FARM PRODUCTION DIVERSITY AND ITS ASSOCIATION WITH DIETARY DIVERSITY AMONG SMALLHOLDER FARMERS IN KISII AND NYAMIRA COUNTIES, KENYA

Davis Nguthi Muthini

BSc, MSc (University of Nairobi)

Registration Number: A80/50979/2016

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Faculty of Agriculture
University of Nairobi

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DECLARATION

This thesis is my original work and has not been submitted for a degree in any other University.

Signature: Date: 10th November, 2020

Davis Nguthi Muthini

Reg. No. A80/50979/2016

This thesis has been submitted with our approval as University supervisors

Signature …………………. Date: 26-11-2020……………………

Dr. Jonathan Makau Nzuma

Department of Agricultural Economics, University of Nairobi

Signature… …… Date…26 - 11 - 2020.................

Prof. Rose Adhiambo Nyikal

Department of Agricultural Economics, University of Nairobi

Signature: ………………… Date: 26/11/2020………………….

Dr. Catherine Kunyanga,

Department of Food Science, Nutrition and Technology,

University of Nairobi

DECLARATION OF ORIGINALITY

NAME OF STUDENT: Davis Nguthi Muthini

REGISTRATION NUMBER: A80/50979/2016

COLLEGE: College of Agriculture and Veterinary Sciences (CAVS)

FACULTY: Agriculture

DEPARTMENT: Agricultural Economics

COURSE NAME: PhD in Agricultural Economics

TITLE OF THE WORK: Farm Production Diversity and its Association with Dietary Diversity among Smallholder Farmers in Kisii and Nyamira Counties, Kenya

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DEDICATION

To all people who perform random acts of kindness, with no expectation of reward, safe in the knowledge that one day someone might do the same for them.

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LIST OF ABBREVIATIONS

ADDA:	Agriculture and Dietary Diversity in Africa
AIV:	African Indigenous Vegetables
ATE:	Average Treatment Effect
BMEL:	German Federal Ministry of Food and Agriculture
CDDS:	Child Dietary Diversity Score
DDS:	Dietary Diversity Scores
FAO:	Food and Agriculture Organization of the United Nations
FVS:	Food Variety Score
GDP:	Gross Domestic Product
GLOPAN:	Global Panel on Agriculture and Food Systems for Nutrition
HDDS:	Household Dietary Diversity Score
IDDS:	Individual Dietary Diversity Score
IFPRI:	International Food Policy Research Institute
IHS:	Integrated Household Survey
JEA:	Joint Exposure and Adoption
KALRO:	Kenya Agriculture and Livestock Research Organization
KNBS:	Kenya National Bureau of Statistics
MDG:	Millennium Development Goals
NGO:	Non-Governmental Organization
OLS:	Ordinary Least Squares
OFSP:	Orange Flesh Sweet Potatoes
PBC:	Perceived Behavioral Control
PD:	Farm Production Diversity
PSB:	Population Selection Bias ‘
QPM:	Quality Protein Maize
SDGs:	Sustainable Development Goals
TPB:	Theory of Planned Behavior
WDDS:	Women’s Dietary Diversity Score
WFS:	World Food Summit
WHO:	World Health Organization

GENERAL ABSTRACT

Undernutrition and micronutrient malnutrition affect close to one billion people globally. Interventions such as biofortification, farm production diversity, and market linkages target to exploit farming and marketing systems to reduce undernutrition. The impact of consumption of biofortified crops on nutrition has been studied extensively. However, the impact of awareness of varieties and knowledge of nutrition qualities of biofortified crops on adoption is not well understood. Similarly, whereas a direct link between farm production diversity and household dietary diversity is well established in literature, a similar link has not been sufficiently established for women and children.

The effect of increasing production diversity on dietary diversity was found to be small in many of the previous studies, which could be explained by the partial effect of diets sourced from the market. There are no studies in literature that have expressly differentiated diets by sources, that is, subsistence and market pathways. This study evaluates the effect of farm production diversity and food sourcing pathways on diet diversity using panel data collected from 808 respondents selected through multistage sampling in Kisii and Nyamira Counties, Kenya. The two counties were selected based on the prevailing high malnutrition rates in the face of thriving agriculture. Data were analyzed through descriptive and inferential statistical methods using *Stata 14* software. The results from the study have been presented in the form of three papers that are discussed hereafter.

The first paper evaluates the impact of variety awareness and nutrition knowledge on the adoption of KK15 bean variety which contains high levels of zinc and iron. The Average Treatment Effect (ATE) framework was applied to control for variety awareness and knowledge of variety nutrition attributes among respondents.

The results show that farmers who had knowledge of the nutrition attributes of KK15 beans were more likely to adopt the variety. The potential adoption loss due to lack of knowledge of the nutritional benefits was 8 percent. Adoption of biofortified crops can therefore be enhanced if information on the nutrition characteristics of the varieties is widely disseminated in the population.

The second paper applies the Poisson model to evaluate the association between farm production diversity and diet diversity at household and individual levels. The study findings indicate that farm production diversity is significantly associated with the diet diversity of women and that of the entire household, but not with the diet diversity of children. Animal species diversity has the highest magnitude of association with dietary diversity in this study. Every additional animal species kept leads to a 0.33 and 0.13 increase in household dietary diversity and the dietary diversity of women respectively. Children's diet diversity is associated with household size and education of the mother. The study highlights the need to incorporate individual dietary requirements in policy and nutrition interventions.

The third paper also applies the Poisson model to examine the effect of different food sourcing pathways on the household's and individual's diet diversity. In particular, the analysis focusses on the dietary diversity from subsistence and the market. The findings show that farm production diversity is positively associated with dietary diversity obtained from subsistence, but negatively associated with dietary diversity obtained from the market. The results underscore the important role of markets for the diets of smallholder farmers, even in subsistence-oriented settings, possibly because they are not able to produce enough food from their small farms. Thus, while farm diversification is an important step towards nutrition, improving market access for smallholders may deliver more benefits.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

A recent Food and Agriculture Organization of the United Nations [FAO] food security report shows that, globally, close to one billion people are undernourished (FAO *et al*, 2019). The number of chronically undernourished people increased from 777 million in 2015 to 821 million in 2017, a reverse from the declining trend observed in the decade prior to 2015. The majority of the undernourished people live in rural areas of developing countries in Africa and Asia. In Africa, 21 percent of the population (256 million people) is undernourished. FAO *et al* (2019) report that Africa is leading in levels of child stunting, which is mainly caused by poor nutrition. Prevalence of undernourishment is highest in Eastern Africa at 31.4 percent (222 million people).

