribusiness, University of Ghana, Legon, Accra. Please, you are kindly requested to provide appropriate responses to the set of questions included in the questionnaire. Respondents are assured that data collected will **ONLY** be used purposely for academic work, that is, all responses provided shall remain confidential. Thank you for your time in advance.

For further inquiries, please contact through the following: Mobile: 0206648050/0249285852 Email: ajakolgo001@st.ug.edu.gh

PART A: PRELIMINARY INFORMATION FOR DATA MANAGEMENT

Name of interviewer ……………………………………………………………………………….

District ………………………………………..……………..…………………………..…..…

Name of interviewee ……………………………………………………………………………..…

Community ………..…………………………..……………….………………………………….

Phone number of interviewee………………………………………………………………..........

Date of interview ……………………………………………………………………………………..

Please Circle the Appropriate Option of the Answers Provided for Closed Ended Questions and Fill in the Answers in the Open-Ended Questions Below.

PART B

Q1. Socio economic variables

Gender of farmer?	**Marital status?**	**Educational level?**	**Age of farmer?**	**Are you the head of the family?**	**What is your household size? (head count)**
1. Male 2. Female	1. Single 2. Married 3. Widow 4. Widower 5. Divorced	1. None 2. Primary level 3. JHS/Middle 4. SHS 6. Tech/vocational 7. Polytechnic 8. University/Above		1. Yes 0. No	

Q2. Socio-economic variables continued

Is farming your major occupation?	**If no, please what is your major occupation?**	**If yes, how long have you been farming onions and or pepper (years)?**	**Do you engage in non-farming activity?**	**If yes, what non-farming activity? *(tick as many as appropriate)***	**Years of work**
1. Yes 0. No	1.Petty trading 2. Salary employee 3. Artist 4. Carpentry 5. Masonry 6. Weaving 7. 'Pito' brewing 8. Welding 9. Dress making 10. Pepper trading 11.Food processing 12. Transporter 13. On-farm labour 14. Fishing 15. Blacksmithing 16. Tailoring 17. Tailoring 15. Others		1.Yes 0. No	1.Petty trading 2. Salary employee 3. Artist 4. Carpentry 5. Masonry 6. Weaving 7. 'Pito' brewing 8. Welding 9. Dress making 10. Pepper trading 11.Food processing 12. Transporter 13. On-farm labour 14. Fishing 15. Blacksmithing 16. Tailoring 17. Tailoring 15. Others	

Q3. Institutional variables
Membership of farmer-based group

Do you belong to any farmer- based group?	If yes, what is the name of the group(s)	How beneficial is the group to your farming?	If no, why?
1.Yes 0.No		1. Improved seed 2. Credit 3 .Agronomic practices training 4. Chemical application 5. Others	

Q4. Access to credit

Did you get credit in 2018/19 farming season (GHS)?	If yes, what was the source of credit? (*please, tick as many as appropriate*)	How much credit was received? (GHS)	How did you pay the credit?	If in-cash, what was the cost of credit? (Interest paid)?	If in-kind, what was the cost of credit (interest paid)	How long did you payback the credit?
1. Yes 0. No	1. Friends/relatives 2. Bank 3. Micro finance institutions 4. Savings and loans 5.NGO 6. Susu group 7.Others (specify)		1.In-cash 2.In-kind			1. 3 months 2. 6 months 3. 9 months 4. 1 year 5. Above 1 year

Q5. Agricultural extension contacts

Did you get any extension service in the 2018/19 season?	If yes, how many times did it happen?	In what area(s) did you receive training from the extension officers? (*please, tick as many as appropriate*)
1.Yes 0.No		1. Raising seedlings 2. Planting methods 3. Fertilizer/chemical application 4. Credit application process 5. Irrigations 6. All agronomic practices 7. Book keeping 8. Others

PART C: PEPPER PRODUCTION PROFILE

Q6: What capital assets did you use on pepper farming in 2018/19?

Item	Quantity			Year of purchase			Unit price (Ghs)			Expected lifespan		
	Group A	Group B	Group C	Group A	Group B	Group C	Group A	Group B	Group C	Group A	Group B	Group C
Hoe												
Cutlass												
Knapsack sprayer												
Watering can												
Petrol/diesel pump												
Water hose												
Hand dug well												
Wellington boot												
Jute sacks/bag												
Ware house												

Q7: Land size cultivated in 2018/19

Do you cultivate pepper in dry season?	If no, why?	If yes, farm size (acres)?			Total land size	How did you acquire the land for pepper farming?	Cost of rent for land for dry season farming?
		Plot 1	**Plot 2**	**Plot 3**			
1.Yes 0. No						1.Outright purchase 2.Leased/rented 3.Inherited 4. Share cropping	

Q8: Seed variety and planting methods

What seed variety type was used? (*please, tick as many as appropriate*)	**Name of variety?** (*please, tick as many as appropriate*)	**Quantity of seed sachet (kg)?per acre**	**Unit price (GHS)**	**Source of pepper seed?** (*please, tick as many as appropriate*)	**Planting method?** (*please, tick as many as appropriate*)
1.Improved 2.Traditional 3. both improved and traditional	1.Legon 18 2.M 1.2 3.Scotch bonnet 4. Jalapeno 5. Bird eye 6. Don't know			1. Project/program eg. PFJ 3.Certified seed dealer 4.Friends/relatives 5.Local market 6.Agro input shop 7.Recycled seed	1.Broadcasting 2. Row planting 3.Both broadcasting and row planting 3.Others

Q9. Type and frequency/volume of water for irrigation (N = number of irrigations per month, V = quantity (volume) of water per acre)