In Kenya, more than 20 percent of the population (11.7 million people) is undernourished (FAO *et al*, 2018). About 26 percent of Kenyan children are stunted, while 4 percent are wasted and 11 percent underweight (Kenya National Bureau of Statistics [KNBS], 2014). In addition, severe wasting, underweight, and stunting affect 1 percent, 2 percent, and 8 percent of Kenyan children respectively. According to FAO *et al* (2017), one in three Kenyan women within reproductive age (15-49 years) suffers from anaemia. Increased levels of undernutrition among these population sections increase their risk of poor health and mortality. Beyond enhanced access to sufficient quantities of food, dietary diversity and quality of diets are important aspects nutrition security. Women and Children are most vulnerable to malnutrition because of their high nutritional requirements for growth and development and different physiological requirements (Blössner and Onis, 2005; FAO and FHI 360, 2016).

Generally, women require more iron than men, additionally, pregnant and lactating women require more of most nutrients than men, thus may require more nutrient-dense diets (National Research Council, 2006; Torheim and Arimond, 2013). The micronutrient status of women during pregnancy and lactation affects their offspring's health and development (Torheim and Arimond, 2013). For children, special nutrition needs are as a result of rapid growth and development, greater susceptibility to infections, among others. Adequate nutrition within this phase of growth greatly impacts survival and adult outcomes, including human capital and economic output (Martorell, 2017).

Undernourishment and micronutrient malnutrition are the leading risk factors for illness and death, causing economic loss to households and loss of national income to countries (IFPRI, 2017; Gödecke *et al*., 2018; FAO *et al*., 2019). Particularly, undernutrition reduced the Gross Domestic Product (GDP) of Africa and Asia by up to 11 percent, mainly due to lost productivity and healthcare costs (FAO *et al*., 2019). The current trend of undernutrition prevalence may derail the achievement of the 2nd Sustainable Development Goal (SDG) to "End hunger, achieve food security and improved nutrition, and promote sustainable agriculture" by 2030 (United Nations, 2015). Further, the 3rd SDG of achieving "Good health and well-being for people", especially on child and maternal mortality may not be achieved if undernutrition levels do not drop.

According to FAO *et al*. (2019), the leading factors that exacerbate the undernutrition trends include slowing economic growth, conflict and instability leading to population displacement, climate change and increasing climate variability. These factors negatively affect agricultural productivity, food production and natural resources, which in turn weakens food systems and rural livelihoods.

Correspondingly, Fanzo *et al* (2013) report that developing countries have mainly focused on increasing the productivity of food staples, mainly starchy foods such as maize, rice, and wheat. This has exposed especially the poor to monotonous diets, causing micronutrient malnutrition (World Bank, 2008). Consequently, recent development programs are promoting “nutrition sensitive agriculture” through interventions such as farm production diversification, biofortification, animal source proteins and indigenous or traditional crops such as cassava and sweet potatoes in low-income countries (Pfeiffer and McClafferty 2007; Masset *et al,* 2012; Webb 2013).

Biofortification aims to increase the micronutrient density of staple crops through plant breeding, transgenic techniques, or agronomic practices (Pfeiffer & McClafferty, 2007; Bouis and Saltzman, 2017). Biofortification can be an effective pathway, as it targets staple crops that are already being consumed in target areas. It is also linked to farm production diversity, as farmers have to either add new varieties or substitute existing varieties for the biofortified varieties.

Biofortification requires diffusion of the varieties in to the population through adoption and consumption. Thus, biofortification requires complementary interventions to create awareness of the technologies. An example is the Agriculture and Dietary Diversity in Africa (ADDA) project that aimed at promoting adoption of nutrient enhanced crop varieties through nutrition training. The project specifically focused the *KK 15* bean variety which contains high levels of zinc and iron, and thus important in the fight against micro-nutrient deficiency (Kenya Agricultural & Livestock Research Organization [KALRO], 2016).

Majority of those affected by undernutrition are smallholder households in rural areas of developing countries (FAO *et al*, 2019). Thus, the subsistence production can be an effective pathway to nutrition security for the poor and pre-transition countries (World Bank, 2008). If households consume what they grow, then producing a wide range of nutritious foods (farm production diversification) can improve household nutrition. Previous studies have found a positive association between farm production diversity and Household Dietary Diversity Scores, although the mean effects have been generally small (Jones *et al*, 2014; Sibhatu *et al*, 2015; Sibhatu and Qaim, 2018).

Lastly, although smallholder households in sub-Saharan Africa are considered subsistent, commercialization and market access can substitute for own production through selling surplus farm produce and purchasing food items not grown in the farm (Hoddinott et al, 2015; Sibhatu *et al*, 2015; Koppmair *et al*, 2016; Sibhatu & Qaim, 2017). In addition, collection of wild fruits and vegetables can contribute significant food proportions to households. Wild fruits and vegetables can be important sources of micronutrients, especially for women and children due to their high demands for micronutrients (Wan *et al*, 2011). This is especially important for low-income households, as the household diets can be diversified and nutrient intake improved with little or no additional cost.

1.2 Statement of the Research Problem

Undernutrition is a major cause of diseases and imposes a high cost burden on households in developing countries (IFPRI, 2017; Gödecke *et al.*, 2018). Agriculture provides a pathway to reduce undernutrition among the poor and vulnerable in the rural small farm sector through improved food access and micronutrient availability.

Some recent nutrition interventions in the small farm sector have focused on biofortification, farm production diversity, and market linkages (Pfeiffer and McClafferty 2007; Masset *et al,* 2012; Webb 2013; Khonje et al, 2015; Ruel et al, 2018; Sibhatu and Qaim, 2018). The impact of consumption of bio-fortified crops on nutrition has been studied extensively (Pfeiffer and McClafferty 2007). However, studies on the impact of awareness of varieties and knowledge of nutrition attributes of biofortified crops on adoption are scarce. Further, previous studies have reported a direct link between farm production diversity and household dietary diversity score, however a link between farm production diversity and diet diversity for women and children has not been sufficiently established in the literature. Women and children are more vulnerable to undernutrition due to their unique physiological requirements (Mayo-Wilson *et al*, 2011; FAO and FHI 360, 2016).

Subsistence households consume most of what they produce from the farm, yet they still obtain a substantial quantity of food from the market (Frelat *et al*., 2016; GLOPAN, 2016; Sibhatu and Qaim, 2017). Thus, the market pathway also affects diets and thus nutrition outcomes. Food sourcing from the market could explain the weak association between farm production diversity and dietary diversity found by previous studies (Jones *et al*. 2014; Berti, 2015; Sibhatu *et al*. 2015; Verger *et al*., 2017). While the role of markets for smallholder diets was highlighted in earlier research (Barrett, 2008; Koppmair et al., 2017), the studies have not explicitly differentiated between subsistence and market pathways. This research gap is addressed in this study.