Sources of water for irrigations? (*please, tick as many as appropriate*)	**If reservoir, cost of water levy per acre? (GHS)**	**If hand-dug, cost of getting the water (GHS)?**	**How did you irrigate the farms?** (*please, tick as many as appropriate*)	**How many times and volume per unit irrigation water did you irrigate your farm in the dry season 2018/19**								**Total irrigation (N+N+N+N)**	**Total vol. of water (V+V+V+V)**	**Cost of labour for irrigations per acre (GHS)**
				1st Month		**2nd Month**		**3rd Month**		**4th Month**				
1.Small reservoir (small dams) 2.Large reservoir (large dams) 3. Permanent well 4. Temporal well 5. Riverine water irrigation 6. Riverine alluvial dug out 7. Borehole 8. Other			1.Hand fetch 2.Gravity-fed 3.Petrol/diesel pump 4.Sprinkler 5. Drip irrigation 6. Others	**N**	**V**	**N**	**V**	**N**	**V**	**N**	**V**			

Q10. Fertilizer/ manure applied

Application	**Fertilizers applied on pepper farm in 2018?**					**Unit cost of fertilizer/manure (GHS)?**				
	NPK (50kg bag)	**SOA (50kg bag)**	**Urea (50kg bag)**	**Liquid fertilizer (1000mg)**	**Organic manure (bag)**	**NPK (50kg)**	**SOA (50kg)**	**Urea (50kg)**	**Liquid fertilizer (1000mg)**	**Organic Manure**
First										
Second										

Q11. What agrochemical (s) applied?

Application	Name of weedicide	Name, quantity and cost of weedicides		Name of pesticide (eg. Durstin 4E, Sulfur 80, Topsin)	Name, quantity and cost of pesticides	
		Quantity (litres) Per Acre	Unit cost (GHS)		Quantity (litres) Per Acre	Unit cost (GHS)
1.						
2.						

Q12. Farm activity and labour requirement were used for dry season's pepper farming? (A= Adult, C= Children)

Farm activity	Family labour													Hired labour											
	Male						Female						male						Female					
	No.		No. of days		wage /day	total wage paid	No.		No. of days		Wage /day	Total wage paid	No.		No. of days		Wage /day	Total wage	No.		No. of days		Wages/day	Total wage paid
	A	C	A	C			A	C	A	C			A	C	A	C			A	C	A	C		
Nursery																								
Land clearing																								
Tilling/ploughing																								
Harrowing/ ridging																								
Transplanting																								
Fencing																								
Irrigation																								
Fertilizing																								
1st weeding																								
2nd weeding																								
Spraying																								
Harvesting																								
bagging																								
transportation																								

Q13. Please indicate the month, quantity of pepper harvested, where was it sold and amount per bag in 2018/19

When did you harvest your pepper? (month)	Quantity harvested (kg)?	Quantity sold (kg)?	Where sold?	Price per kg or bag (GHS)?

Q14. Pepper storage and losses incurred in 2018/19

Do you have access to pepper storage facility?	If yes, did you use it?	If no, give reasons	If you use it, quantity of pepper stored?	How long did you store pepper?	Unit cost of storing pepper (GHS)	Quantity spoilt (kg)?	Quantity good (kg)?
1. Yes 0. No	1. Yes 0. No						

Q15. Income and expenditure from pepper farming

Please, indicate how much of your income was spend on each of the following household expenditure items in past 12 months

Expenditure item	Amount from onions income (GHS)
Food (eg. cereals, roots and tubers, vegetables, pulses, meat, ingredients etc)	
Hospital bills	
Education (eg. School fees)	
Housing (eg. build room, rent room, renovates room etc)	
Acquire assets (buy phone, radio, bicycle, motto bike etc	
Clothing	
Next farming season's preparation (eg. seeds, fertilizer, farm implements etc)	
Electricity bill	
Water bill	
Others (sanitation, public transport, fuel, recharge card, social events, remittance etc	

PART D. ONIONS PRODUCTION PROFILE

Q16. What capital assets did you use on onions farming in 2018/19?

Item	**Quantity**			**Year of purchase**			**Unit price (GHS)**			**Expected lifespan**		
	Group A	Group B	Group C	Group A	Group B	Group C	Group A	Group B	Group C	Group A	Group B	Group C
Hoe												
Cutlass												
Knapsack sprayer												
Watering can												
Petrol/diesel pump												
Water hose												
Hand dug well												
Wellington boot												
Jute sacks/bag												
Ware house												

Q17. Cultivation of onions in the 2018/19 dry season

Do you cultivate onions in the dry season?	If yes, what was the farm size (acres) in 2019?			Total acreage cultivated	How did you acquire the land for onion farming? (*please, tick as many as appropriate*)	Cost of land per acre if rented for dry season farming (GHS)
	Plot 1	**Plot 2**	**Plot 3**			
1.Yes 0. No					1. Outright purchase 2. Leased/rented 3. Inherited 4. Share cropping	

Q18. Type and frequency/volume of water for irrigation (N = number of irrigations per month, V = quantity (volume) of water per acre)

Sources of water for irrigations? (*please, tick as many as appropriate*)	If reservoir, cost of water levy per acre? (GHS)	If hand-dug, cost of getting the water (GHS)?	How did you irrigate the farms? (*please, tick as many as appropriate*)	How many times and volume per unit irrigation water did you irrigate your farm in the dry season 2018/19								Total irrigation (N+N+N+N)	Total vol. of water (V+V+V+V)	Cost of labour for irrigations per acre (GHS)
				1st month		2nd month		3rd month		4th month				
1.Small reservoir (small dams) 2.Large reservoir (large dams) 3. Permanent well 4. Temporal well 5. Riverine water irrigation 6. Riverine alluvial dug out 7. Borehole 8. Other			1.Hand fetch 2.Gravity-fed 3.Petrol/diesel pump 4.Sprinkler 5. Drip irrigation 6. Others	**N**	**V**	**N**	**V**	**N**	**V**	**N**	**V**			

Q20. What were the variety of seed, quantity planted, sources and planting method?

Variety of seed cultivated?	Name of the variety?(tick as many as appropriate)	Quantity of seed (kg) per acre	Unit cost of seed per acre (GHS)	Source (s) of onions seed? (*please, tick as many as appropriate*)	Planting method
1.Improved 2.Traditional 3. Both improved and traditional	1.Bawku red 2. "Malavi" 3. Red creole 4. "Gaabu" 5." Alata" 6. "Galmi" 7. Don't know			1.Project/program 3.Certified seed dealer 4.Friends/relatives 5.Local market 6.Agro input shop 7.Recycled seed	1.Broadcasting 2. Row planting 3.Both broadcasting and row planting 4.Others

Q21. What quantity of fertilizer/ manure was applied?

Applications	Fertilizers/manure applied on onions farm in 2019?					Unit cost of fertilizer/manure (GHS)?				
	NPK (50kg bag) per acre	SOA (50kg bag) per acre	Urea (50kg bag) per acre	Liquid fertilizer (1000mg) per acre	Organic manure per acre	NPK(50kg) per acre	SOA(50kg) per acre	Urea(50kg) per acre	Liquid fertilizer (1000mg) per acre	Organic Manure per acre
1.										
2.										

Q22. What agrochemicals were applied?

Application	Name of weedicide	Quantity and cost of weedicides		Name of pesticide (eg. Durstin 4E, Sulfur 80, Topsin)	Quantity and cost of pesticides	
		Quantity (litres) per acre	Unit cost (GHS) per acre		Quantity (litres) per acre	Unit cost (GHS) per acre
1.						
2.						

Q23. What were the farm activities and labour required per acre for the 2019 dry season farming? (A = Adult, C = Children)

Farm activity	Family labour												Hired labour											
	Male						Female						male						Female					
	No.		No. of days		wage /day	total wage paid	No.		No. of days		Wage /day	Total wage paid	No.		No. of days		Wage /day	Total wage	No.		No. of days		Wage s/day	Total wage paid
	A	C	A	C			A	C	A	C			A	C	A	C			A	C	A	C		
Nursery																								
Land clearing																								
Tilling/ploughing																								
Harrowing/ ridging																								
Transplanting																								
Fencing																								
Irrigation																								
Fertilizing																								
1st weeding																								
2nd weeding																								
Spraying																								
Harvesting																								
bagging																								
transportation																								

Q24. What are the effects of pests and diseases as well as government's subsidies on onions production?

Do you experience pests and diseases on your onion farm?	What are the common diseases on your farm?	What are the common pests on your farm?	Did you get government subsidy for onion farming in 2019?	If yes, what were subsidised? (*please, tick as many as appropriate*)	Quantity of seed (kg)	Name of fertilizer	Quantity of fertilizer (bags)	No. of extension visits
1 yes 0. no			1.yes 0.no	1. seed 2. fertilizer 3. extension service				

Q25. Please indicate the month, quantity of onions harvested, where sold and amount per bag and total income in 2018/19

When did you harvest your onions (month)?	Quantity harvested (bags) per acre?	Quantity sold (bags)?	Where sold?	Price per bag (GHS)?	Total income from farm (GHS)	How much of the onions income was spent on household's food?
Total						

Q26. Onions storage and losses incurred in 2018/19

Do you have access to onion storage facility?	If yes, did you use it?	If no, give reasons	If you use it, what quantity of onions was stored?	How long did you store onions?	Unit cost for storing onions (GHS)	Quantity spoilt (bag)?	Quantity good (kg)?
1. Yes 0. No	1. Yes 0. No						

PART E. TOMATOES PRODUCTION PROFILE

Q27. What capital assets did you use on tomatoes farming in 2018/19?

Item	**Quantity**			**Year of purchase**			**Unit price (GHS)**			**Expected lifespan**		
	Group A	Group B	Group C	Group A	Group B	Group C	Group A	Group B	Group C	Group A	Group B	Group C
Hoe												
Cutlass												
Knapsack sprayer												
Watering can												
Petrol/diesel pump												
Water hose												
Hand dug well												
Wellington boot												
Jute sacks/bag												
Ware house												

Q28. Cultivation of tomatoes in the 2018/19 dry season

Do you cultivate tomatoes **in the dry season?**	**If yes, what was the farm size (acres) in 2019?**			**Total acreage cultivated**	**How did you acquire the land for** tomatoes **farming?** (*please, tick as many as appropriate*)	**Cost of land per acre if rented for dry season farming (GHS)**
	Plot 1	**Plot 2**	**Plot 3**			
1.Yes 0. No					1. Outright purchase 2. Leased/rented 3. Inherited 4. Share cropping	

Q29. Type and frequency/volume of water for irrigation (N = number of irrigations per month, V = quantity (volume) of water per acre)

Sources of water for irrigations? (*please, tick as many as appropriate*)	**If reservoir, cost of water levy per acre? (GHS)**	**If hand-dug, cost of getting the water (GHS)?**	**How did you irrigate the farms?** (*please, tick as many as appropriate*)	**How many times and volume per unit irrigation water did you irrigate your farm in the dry season 2018/19**								**Total irrigation (N+N+N+N)**	**Total vol. of water (V+V+V+V)**	**Cost of labour for irrigations per acre (GHS)**
				1st month		**2nd month**		**3rd month**		**4th month**				
1.Small reservoir (small dams) 2.Large reservoir (large dams) 3. Permanent well 4. Temporal well 5. Riverine water irrigation 6. Riverine alluvial dug out 7. Borehole 8. Other			1.Hand fetch 2.Gravity-fed 3.Petrol/diesel pump 4.Sprinkler 5. Drip irrigation 6. Others	**N**	**V**	**N**	**V**	**N**	**V**	**N**	**V**			

Q30. What were the variety of seed, quantity planted, sources and planting method?

Variety of seed cultivated?	**Name of the variety?(tick as many as appropriate)**	**Quantity of seed (kg) per acre**	**Unit cost of seed per acre (GHS)**	**Source (s) of tomatoes seed?** (*please, tick as many as appropriate*)	**Planting method**
1.Improved 2.Traditional 3. Both improved and traditional	1.pectomech 2.Power rano 3. Techiman 4. No name 5. Ada lorry tyre 6. Nimagent F 1 7. Meenagiant 8. Heinz 9. wosowoso 10. Burkina 11. others			1.Project/program 3.Certified seed dealer 4.Friends/relatives 5.Local market 6.Agro input shop 7.Recycled seed	1.Broadcasting 2. Row planting 3.Both broadcasting and row planting 4.Others

Q31. What quantity of fertilizer/ manure was applied?