The study used cross-section data collected from farming households in Nyanza region Counties of Kisii and Nyamira in November/December 2015 and November/December 2016. The two Counties are characterized by high population density, very small farm sizes (mostly below 2 acres), and favorable agricultural potential (GoK, 2014). However, 25.5 percent of children in Nyamira and Kisii are stunted, against a national average of 26 percent, while almost ten percent are underweight (KNBS, 2014). Thus, the Counties exhibit an irony of prevailing high malnutrition rates, and simultaneously, a thriving agriculture sector.

1.3 Purpose and objectives of the study

The purpose of this study is to evaluate the association between farm production and dietary diversity in Kisii and Nyamira Counties, Kenya.

The specific objectives of the study are:

i. To assess the impact of variety awareness and knowledge of nutrition attributes on adoption of biofortified crop varieties

ii. To evaluate the association between farm production diversity and diet diversity of household, women and children

iii. To assess the association between food sourcing pathways and diet diversity of households, women and children

1.4 Hypotheses

The following hypotheses were tested:

i. Variety awareness and knowledge of nutrition attributes have no effect on the adoption of biofortified crop varieties.

ii. Farm production diversity has no effect on diet diversity of households, women and children in rural households.

iii. Farm production diversity is positively associated with dietary diversity from subsistence and negatively associated with dietary diversity from the market.

1.5 Justification

Developing countries lose a considerable portion of their Gross Domestic Product (GDP) due to the negative effects of malnutrition (Stein and Qaim, 2007; IFPRI, 2017). Malnutrition is a threat to the attainment of Kenya's Vision 2030 due to potential negative effects on the health status of the population. The second of the Sustainable Development Goals is to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. This study contributes to the achievement of Vision 2030 and the Sustainable Development Goals (SDGs) by providing practical policy and intervention solutions to the problem of malnutrition especially in the context of rural areas in developing countries.

The National Food and Nutrition Security Policy envisions that micronutrient deficiencies will be addressed through the promotion of more diversified diets, bio-fortification, food fortification, and vitamin and mineral supplementation. The findings of the study will provide information on linkages between the agriculture sector and nutrition, and specifically through diet diversification and biofortification. This will be important in exploiting the potential of the sector in reducing levels of undernutrition.

The findings of the study provide insights into exploiting agriculture to reduce malnutrition. The insights will be useful for the National government, as well as the County governments in developing nutrition policies and implementing nutrition interventions. The results presented here refer to farm households in Kisii and Nyamira Counties. However, the situation in these Counties is typical for most of the Kenyan and African small farm sector, thus the general findings may also apply to other contexts within the region.

CHAPTER TWO

LITERATURE REVIEW

This chapter is a review of literature on agriculture and nutrition linkages, and methodological issues. The first section reviews theoretical literature, while the second section is a review of empirical literature.

2.1 Review of Theoretical Approaches to Analyzing Nutrition

Adoption of better nutrition actions such as the adoption of biofortified varieties or dietary diversity is influenced by both intrinsic and extrinsic factors. Extrinsic factors include characteristics of the adopter and the external environment in the decision-making process, while intrinsic factors include perceptions, knowledge, skills, beliefs and attitudes of the farmer (Meijer *et al.*, 2015). The effectiveness of nutrition interventions depends on the aforementioned social and behavioural tendencies that are sometimes deeply entrenched. Thus, social and behavioural change theories can be used to promote positive transformation in nutrition behaviours through communication and information, either as standalone intervention or in combination with other actions that target the external environment (Kennedy *et al.,* 2018). This section reviews behavioural theories and behavioral change as they relate to household nutrition and dietary choices.

One of the theories commonly used in dietary and nutrition behaviour is the Theory of Planned Behavior (TPB) (Ajzen, 1991). The theory describes human behaviour in specific contexts, that is, intent to engage in a behaviour or activity, as a function of individual and social factors. Figure 1.1 represents the TPB as applied to adoption of improved dietary and nutrition practices.

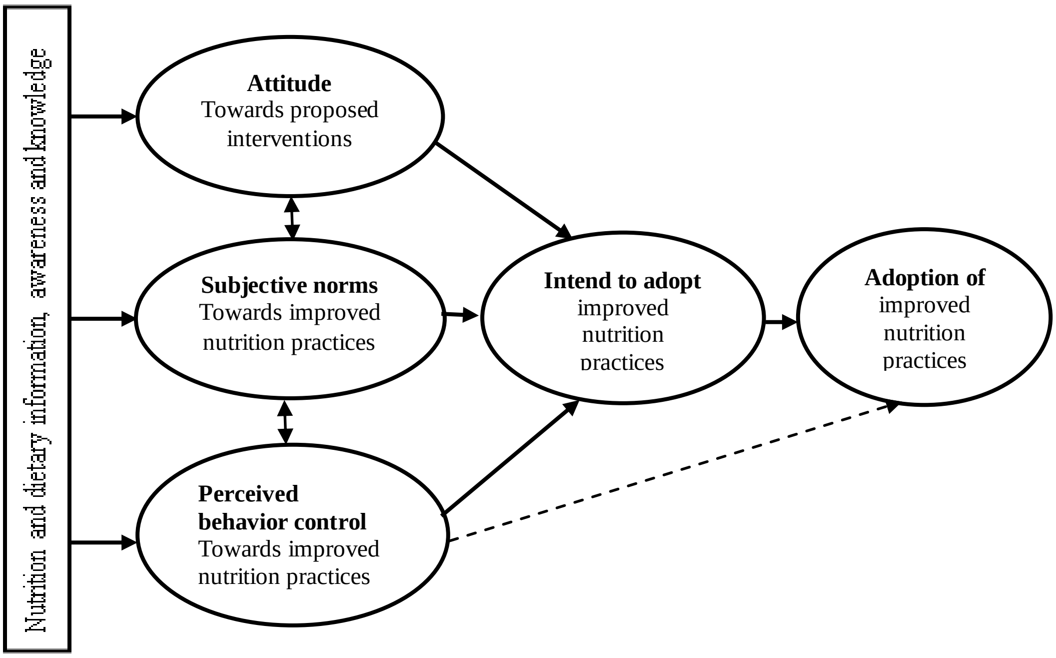

Figure 1.1: Theory of Planned Behavior as applied to adoption of improved dietary and nutrition practices

Source: Adapted from Ajzen (1991)

As illustrated in Figure 2.1, nutrition interventions such as promotion of biofortified varieties expose farmers and households to information and knowledge on nutrition and dietary practices. This new information influences pre-existing attitudes, subjective norms, and perceptions on the improved practices (Figure 2.1). According to Ajzen (1991), attitude refers to the value that a farmer attaches to adopting the new practice. The value could be improved nutrition or reduced incidence of malnutrition-related disease in the home. Perceived behavioural control (PBC) has to do with the individual's perceptions of ease or difficulty of the new practice, given the available resources and skills. Such could include maintaining diverse crops in the farm given the size of the farm available. Subjective norms denote the influence of people close to the individual on the adoption decision (Ajzen, 1991). The three conditions influence farmer's intention to adopt the improved practices, which ultimately leads to adoption.