Applications	Fertilizers/manure applied on tomatoes farm in 2019?					Unit cost of fertilizer/manure (GHS)?				
	NPK (50kg bag) per acre	SOA (50kg bag) per acre	Urea (50kg bag) per acre	Liquid fertilizer (1000mg) per acre	Organic manure per acre	NPK(50kg) per acre	SOA(50kg) per acre	Urea(50kg) per acre	Liquid fertilizer (1000mg) per acre	Organic Manure per acre
1.										
2.										

Q32. What agrochemicals were applied?

Application	Name of weedicide	Quantity and cost of weedicides		Name of pesticide (eg. Durstin 4E, Sulfur 80, Topsin)	Quantity and cost of pesticides	
		Quantity (litres) per acre	Unit cost (GHS) per acre		Quantity (litres) per acre	Unit cost (GHS) per acre
1.						
2.						

Q33. What were the farm activities and labour required per acre for the 2019 dry season tomatoes farming? (A = Adult, C = Children)

Farm activity	Family labour												Hired labour											
	Male						Female						male						Female					
	No.		No. of days		wage /day	total wage paid	No.		No. of days		Wage /day	Total wage paid	No.		No. of days		Wage /day	Total wage	No.		No. of days		Wage s/day	Total wage paid
	A	C	A	C			A	C	A	C			A	C	A	C			A	C	A	C		
Nursery																								
Land clearing																								
Tilling/ploughing																								
Harrowing/ ridging																								
Transplanting																								
Fencing																								
Irrigation																								
Fertilizing																								
1st weeding																								
2nd weeding																								
Spraying																								
Harvesting																								
bagging																								
transportation																								

Q34. What are the effects of pests and diseases as well as government's subsidies on tomatoes **production?**

Do you experience pests and diseases on your tomatoes farm?	**What are the common diseases on your farm?**	**What are the common pests on your farm?**	**Did you get government subsidy for** tomatoes **farming in 2019?**	**If yes, what were subsidised?** (*please, tick as many as appropriate*)	**Quantity of seed (kg)**	**Name of fertilizer**	**Quantity of fertilizer (bags)**	**No. of extension visits**
1 yes 0. no			1.yes 0.no	1. seed 2. fertilizer 3. extension service				

Q35. Please indicate the month, quantity of tomatoes harvested, where sold and amount per bag and total income for tomatoes in 2018/19

When did you harvest your tomatoes **(month)?**	**Quantity harvested (bags) per acre?**	**Quantity sold (bags)?**	**Where sold?**	**Price per bag (GHS)?**	**Total income from farm (GHS)**	**How much of the** tomatoes **income was spent on household's food?**
Total						

Q36. Tomatoes storage and losses incurred in 2018/19

Do you have access to tomatoes **storage facility?**	**If yes, did you use it?**	**If no, give reasons**	**If you use it, what quantity of** tomatoes **was stored?**	**How long did you store** tomatoes**?**	**Unit cost for storing** tomatoes **(GHS)**	**Quantity spoilt (bag)?**	**Quantity good (kg)?**
1. Yes 0. No	1. Yes 0. No						

PART F. GARDEN EGGS PRODUCTION PROFILE

Q37. What capital assets did you use on garden eggs farming in 2018/19?

Item	**Quantity**			**Year of purchase**			**Unit price (GHS)**			**Expected lifespan**		
	Group A	Group B	Group C	Group A	Group B	Group C	Group A	Group B	Group C	Group A	Group B	Group C
Hoe												
Cutlass												
Knapsack sprayer												
Watering can												
Petrol/diesel pump												
Water hose												
Hand dug well												
Wellington boot												
Jute sacks/bag												
Ware house												

Q38. Cultivation of garden eggs in the 2018/19 dry season

Do you cultivate garden eggs in the dry season?	**If yes, what was the farm size (acres) in 2019?**			**Total acreage cultivated**	**How did you acquire the land for garden eggs farming?** (*please, tick as many as appropriate*)	**Cost of land per acre if rented for dry season farming (GHS)**
1.Yes 0. No	**Plot 1**	**Plot 2**	**Plot 3**		1. Outright purchase 2. Leased/rented 3. Inherited 4. Share cropping	

Q39. Type and frequency/volume of water for irrigation (N = number of irrigations per month, V = quantity (volume) of water per acre)

Sources of water for irrigations? (*please, tick as many as appropriate*)	**If reservoir, cost of water levy per acre? (GHS)**	**If hand-dug, cost of getting the water (GHS)?**	**How did you irrigate the farms?** (*please, tick as many as appropriate*)	**How many times and volume per unit irrigation water did you irrigate your farm in the dry season 2018/19**								**Total irrigation (N+N+N+N)**	**Total vol. of water (V+V+V+V)**	**Cost of labour for irrigations per acre (GHS)**
				1st month		**2nd month**		**3rd month**		**4th month**				
				N	**V**	**N**	**V**	**N**	**V**	**N**	**V**			
1.Small reservoir (small dams) 2.Large reservoir (large dams) 3. Permanent well 4. Temporal well 5. Riverine water irrigation 6. Riverine alluvial dug out 7. Borehole 8. Other			1.Hand fetch 2.Gravity-fed 3.Petrol/diesel pump 4.Sprinkler 5. Drip irrigation 6. Others											

Q40. What were the variety of seed, quantity planted, sources and planting method?

Variety of seed cultivated?	**Name of the variety?(tick as many as appropriate)**	**Quantity of seed (kg) per acre**	**Unit cost of seed per acre (GHS)**	**Source (s) of garden eggs seed?** (*please, tick as many as appropriate*)	**Planting method**
1.Improved 2.Traditional 3. Both improved and traditional	1. Long purple 2. Black beauty 3. Florida market 4. Ntrowa Pa 5. Ojwanshua 6. Baby augergines (Ravaya)			1.Project/program 3.Certified seed dealer 4.Friends/relatives 5.Local market 6.Agro input shop 7.Recycled seed	1.Broadcasting 2. Row planting 3.Both broadcasting and row planting 4.Others

Q41. What quantity of fertilizer/ manure was applied?

Applications	**Fertilizers/manure applied on** garden eggs **farm in 2019?**					**Unit cost of fertilizer/manure (GHS)?**				
	NPK (50kg bag) per acre	**SOA (50kg bag) per acre**	**Urea (50kg bag) per acre**	**Liquid fertilizer (1000mg) per acre**	**Organic manure per acre**	**NPK(50kg) per acre**	**SOA(50kg) per acre**	**Urea(50kg) per acre**	**Liquid fertilizer (1000mg) per acre**	**Organic Manure per acre**
1.										
2.										

Q42. What agrochemicals were applied?

Application	**Name of weedicide**	**Quantity and cost of weedicides**		**Name of pesticide (eg. Durstin 4E, Sulfur 80, Topsin)**	**Quantity and cost of pesticides**	
		Quantity (litres) per acre	**Unit cost (GHS) per acre**		**Quantity (litres) per acre**	**Unit cost (GHS) per acre**
1.						
2.						

43. What were the farm activities and labour required per acre for the 2019 dry season garden eggs farming? (A = Adult, C = Children)

Farm activity	**Family labour**												**Hired labour**												
	Male						**Female**						**male**						**Female**					
	No.		**No. of days**		**wage /day**	**total wage paid**	**No.**		**No. of days**		**Wage /day**	**Total wage paid**	**No.**		**No. of days**		**Wage /day**	**Total wage**	**No.**		**No. of days**		**Wage s/day**	**Total wage paid**
	A	**C**	**A**	**C**			**A**	**C**	**A**	**C**			**A**	**C**	**A**	**C**			**A**	**C**	**A**	**C**		
Nursery																								
Land clearing																								
Tilling/ploughing																								
Harrowing/ ridging																								
Transplanting																								
Fencing																								
Irrigation																								
Fertilizing																								
1st weeding																								
2nd weeding																								
Spraying																								
Harvesting																								
bagging																								
transportation																								

Q44. What are the effects of pests and diseases as well as government's subsidies on garden eggs **production?**

Do you experience pests and diseases on your garden eggs farm?	**What are the common diseases on your farm?**	**What are the common pests on your farm?**	**Did you get government subsidy for** garden eggs **farming in 2019?**	**If yes, what were subsidised? (***please, tick as many as appropriate***)**	**Quantity of seed (kg)**	**Name of fertilizer**	**Quantity of fertilizer (bags)**	**No. of extension visits**
1 yes 0. no			1.yes 0.no	1. seed 2. fertilizer 3. extension service				

Q45. Please indicate the month, quantity of garden eggs **harvested, where sold and amount per bag and total income for tomatoes in 2018/19**

When did you harvest your garden eggs **(month)?**	**Quantity harvested (bags) per acre?**	**Quantity sold (bags)?**	**Where sold?**	**Price per bag (GHS)?**	**Total income from farm (GHS)**	**How much of the** garden eggs **income was spent on household's food?**
Total						

Q46. Garden eggs storage and losses incurred in 2018/19

Do you have access to garden eggs storage **facility?**	**If yes, did you use it?**	**If no, give reasons**	**If you use it, what quantity of** garden eggs **was stored?**	**How long did you store** garden eggs**?**	**Unit cost for storing** garden eggs **(GHS)**	**Quantity spoilt (bag)?**	**Quantity good (kg)?**
1. Yes 0. No	1. Yes 0. No						

PART E HOUSEHOLD FOOD SECURITY INFORMATION

Q1. Household Level

Gender of household head?	Marital status?	Educational level?	Age of household head?	Household size of farmer? (head count)	Location of residence
1. Male 0. Female	1. Single 2. Married 3. Widow 4. Separated 5. Widower 6. Divorced	1. None 2. Primary level 3. JHS/Middle 4. SHS 5. Tech/vocational 6. Polytechnic 7. University/Above			1. Urban 0. Rural

Q2. Please the composition the composition of the household membership based on the following criteria

S/No	Age range (monthly, years)	Gender 1. Male 0. female	Relationship with Hh head	Health status

Note: code for health status: 1 = ill, 2 = disable, 3= healthy to work

Code for relationship with Hh head: 1= husband, 2 =wife, 3 = son, 4 = daughter, 5 = nephew, 6 = niece, 7 = grandchild

Q3. Please indicate your household asset profile below (*indicate as many as appropriate*)

S/No	Asset	1. Yes 0. No	Number owned
1	Bicycle		
2	Motor cycle		
3	Tricycle (Motor king)		
4	Tricycle (Can Do)		
5	Tractor		
6	Truck/car		
7	Radio set		
8	Television set		
9	Mobile phone		
10	Grinding mill		
11	Fridge		

12	Satellite dish		
13	Land		
14.	Irrigation equipment		
15	Gas store/oven		
16	Savings/susu		
17	Others		

Q4. Please indicate food crops your household cultivated and consumed last year? ***(fill as many as appropriate)***

S/No	**Name of crop**	**Land size (acres)**	**Quantity harvested (kg)**	**Quantity consumed (kg)**	**Quantity sold (kg)**	**Amount realised (GHS)**
1	Maize					
2	Rice					
3	Millet					
4	Sorghum					
5	Groundnuts					
6	Bambara nuts					
7	Cowpea					
8	Soy bean					
9	Vegetables					
10	Fruits					
11	Others					
	Total amount					

Q5. Please indicate the livestock your household owns and income realised for last year (*answer as many as appropriate*)

S/No	**Livestock**	**Number owned**	**Number sold in last 12 months**	**Amount realised (GHS)**
1	Fowls			
2	Guinea fowls			
3	Goats			
4	Sheep			
5	Cattle			
6	Donkeys			
7	Pigs			
8	Dog			
9	Horse			
	Total amount			

Q6. Please indicate from the sources below, the income received from you or any other household member (s) for the past 12 months