This theory informs the design of the current study, in which researchers seek to understand the pathways through nutrition information disseminated during promotion of biofortified varieties affect households' adoption behavior. Understanding household decisions to shift from the regular varieties to bio-fortified ones, or increasing farm production diversity for diet diversity requires an understanding of the determinants of their behaviors and factors that trigger a change in these behaviors.

2.2 Review of past Empirical Studies

Food security exists 'when all people, at all times, have physical 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). Attaining food security was named as the first Millennium Development Goal (MDG). Globally, the majority of countries attained MDG 1 as the monitoring period ended in 2015. However, as the 2015 food security report indicates, globally, the World Food Summit (WFS) goal of attaining nutrition was missed by a large margin. Undernutrition and other forms of malnutrition remain high in developing countries (FAO, 2015).

Nutrition security is now included in the Sustainable Development Goals, goal two which is to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. Nutrition security is defined as a 'condition when all people at all times consume food of sufficient quantity and quality in terms of variety, diversity, nutrient content, and safety to meet their dietary needs and food preferences for an active and healthy life, coupled with a sanitary environment, adequate health, and care' (FAO, 1996). Undernutrition is caused by deficiencies in energy, protein, and/or micronutrients.

Micronutrient deficiency is also known as hidden hunger. It occurs when “intake or absorption of vitamins and minerals is too low to sustain good health and development in children and normal physical and mental function in adults”. Hidden hunger affects the health and development of a large share of the population without showing less obvious “invisible” effects. Clinical symptoms such as night blindness from vitamin A deficiency or goitre due to insufficient iodine intake, only become noticeable once deficiencies become severe, hence the name “hidden hunger” (IFPRI, 2014).

Micronutrient deficiencies cause an estimated 1.1 million of the 3.1 million child deaths that occur each year as a result of undernutrition (Black *et al.*, 2013). The most common deficiencies in children are vitamin A, iodine, iron and zinc deficiencies. Vitamin A and zinc deficiency weaken the immune system, thus affecting child health and survival. Deficiency of iodine and iron prevents children from reaching their intellectual and physical potential (Allen 2001). Women and Children have greater needs for micronutrients (Darnton-Hill *et al.,* 2005), and women can cause an intergenerational cycle of malnutrition through birth of affected children (Blössner and Onis, 2005; FAO and FHI 360 2016)

Micronutrient malnutrition is mainly caused by a poor diet that is based mostly on staple crops, such as maize, wheat, rice, and cassava. These foods provide energy but contain relatively low quantities of vitamins and minerals. Victims of micronutrient malnutrition are those that lack access to or cannot afford a wide range of nutritious foods such as animal-source diets (eggs, fish, meat, and dairy), vegetables and fruits (IFPRI, 2014). Some of the most effective ways of reducing hidden hunger include fortification (Farebrother *et al.*, 2015), biofortification (Bouis and Saltzman, 2017) and increasing dietary diversity (Thompson and Amoroso 2014).

Previous studies assess whether small farm households consume foods containing the various micronutrients as measured by dietary diversity. However, there is a gap in literature on the linkage with the sources of the food, either subsistence or from markets. Indeed, obtaining food from the different sources is not without constraint. For instance, own food production could be limited by factors such as labor and land, while access from the market could be limited by their income and physical access to the market, among other factors analyzed herein.

2.2.1 Dietary Diversity

Dietary diversity has been validated as a proxy for nutrient adequacy in women and children (Ruel and Menon, 2003; Arimond and Ruel, 2004; Steyn *et al.*, 2006). Dietary diversity scores are correlated with more comprehensive measures of diets and nutrition (Fongar *et al.*, 2018; Headey and Ecker, 2013). Different diet diversity indicators that cater to nutritional requirements of different gender and age groups have been developed. Household dietary diversity is commonly measured using the Household Dietary Diversity Score (HDDS), which is computed using data on 12 food groups based on a 24 hour of 7-day recall of all foods consumed at home by household members (FAO, 2011).

Dietary diversity scores for women are calculated using 9 food groups following FAO (2011). Foods such as condiments, sugar and sugary foods, and beverages, are included in HDDS because they require financial resources to obtain, and thus may help reflect household economic access to diverse diets. The dietary diversity scores for children can be calculated using the 7 food groups proposed by WHO (2010). The scores were developed for children 6-23 months.

The age of children can be extended to 6-59 months to cover the first five years of life when children are most susceptible to negative impacts of undernutrition (Grantham-McGregor et al, 2007).

2.2.2 Farm Production Diversity

Farm production diversity is a measure of the variability of crop varieties grown on the farm and animal species kept. It can be measured as a count of species (Jones *et al.*, 2014; Koppmair *et al.*, 2017), or as a weighted index of species diversity on the farm (Jones *et al.*, 2014; Sibhatu and Qaim, 2015). Weighted methods seek to develop a 'diversity index' which represents the relative abundance of a species. Various methods of measuring diversity index have been developed to measure ecological biodiversity, some of which have been adapted to measure farm production diversity. The methods include; Margalef index, Shannon-Weaver, Berger-Parker index and Simpson's index.

The Margalef index is mostly used to measure species richness typically over large spaces or samples. The index is easy to calculate and can be used in conjunction with other indexes. It is highly sensitive to sample sizes although it tries to compensate for sampling effects (Magurran, 2005). It is a very simple index to apply that can be used in conjunction with indices sensitive to evenness or changes in dominant species, such as the dominance Berger-Parker index (Berger and Parker, 1970). The Margalef index is often used in agrobiodiversity and recently in farm production diversity studies as it accounts for the area cultivated with different crop species on the farm (Di Falcao and Chavas 2009; Sibhatu *et al.*, 2015). Nevertheless, the method would not be favorable for this study due to tendency of the results to be different if "densities are used instead of total numbers" (Gamito, 2010).