Income source (*fill as many as appropriate)*		Amount (GHS)	Income flow period (yearly, monthly, daily)
1.	Petty trading		
2.	Salary employee		
3.	Artist		
4.	Carpentry		
5.	Masonry		
6.	Weaving		
7.	'Pito' brewing		
8.	Welding		
9.	Dress making		
10.	Onions trading		
11.	Pepper trading		
12.	Food processing		
13.	Transporter		
14.	On-farm labour		
15.	Fishing		
16.	Blacksmithing		
17.	Tailoring		
18.	Butcher		
19.	Selling guinea fowl meat		
20.	Sells beverages (alcohol/non-alcohol)		
21.	Sells mock		
22.	Others		

Q7. Please from the sources below the non-labour income received from you or any household member for the past 12 months *(fill as many as appropriate)*

S/No	Member ID.	Name of activity	Amount (GHS)	Period of cash flow (yearly, monthly etc)
1		Remittances		
2		Pension		
3		Rent property		
4		Interest on savings		
5		Transfers and gifts		

Q8. Please indicate the expenditure incurred on each of the household items for the past 12months

S/no	Expenditure item *(indicate as many as appropriate)*	Period (Month)	Amount (GHS)
1.	Food		
2	Education		
3	Health		
4	Water bill		
5.	Electricity bill		
6	Public transport		
7	Sanitation		
8	Social events eg. wedding, funerals, outdooring etc		
9	Building house (s)		
10	Marriage		
11	Remittances/transfers		
12	Clothing		
13	Others		
	Total amount		

Q9. Please indicate the quantities of food items the household consumed in a week (7days) and the unit of measurement for each of them

S/No	Food variety *(indicate as many as appropriate)*	Quantity	Unit measure
1	**Cereals**		
	Millet (TZ, Porridge, etc) ,		
	Maize (TZ, Banku, Porridge)		
	Sorghum		
	Rice (Rice Balls, Rice and Stew, Jollof etc)		
2	**Roots and tubers**		
	Yam, Fufu, Boiled or fried yam etc)		
	Cassava (fufu, gari, konkonte etc)		
3.	**Pulses, legumes and nuts**		
	Bambara nuts, Beans, Cowpea, Soy beans)		
	Beans		
	Cowpea		
	Soy beans		
4.	**Milk and milk products (yogurt, ice scream** etc)		

5.	Vegetables (Hibiscus, Lettuce, okra etc)		
6	Eggs		
7	Fish and sea food		
8.	**Meat, poultry and offal**		
	Beef		
	Mutton (sheep meat)		
	Chevon (goat meat)		
	Pork (pig meat)		
	Poultry		
9.	**Sugar/honey**		
10,	**Fruits**		
	Orange		
	banana,		
	Mango		
22	Pawpaw		
11.	**Oil and fats**		
	Any oil		
	Palm oil		
	Butter		

Units: 1. "Alonka" or "Kuriba", Bowl, 2. Basin 3. Bucket 4. bottle **Please note:** Direct this question to the principal person responsible for preparing the food

Q10. Please indicate whether any household member has eaten food (home and away) from the following food items in the last 24 hours

S/No	Food variety	1 = Yes (tally)	Frequency	0. No (*tally*)	Frequency
1	**Cereals**				
	Millet (TZ, Porridge, etc) ,				
	Maize (TZ, Banku, Porridge)				
	Sorghum				
	Rice (Rice Bawls, Rice and Stew, Jollof etc)				
2	**Roots and tubers**				
	Yam, Fufu, Boiled or fried yam etc				
	Cassava (fufu, gari, konkonte etc)				
3.	**Pulses, legumes and nuts**				
	Bambara nuts, Beans, Cowpea, Soy beans)				
	Beans				
	Cowpea				
	Soy beans				

4.	**Milk and milk products (yogurt, ice scream etc)**				
5.	**Vegetables (Hibiscus, Lettuce, okro etc)**				
6	**Eggs**				
7	**Fish and sea food**				
8.	**Meat, poultry and offal**				
	Beef				
	Mutton (sheep meat)				
	Chevon (goat meat)				
	Pork (pig meat)				
	Poultry				
9.	**Sugar/honey**				
10,	**Fruits**				
	Orange				
	banana,				
	Mango				
22	Pawpaw				
11.	**Oil and fats**				
	Any oil				
	Palm oil				
	Butter				

Community Level Variable

Q11. Please indicate the proximity of farmer's home to farm fields, market and all-weather roads and their respective time of travel

Farm fields		**Nearest market**		**Nearest to all-weather roads**	
Kilometre	Time	Kilometre	Time	Kilometre	Time

Q12. Please indicate about food storage warehouse, credit union, and access to credit below

Do you have a community food storage ware house?	If yes, did you use it?	Do you belong to any community credit union (SUSU) operating in your community?	If yes, did you obtain credit from the union during the last cropping season?	If yes, what was the source of the credit? (*please tick as many as appropriate*)
1. Yes 0. No	1. Yes 0. No	1. Yes 0. No	1. Yes 0. No	1. NGO 2. District assembly 3. Bank 4. credit union 5. others specify………………

Q13. Please the presence of the following government policies in your community and the beneficiaries

Did you or any member participate in the planting for food and jobs programme?	If yes, what facility did you benefit? (*please tick as many as appropriate*)	Do you benefit from any NGO or Government's irrigation scheme?	Do you or any of your family member benefit from the livelihood empowerment against poverty programme of the government?	If yes, how much did you collect in the last 12 months? GHS	Does any of your children benefit from the government schools' feeding programme?
1. Yes 0. No	1. Fertilizer subsidy 2. Seed subsidy 3. Extension service	1. Yes 0. No	1. Yes 0. No		1. Yes 0. No