The Berger-Parker- Index is the proportion of the most common species in the community or sample. It measures the relative abundance of a species by estimating the “distribution of individuals in a system among different species” (Berger and Parker, 1970). It estimates the proportional abundance of the most abundant species (Magurran, 2005). However, the index would not be appropriate for this study as it is highly biased by sample size and richness and does not make use of all the sample information available (Magurran, 2005).

The Shannon Index is used to measure the “evenness of a species by combining richness and relative abundance”. It takes in to account the “degree of evenness in species abundances” (Magurran, 2005). The index, however, has a disadvantage in that it fails to distinguish between species evenness and richness, which causes a challenge in interpretation because evenness or abundance can cause an increase in the index, without clear distinction on the source. However, Hayek and Muzas (1997) note that the index can also be decomposed into the two components, which can be used to interpret diversity.

The Simpson’s index is defined as the probability that any two individuals selected at random from an infinitely large community will be of the same species (Simpson 1949). The index is a robust and meaningful measure of diversity as it captures species’ variance and distribution (Magurran, 2005). It is popular in biodiversity studies (Magurran, 2005) and has been used as a measure of farm production diversity in nutrition studies (Jones *et al*., 2014). Although originally developed to measure the relative uniformity of abundance of a species (evenness), the Simpson’s index can be transformed to measure the number of species (richness) (Magurran, 2005; Jones *et al*., 2014). Given the circumstances of this study, the Simpson’s index would be most favorable method due to its ability to account for the size of land occupied by a specific crop species in the farm relative to other crops.

Other methods that have been used to measure farm production diversity include unweighted counts of plant species grown and animals kept (Sibhatu *et al.*, 2015; Koppmair *et al.*, 2016). This method has been applied in conjunction with weighted measures for comparison purposes and robustness checks. Sibhatu *et al* (2015) used a simple count of crop and animal species on the farm, and also calculated the Margalef index to compare. The finding showed that results are not affected by the method used to measure farm production diversity, rather by whether the measure included crops and animals, or just crops only. Similarly, Jones *et al* (2014) report that both weighted and unweighted measures of farm production diversity are heavily correlated, and result in similar outputs when regressed against dietary diversity.

It is prudent to use different measures of farm diversity, with a mix of both weighted and simple counts so as to allow assessment of the robustness of results and consistency of the association between farm production diversity and dietary diversity.

2.2.3 Farm Production Diversity and Dietary Diversity

Farm production diversity can be an effective strategy for mitigating micronutrient malnutrition and food insecurity, as well as production risks. Subsistence oriented households produce food for own consumption, thus, production of different types of foods results to diet quality and diversity. For such households, a greater focus on staples results in greater access to and consumption of energy, while production of fruit, vegetables, and animal source foods (dairy, eggs, fish, and meat) results to greater access to energy, protein, and fat, as well as improved quality and micronutrient content of diets. Indeed, several scholars have assessed the linkages between farm production diversity and dietary diversity, with mixed results.

Rajendran *et al* (2014) sought to determine whether crop diversity contributed to dietary diversity among Tanzanian farming households. The study focused on African Indigenous vegetables (AIV) that had been introduced in the study area because of their particular ability to enhance household income as well as nutritional benefits. Using data collected from 300 farming households in Tanzania, the study employed multiple linear regression to test the hypothesis that an increase in the number of crops grown on the farm would lead to an increase in the variety of foods consumed by the household. The study also aimed at looking at how farmers respond during transitional periods in cropping systems. To achieve the transition environment, AIVs were introduced to farmers in a maize growing region.

The study by Rajendran *et al* (2014) found an independent association between crop diversity and dietary diversity, this association is, however, eliminated when covariates are introduced. Therefore, dietary diversity is a function of factors such as household size, education, and income. It is, however, important to note that the study concentrated on crop diversity alone. Leaving out other important farm enterprises, which can be direct sources of food or indirect as a source of income such as livestock keeping, could bias the results. Nyamira and Kisii Counties, for instance, have both livestock and crop enterprises in the smallholdings, therefore the approach here would be inconclusive. Further analysis is necessary to determine the dynamics of the association, by analyzing sources of income, whether on-farm and off-farm, as well as intrahousehold expenditure decisions.

Hodinnot *et al* (2015) carried out a study to determine the effect of cow ownership on child nutrition in rural Ethiopia using Ordinary Least Squares (OLS). The researchers analyzed food consumption and socioeconomic data from 1867 households, and used height for age in children as the dependent variable. The study found that children in households that owned a cow consumed more milk, experienced higher linear growth and were less likely to be stunted. This is an indication of the probable significance of livestock on the dietary diversity of households in some contexts. This would be tested in this study by computing farm production diversity based on livestock kept by the household.

Jones *et al* (2014) applied the Ordinary Least Squares (OLS) method to analyze cross-sectional data from the Malawi third Integrated Household Survey (IHS). The study aimed to determine the linkage between farm diversity and household dietary diversity. The IHS is a nationally representative sample data of farming households in Malawi. The authors created two multiple regression models using two indicators of dietary diversity as dependent variables, and three indicators of farm diversity as well as confounders as independent variables. The study found that found a positive linkage between farm diversity as measured by farm diversity and household dietary diversity. The linkage was more pronounced in wealthier households, and those headed by women.

The DDS used by Jones *et al* (2014) is a count of 1-12 or 1-9 food groups. Thus, the dependent variable is in the form of count data. Although count data can be analyzed using multiple linear regression, the results can be improved by using models that account for the properties of count data. Such properties include the presence of numerous zeros and small values and the discrete nature (Greene, 2007). Additionally, analyzing count data with OLS leads to biased results due to among other reasons; the inability of OLS to account for the zero-truncated data, heteroskedasticity, and non-normality (Sturman, 1999). To avoid the bias, it is prudent to explore other models that account for count data, which we do in this study.

Sibhatu *et al* (2015) assessed the linkages between farm diversity and dietary diversity using household-level data from Indonesia, Kenya, Ethiopia, and Malawi. The study applied the Poisson estimator to regress Dietary Diversity Score (DDS) against several independent variables. The method is more plausible since DDS is a count data of 9 or 12 food groups. The Poisson regression is suitable for analyzing data in cases where the dependent variables are count data (Greene, 2007). The study used as measures of farm diversity both crop and animal count and the Margalef index for comparison and for robustness check. The findings show a non-linear association between farm diversity and household diet diversity, an indication that as farms diversify indefinitely, they lose the income and productivity benefits of specialization, and this could lead to lower diet diversity. However, the study by Sibhatu *et al* (2015) focused on household level data, which may not be representative of the dietary behaviours of the vulnerable individuals within the home, such as women and children. More research with a focus on individual level data is required to assess whether the same findings are applicable to such individuals.

Ecker (2018) sought to determine whether agricultural transformation experienced in Africa in the last decade affected household food and nutrition security. The study analyzed the trends in the linkages between farm production diversity and household dietary diversity in rural Ghana between 2006 and 2013. With agricultural transformation, it is expected that households specialize on the farm and become increasingly reliant on the market for food. However, this is only practical in cases where market access is not a challenge, which is not the case in most of rural sub Saharan Africa where market failure could be rampant. Thus, agricultural transformation in such instances, if not accompanied by increased purchase of diverse diets from the markets, will lead to reduced dietary diversity (Ecker, 2018).

The results from Ecker (2018) show a consistent positive association between production diversity indicators and household dietary diversity. Further, the results reveal that contrary to expectations, farm production diversification became increasingly more important for increasing household dietary diversity across the study period. This was in spite of the agricultural transformation that happened during the seven-year period covered by the study. Similarly, the association between household dietary diversity and household income was positive across the period. The two results may indicate that income growth does not substitute farm production diversity, but that both play a complementary role in improving household dietary diversity.

Food market conditions and farming systems vary widely across countries and regions in Africa; thus, research findings are sometimes context and area specific. Thus, more research in different contexts is desirable to determine if such results are replicable.

2.2.4 Market Participation and Dietary Diversity

Smallholder households in developing countries are mainly subsistence oriented, that is, they depend on own production sources for food. Thus, diets of these households have been presumed to reflect the plants they grow or livestock they keep on their farms. However, some recent studies found a weak association between farm production diversity and dietary diversity in the small farm sector of different developing countries (Jones *et al.*, 2014; Sibhatu *et al.*, 2015; Koppmair *et al.*, 2017; Ecker, 2018). This is an indication that, households acquire food from other sources, mainly from markets, despite their subsistence orientation in production decisions.

Koppmair *et al*. (2016) analyzed survey data collected from smallholder farm households in Malawi in to determine the association between farm production diversity and dietary diversity and the role of other actors such as market access on dietary diversity. The researchers computed dietary diversity scores from 24-hour food recall data for household and individual, while production diversity scores were computed from annual farm production data. Koppmair *et al* (2016) found positive but weak linkage between farm production diversity and dietary diversity, and indication that further increasing farm production diversity may not be the most effective way of improving dietary diversity.

The study by Koppmair *et al* (2016) found that linkage between farm production diversity and dietary diversity weakens as access to markets, as measured by distance, increases. This is probably an effect of food that is sourced from the market. Further research on the linkages between production diversity, markets and dietary diversity is therefore necessary to show the linkages thereof.

Hirvonen and Hoddinott (2017) used household survey data to determine the relationship between food consumption by pre-school children and household agricultural production in rural Ethiopia. The study accounts for market access factors to show how the presence or absence of markets affects household consumption patterns. The study by Hirvonen and Hoddinott (2017) found that, first, children's diets are strongly linked to households' production decisions. However, food consumption patterns also differ by household access to markets. Households that lived near food markets were found to consume more purchased foods and less from own production. Own produced food accounted for less than 50 percent of the consumption for households living less than 3 kilometers from the nearest food market.

However, the study by Hirvonen and Hoddinott (2017) focused on consumption patterns of children only, thus the results cannot be used to infer similar interactions for women or household diets. Sibhatu and Qaim (2017) used representative data from rural Ethiopia covering every month of one year to determine contribution of the various sources of food during different seasons. The study found that 58 percent of rural households' calorie consumption was sourced from subsistence production, while 42 percent was obtained from purchased foods. The proportion obtained from market sourced food increased to more than 50 percent during the lean season.

Sibhatu and Qaim (2017) found that market sources play a greater role for dietary diversity than subsistence sources. The study only used household diet diversity scores, as measured by HDDS. There is a gap in literature relating to analysis of these fluctuations using both household and individual level diet data. This is key, as dietary diversity at individual level is calculated to include one's unique nutrient requirements.

A similar study was undertaken by Zanello *et al* (2019) in Afghanistan. The study sought to find out how seasonality affects the interplay of production diversity, markets and diets among rural households. According to Zanello *et al* (2019), agricultural production in Afghanistan is significantly seasonal, with a lengthy lean period marked by limited agricultural production opportunities during winter. In addition, rural areas of Afghanistan are marked by difficult terrain and poor infrastructure, which leads to variability in market food accessibility. Zanello *et al* (2019) used the cost of transporting a 50 kg of wheat to the nearest market as the proxy for market access, thus capturing the comparative transaction cost of market participation. In addition, the study used the Food Consumption Score (FCS) to measure household dietary diversity.

The study by Zanello *et al* (2019) indicates that household’s consumption and production decisions are non-separable, thus uses instrumental variable methods to account for endogeneity. The results show minimal variation in the diet quality across seasons, an indication that households in the study area successfully smooth their diets across the different seasons. Zanello *et al* (2019) report low cropping and livestock diversity at the farm level, an indication of substantial focus on staple cropping, mainly wheat. The study reveals that livestock diversity is more important for diet diversity, relative to cropping diversity. In addition, seasonality and market access influences some dimensions of diet diversity. For example, enhanced crop diversity is positively associated with dietary diversity in the regular season, but not in the lean season. The results could differ for regions such as Kisii and Nyamira Counties that have minimal seasonal variations in food availability as they receive precipitation in all months of the year.

Ogutu and Qaim (2018) analyzed data from Nyanza region to determine the effect of farm commercialization on nutrition status of smallholder households. The study found that more commercialized households had lower levels of undernutrition, as measured using calorie intake. This, therefore, implies that households with increased market participation were likely to be more nourished. It is however not clear whether the increased calorie intake was accompanied with increased nutrient adequacy as measured using diet diversity. In addition, further analysis that explicitly differentiates between subsistence and market food sources to analyze dietary diversity obtained through both pathways separately is necessary.

2.2.5 Adoption of biofortified varieties

Biofortification is defined by WHO as “the process by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding, or modern biotechnology” (WHO, 2019). It targets increasing micronutrient density of staple crops, crops that are already common in target areas, which makes it effective in alleviating micronutrient malnutrition (Pfeiffer and McClafferty, 2007). Some of the common biofortification cases include iron-biofortification of legumes, rice, sweet potato, beans and cassava; zinc-biofortification of beans, wheat, sweet potato, rice and maize; provitamin A carotenoid-biofortification of maize, sweet potato, and cassava; and amino acid and protein-biofortification of maize, sorghum and cassava.