Appendix IV Regression Results

1. RESULTS OF THE TRAN-LOG FRONTIER REGRESSION

VARIABLES	(1) Frontier	(2) Mu	(3) Usigma	(4) Vsigma
lSNLabourC	0.434***			
	(0.0416)			
lSNvegseedc	0.0988***			
	(0.0383)			
lSNFertcost	0.384***			
	(0.0482)			
lSNAgrochemC	0.321***			
	(0.0309)			
lSNTirrigatnC	0.105***			
	(0.0322)			
lSNLabourC2	0.195			
	(0.120)			
lSNvegseedc2	-0.156			
	(0.102)			
lSNFertcost2	-0.0855			
	(0.0947)			
lSNAgrochemC2	0.0546			
	(0.0352)			
lSNTirrigatnC2	0.383***			
	(0.0761)			
lSNLabourClSNvegseedc	-0.114			
	(0.0736)			
lSNLabourClSNFertcost	0.00880			
	(0.0941)			
lSNLabourClSNAgrochemC	-0.0400			
	(0.0523)			
lSNLabourClSNTirrigatnC	-0.238***			
	(0.0680)			
lSNvegseedclSNFertcost	0.275***			
	(0.0680)			
lSNvegseedclSNAgrochemC	0.0455			
	(0.0533)			
lSNvegseedclSNTirrigatnC	-0.140**			
	(0.0633)			
lSNFertcostlSNAgrochemC	0.0517			
	(0.0563)			
lSNFertcostlSNTirrigatnC	-0.0712			
	(0.0606)			
lSNAgrochemClSNTirrigatnC	-0.0351			
	(0.0405)			
vegirrno			0.00141	
			(0.00355)	
gravityIrrigtn			-1.415***	
			(0.510)	
pumpIrrigtn			-0.872**	
			(0.369)	
o.handIrrigtn			5.29e-11	
			(0)	
Gender			0.623	
			(0.428)	
Age			0.0183	
			(0.0604)	
Age1			0.000197	
			(0.000661)	
HhSize			0.0945***	
			(0.0325)	
FExp			-0.0762***	
			(0.0190)	
Obtcredit			-0.180	
			(0.319)	
Extvisit			-0.117*	
			(0.0683)	

pepper			-0.398	
			(0.285)	
onion			-0.179	
			(0.328)	
tomato			0.450	
			(0.328)	
GE			-0.178	
			(0.483)	
1.educ			0.118	
			(0.280)	
2.educ			0.182	
			(0.413)	
3.educ			-0.815	
			(0.496)	
LabourC				-0.000643***
				(0.000186)
vegseedc				-0.000135
				(0.00138)
Fertcost				0.00227**
				(0.00104)
AgrochemC				-0.00281**
				(0.00125)
TirrigatnC				0.000177
				(0.000365)
Constant	0.184***	-0.0740	-2.212	-1.828***
	(0.0420)	(0.166)	(1.503)	(0.285)
Observations	322	322	322	322

Probit Model Analysis

```
Probit regression                               Number of obs     =        322
                                                LR chi2(14)       =      79.80
                                                Prob > chi2       =     0.0000
Log likelihood =  -175.1733                     Pseudo R2         =     0.1855
```

FSstatus	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Hhsize	-.0339133	.0189675	-1.79	0.074	-.0710888	.0032623
landha	.4260683	.2339849	1.82	0.069	-.0325337	.8846703
FExp	-.0047665	.010537	-0.45	0.651	-.0254186	.0158856
Gender	-.7594873	.3283574	-2.31	0.021	-1.403056	-.1159187
depR	.0649053	.0415114	1.56	0.118	-.0164557	.1462662
edulevel	.016589	.01346	1.23	0.218	-.0097921	.0429702
offInc	.124877	.1668967	0.75	0.454	-.2022345	.4519884
Mpfj	.0110982	.1701892	0.07	0.948	-.3224665	.3446628
Dfromfarmtomkt	-.0336694	.0220665	-1.53	0.127	-.0769189	.0095802
Obtcredit	.2322235	.2141134	1.08	0.278	-.1874311	.651878
Lndfrag	-.0503219	.1447237	-0.35	0.728	-.3339751	.2333313
lHhFptn2	.0408854	.026538	1.54	0.123	-.011128	.0928989
lveginc3	1.09121	.1725462	6.32	0.000	.7530257	1.429394
TE	1.280403	.5298815	2.42	0.016	.2418544	2.318952
_cons	-8.366896	1.447225	-5.78	0.000	-11.2034	-5.530386

.

	dy/dx	Delta-method Std. Err.	z	P>|z|	[95% Conf.	Interval]
Hhsize	-.0126474	.0070746	-1.79	0.074	-.0265133	.0012185
landha	.1588956	.0867412	1.83	0.067	-.011114	.3289052
FExp	-.0017776	.00393	-0.45	0.651	-.0094803	.0059251
Gender	-.283239	.1217005	-2.33	0.020	-.5217676	-.0447105
depR	.0242054	.0154542	1.57	0.117	-.0060843	.0544951
edulevel	.0061866	.0050169	1.23	0.218	-.0036463	.0160195
offInc	.0465709	.062249	0.75	0.454	-.0754349	.1685768
Mpfj	.0041389	.0634702	0.07	0.948	-.1202604	.1285382
Dfromfarmtomkt	-.0125565	.008233	-1.53	0.127	-.0286929	.00358
Obtcredit	.0866041	.0797871	1.09	0.278	-.0697757	.242984
Lndfrag	-.0187668	.0539834	-0.35	0.728	-.1245724	.0870388
lHhFptn2	.0152476	.0098869	1.54	0.123	-.0041303	.0346255
lveginc3	.4069499	.0641298	6.35	0.000	.2812577	.5326421
TE	.4775064	.1967696	2.43	0.015	.0918451	.8631678

```
Ordered probit regression                         Number of obs   =        322
                                                  LR chi2(14)     =     333.40
                                                  Prob > chi2     =     0.0000
Log likelihood = -144.58718                       Pseudo R2       =     0.5355
```

fs1	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Hhsize	-.0367251	.0253616	-1.45	0.148	-.0864329	.0129826
landha	.2812693	.1927543	1.46	0.145	-.0965221	.6590608
FExp	-.0104101	.0120969	-0.86	0.389	-.0341196	.0132994
Gender	.4022724	.2940808	1.37	0.171	-.1741153	.9786602
depR	.0874263	.045257	1.93	0.053	-.0012757	.1761283
edulevel	-.0385446	.0156878	-2.46	0.014	-.0692921	-.0077971
offInc	-.8317177	.2098115	-3.96	0.000	-1.242941	-.4204946
Mpfj	.2800127	.1879723	1.49	0.136	-.0884062	.6484316
Dfromfarmtomkt	.0639725	.0229839	2.78	0.005	.0189249	.1090201
Obtcredit	.2092463	.256521	0.82	0.415	-.2935256	.7120181
Lndfrag	.0981003	.1618419	0.61	0.544	-.219104	.4153046
lHhFptn2	.1060357	.0343252	3.09	0.002	.0387594	.173312
VegIncome	-5.251903	.5932383	-8.85	0.000	-6.414628	-4.089177
TE	-1.219739	.5761003	-2.12	0.034	-2.348875	-.0906028
/cut1	-2.176406	.6394599			-3.429725	-.9230878
/cut2	-.5400739	.6220408			-1.759252	.6791036

```
.
end of do-file

. do "C:\Users\ANABA\AppData\Local\Temp\STD02000000.tmp"

.  mfx, predict (outcome (1))

Marginal effects after oprobit
      y  = Pr(fs1==1) (predict, outcome (1))
         =  .73682556
```

variable	dy/dx	Std. Err.	z	P>|z|	[	95% C.I.]	X
Hhsize	.0119868	.00825	1.45	0.146	-.004176	.02815	7.30124
landha	-.0918041	.06314	-1.45	0.146	-.215562	.031954	.61067
FExp	.0033978	.00393	0.86	0.387	-.004304	.011099	9.12422
Gender*	-.1166183	.07525	-1.55	0.121	-.264113	.030876	.903727
depR	-.0285353	.01478	-1.93	0.054	-.057513	.000443	2.50637
edulevel	.0125806	.00509	2.47	0.014	.002595	.022566	7.09938
offInc*	.2794524	.07481	3.74	0.000	.13282	.426085	.599379
Mpfj*	-.0926456	.06316	-1.47	0.142	-.216435	.031144	.409938
Dfromf~t	-.0208801	.00766	-2.73	0.006	-.035898	-.005862	4.50248
Obtcre~t*	-.0710335	.09031	-0.79	0.432	-.248033	.105966	.177019
Lndfrag	-.0320191	.05309	-0.60	0.546	-.136083	.072045	.322981
lHhFptn2	-.0346092	.01154	-3.00	0.003	-.057232	-.011987	5.14196
VegInc~e	1.714179	.17132	10.01	0.000	1.37839	2.04997	.488271
TE	.3981129	.18771	2.12	0.034	.03021	.766016	.722758

(*) dy/dx is for discrete change of dummy variable from 0 to 1

```
. mfx, predict (outcome (2))

Marginal effects after oprobit
      y  = Pr(fsl==2) (predict, outcome (2))
         =  .25156826
```

variable	dy/dx	Std. Err.	z	P>|z|	[95% C.I.	]	X
Hhsize	-.0108725	.00753	-1.44	0.149	-.025633	.003888	7.30124
landha	.0832697	.05746	1.45	0.147	-.029354	.195894	.61067
FExp	-.0030819	.00357	-0.86	0.389	-.010088	.003924	9.12422
Gender*	.1080101	.07095	1.52	0.128	-.031041	.247061	.903727
depR	.0258825	.01354	1.91	0.056	-.00066	.052425	2.50637
edulevel	-.0114111	.0047	-2.43	0.015	-.020619	-.002203	7.09938
offInc*	-.2458248	.06444	-3.81	0.000	-.372132	-.119518	.599379
Mpfj*	.0835331	.05678	1.47	0.141	-.02775	.194816	.409938
Dfromf~t	.018939	.00703	2.70	0.007	.005166	.032712	4.50248
Obtcre~t*	.0635969	.07981	0.80	0.426	-.092827	.220021	.177019
Lndfrag	.0290425	.04814	0.60	0.546	-.065309	.123395	.322981
lHhFptn2	.0313918	.0107	2.93	0.003	.01041	.052373	5.14196
VegInc~e	-1.554824	.1926	-8.07	0.000	-1.93232	-1.17733	.488271
TE	-.3611032	.17244	-2.09	0.036	-.699079	-.023128	.722758

(*) dy/dx is for discrete change of dummy variable from 0 to 1

```
. mfx, predict (outcome (3))

Marginal effects after oprobit
      y  = Pr(fsl==3) (predict, outcome (3))
         =  .01160617
```

variable	dy/dx	Std. Err.	z	P>|z|	[95% C.I.	]	X
Hhsize	-.0011143	.00086	-1.30	0.193	-.002793	.000565	7.30124
landha	.0085344	.00674	1.27	0.205	-.004674	.021743	.61067
FExp	-.0003159	.00038	-0.83	0.405	-.00106	.000428	9.12422
Gender*	.0086082	.00576	1.49	0.135	-.002682	.019899	.903727
depR	.0026527	.00167	1.59	0.113	-.000626	.005932	2.50637
edulevel	-.0011695	.00063	-1.85	0.064	-.002407	.000068	7.09938
offInc*	-.0336276	.0168	-2.00	0.045	-.066558	-.000697	.599379
Mpfj*	.0091126	.00743	1.23	0.220	-.005458	.023683	.409938
Dfromf~t	.0019411	.00104	1.87	0.062	-.000095	.003977	4.50248
Obtcre~t*	.0074367	.01094	0.68	0.497	-.014012	.028885	.177019
Lndfrag	.0029766	.00511	0.58	0.561	-.007047	.013001	.322981
lHhFptn2	.0032174	.00159	2.03	0.042	.00011	.006325	5.14196
VegInc~e	-.1593551	.05935	-2.68	0.007	-.275683	-.043027	.488271
TE	-.0370098	.02181	-1.70	0.090	-.079762	.005743	.722758

(*) dy/dx is for discrete change of dummy variable from 0 to 1