Adoption of bio-fortified varieties can lead to increased consumption of nutrients therein, and consequently effectiveness in combating malnutrition. Kaguongo *et al* (2010) analyzed data collected from a representative sample of 340 farmers in Kenya to assess factors that affect adoption and intensity of adoption of Orange-Fleshed Sweet Potato (OFSP). The study applied logit and logit transformed regression models. Farmers were aggregated into participants or non-participants based on whether they participated in an extension program promoting traditional foods. Both baseline and follow up data were collected and analyzed for impact assessment. The study analyzed the influence of participation in the extension intervention on adoption. Factors such as location, nutrition and value-addition knowledge, and availability of planting materials were found to influence adoption. It is obvious that extension services influence adoption through transfer of information and knowledge of varieties, however, these information pathways were not analyzed in detail.

De Groote *et al* (2010) assessed the adoption of Quality Protein Maize (QPM) in East Africa. QPM has improved protein quality, as well as agronomic and storage qualities similar to those of conventional maize. The study applied logistic regression to determine the factors that influenced adoption of the varieties. Farmers in Kenya were found not to have adopted the variety, while up to 70 percent of farmers in Uganda and 30 percent in Tanzania had adopted. The study linked the difference in levels of adoption to diffusion of information on the new technology in the two areas. Whereas familiarity with QPM was high (74-80 percent of farmers), it was very low in Kenya (19 percent). Understanding of nutritional attributes of QPM was even lower, 7 percent in Kenya compared 47-55 percent, in other countries. De Groote *et al* (2010) found that adoption of QPM was significantly influenced farmers' participation in extension activities, and their understanding of the nutritional benefits of QPM. The actual impact of information on adoption loss or gain was however not analyzed in the study.

Adoption of new technologies is largely affected by awareness of the innovations (Diagne and Demont, 2007). In addition to awareness of the technology, knowledge of the nutritional attributes of the varieties can have significant influence on the adoption and consumption of biofortified crops. Even for farmers who possess the two aforementioned characteristics, access to propagation materials such as seeds or vines for sweet potato can still influence adoption (Kabunga *et al.*, 2012). The common approach in adoption literature is to model the decision to adopt, or otherwise, using binary choice models (De Groote *et al.*, 2010; Knowler and Brandshaw, 2007). However, as Diagne and Demont (2007) point out, this method does not accurately estimate population adoption rate as it does not take into consideration non-exposure bias and selection bias.

Non-exposure bias results in an underestimation of population adoption rate as farmers not exposed to a new technology cannot adopt it. Similarly, selection bias results from adoption by farmers who get exposed first or ‘progressive’ farmers who most likely interact with technology promoters such as extension officers, leading to overestimation of population adoption rate. In addition, even if farmers were aware of the technology, they would not adopt if they did not have access (Diagne and Demont, 2007; Dontsop-Nguezet *et al.*, 2013).

Dontsop-Nguezet *et al* (2013) argue that access to technology equally constrains adoption, which necessitated its inclusion in their modelling to obtain awareness and access unrestricted potential population adoption rate. Kabunga *et al.* (2012) used the ATE approach to correct for selection bias while analyzing the adoption of tissue culture (TC) banana technology in Kenya. The study differentiated between farmers who had heard of the technology (awareness exposure) and those who had knowledge of the attributes of the technology (knowledge exposure). Only farmers who responded in affirmative to the first question were asked about their knowledge of TC variety attributes and performance of TC bananas.

The study found that the parameters of the classical adoption model differed a little with the ATE results after correction of heterogeneous awareness exposure, but differed considerably after correction of heterogeneous knowledge exposure. This, the study concludes, is an indication that most farmers are only aware of a technology, as opposed to proper understanding that would trigger notable changes in cultivation practices and successful adoption. Awareness of a technology as such is not a sufficient condition for adoption of the same.

Dontsop-Nguezet *et al.* (2013) used the ATE model to estimate the population potential adoption rates of the New Rice for Africa (NERICA) varieties in Nigeria when farmers are not constrained by awareness and access to seed. The study evaluated the determinants of adoption, and also estimated the adoption gaps resulting from lack of awareness and access to seed. Dontsop-Nguezet *et al.* (2013) argue that awareness of a new technology is a necessary but not sufficient condition for adoption. This is because farmers without access to the technology may not adopt, even if they are aware, thus access to technology is a necessary condition for adoption.

The study by Dontsop-Nguezet *et al.* (2013) found that the potential adoption rate of NERICA in Nigeria would have been 54 percent if awareness was not a constrain and up to 62 percent if the entire population had access to NERICA seed. The difference, (7 percent) is the access to seed gap, which the study interpreted as the potential drop in demand resulting from lack of access to seed. The study found that the probability of adoption was the same for NERICA-aware subpopulation as the general population. However, the probability of adoption by a farmer belonging to the access unconstrained subpopulation of farmers was significantly different from that for any other farmer randomly picked from the general population.

The ATE framework, as used in impact assessment studies can be applied in adoption to denote the population potential mean adoption outcome, conditional on a vector of covariates. The population adoption rate relates to the Average Treatment Effect (ATE), whereby the outcome of interest, in this case, can be a binary adoption status (yes/no) or adoption intensity, while treatment is exposure to the technology. Thus, the framework can be applied in nutrition studies by including awareness to the nutritional benefit of the technology in the model. In addition to awareness and access to the technology, knowledge (or lack of it) of the nutritional benefit is a potential constraint to adoption and can be included in the model.

From the studies reviewed, it is apparent that gaps exist in the literature on the nexus between nutrition and agriculture, and the role of information on adoption of agricultural nutrition innovations. The interaction between the various variables and the role of different food pathways in the nexus is not clear from literature. The stage is set therefore, for this study to fill the aforementioned gaps in literature.

CHAPTER THREE

VARIETY AWARENESS, NUTRITION KNOWLEDGE AND ADOPTION OF BIOFORTIFIED CROP VARIETIES: EVIDENCE FROM KENYA[1]

Abstract

This paper evaluates the impact of variety awareness and nutrition knowledge on the adoption of biofortified crop varieties using a sample of 661 households from Kisii and Nyamira Counties in Kenya. The study uses the ATE framework to control for information on KK15 beans and knowledge of its nutrition attributes among small scale farmers. The results show that farmers who had knowledge of the nutrition attributes of KK15 beans were more likely to adopt, relative to farmers who were only aware of the variety. A nutrition attribute knowledge gap of 8 percent was estimated from the ATE, which represents the potential adoption loss due to lack of knowledge of the nutritional benefits. Adoption of biofortified crops can therefore be improved by dissemination of information on the varieties and their nutrition attributes. This can be done by entrenching nutrition information in information packages disseminated to farmers by extension service providers, especially when promoting biofortified crops.

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3.1 Introduction

Biofortification is the process of enhancing the micronutrient density in a crop through techniques such plant breeding, agronomic practices, or transgenic procedures. It is an effective means of reducing undernutrition, especially for poor subsistence households, as it targets increasing micronutrient density of staple crops (Pfeiffer & McClafferty 2007). Biofortification focusses on crops that are already common in target areas and is thus potent in alleviating micronutrient malnutrition in developing countries as these crops are available throughout the year.

Empirical evidence from Vitamin A biofortification of Orange-Fleshed Sweet Potatoes (OFSP) shows that targeted agricultural programmes for nutritionally enhanced food crops have a positive nutritional effect (van Jaarsveld et al. 2005). Similarly, research on Quality Protein Maize (QPM) has shown that measurable health impacts can be achieved by increased intakes of balanced protein by substituting common maize with QPM in food intakes (Nuss et al. 2011). However, the effectiveness of such nutrition innovation programmes in combating malnutrition ultimately depends on farm level adoption and consumption patterns.

Adoption of new innovations is largely affected by awareness of the innovations and information diffusion in the population (Diagne & Demont, 2007). When a technology is new and information about it is not completely spread in the population, all individuals do not have an equal chance of knowing and adopting it (Diagne & Demont, 2007). Additionally, Kabunga, Dubois, & Qaim (2012) argue that awareness of new technology is a necessary but not sufficient condition for the adoption of an agricultural technology to take place. For instance, access to propagation materials for the new crop varieties and knowledge on how to successfully use the technology, such as a new crop variety that requires a change in cultivation practices and application, would influence adoption.

For biofortified crops, knowledge of the nutritional benefits of the varieties, as opposed to plain awareness of the existence of the varieties, could potentially influence adoption and consumption. The kind of information disseminated by extension agents, agronomy or nutrition, or both, then becomes important. De Groote *et al,* (2016) find in a study on QPM that farmers showed high familiarity with the varieties, but a low understanding of nutritional attributes and benefits, indicating the failure to disseminate information on the nutrition benefits for biofortified crops. Consequently, De Groote *et al,* (2016) found that adopters of QPM ranked agronomic performance as a more important factor than nutritional benefits in adoption. Thus, farmers who are aware of the variety but lack knowledge of nutrition attributes may not adopt biofortified crops for nutrition, which is the reason for biofortification.

While this gap has been acknowledged in previous research on adoption of biofortified crops, it has hardly been addressed in any empirical study. This study hypothesizes that, in addition to awareness of the variety, adoption of biofortified varieties is influenced by knowledge of the unique nutrition attributes of the varieties. Controlling for awareness and knowledge of nutrition benefits, therefore, avoids underestimating adoption rates due to failure to account for non-adoption explained by lack of awareness or lack of knowledge of nutrition benefits.

The study focusses on the adoption of KK15 beans in Nyanza region. The KK 15 bean variety is a new bean variety bred by Kenya Agricultural and Livestock Research Organization (KALRO). It contains high levels of zinc and iron, and thus important in the fight against micro-nutrient deficiency in Kenya (KALRO, 2016). The KK15 bean variety had faced low dissemination efforts since release, before Africa Harvest, a local Non-Governmental Organization (NGO), started promotion activities in 2016. It was thus expected that awareness and knowledge of the variety nutrition attributes was not complete in the population.

3.2 Study Methods

3.2.1 Analytical Framework

The study applied the Average Treatment Effect (ATE) framework to evaluate the effect of variety awareness and nutrition knowledge on adoption. The ATE is commonly applied in impact assessment but can be used in evaluating adoption to eliminate bias resulting from incomplete information exposure in the population and selection bias (Diagne & Demont, 2007). Non-exposure bias results in an underestimation of population adoption rate as farmers not exposed to a new technology cannot adopt it (Diagne & Demont, 2007; Kabunga *et al*, 2012; Dontsop-Nguezet *et at*, 2013). Selection bias results from adoption by farmers who get exposed first or 'progressive' farmers who most likely interact with technology promoters such as extension officers, leading to overestimation of population adoption rate.

Diagne & Demont (2007) show that the observed adoption rates as calculated from sample computation and classical adoption models such as logit and probit are not accurate when exposure to the technology is not complete in the population. The ATE framework models actual adoption while controlling for non-random selection (Diagne & Demont, 2007). The outcome of interest is the ATE, which in adoption terms is the population potential mean adoption outcome, conditional on covariates, x (Woodridge, 2002).

Following Woodridge (2002), the population potential mean adoption outcome (ATE), conditional on covariates, x, is presented in equation one.

$$ATE = E(y_1 - y_0 | x) \qquad 3.1$$

Where

y_1 is the potential adoption outcome of a farmer when exposed to the intervention.

y_0 is the potential adoption outcome of a farmer when not exposed to the intervention.

The Average Treatment Effect when the farmer is aware of the variety (variety awareness unconstrained) is expressed in equation as:

$$ATE'T_r = E(y_1 - y_0 | x, r = 1) \qquad 3.2$$

The Average Treatment Effect when the farmer is both aware of the variety and knowledgeable on the nutrition attributes of the variety (variety awareness and nutrition knowledge unconstrained) is expressed as:

$$ATE'T_{rk} = E(y_1 - y_0 | x, r = 1, k = 1) \qquad 3.3$$

The third outcome of interest is what Donstop-Nguezet *et al*, (2013) define as Average Treatment Effect on the Untreated (ATE'U), which is expressed as:

$$ATE'U_{rk} = E(y_1 - y_0 | x, r = 0, k = 0) \qquad 3.4$$

The three outcomes of interest are consistent and unbiased when estimated using the ATE framework, subject to a condition that the distribution of r and k (exposure) are independent of y_0 and y_1 (potential outcome), and conditional on a vector of covariates x (Woodridge, 2003; Donstop-Nguezet *et al,* 2013). The estimations were carried out on the STATA 13 statistical software, with the user-written add-on '*adoption*' by Diagne & Demont (2007).

The estimation is carried out in two steps. The probability of adoption and adoption rates of KK15 beans for farmers who are aware of the variety is estimated first, the second estimation is for those who have knowledge of the nutrition attributes of the variety. In the second step, two models are estimated to analyze determinants of adoption after controlling for awareness of variety and knowledge of nutrition attributes. The results of classical probit and Ordinary Least Squares (OLS), that do not control for awareness of variety and knowledge of nutrition attributes, are also presented alongside the ATE results for comparison. The practical difference between ATE and classic regression is that ATE uses the exposed sub sample (variety awareness or nutrition attribute knowledge), while classic model uses the full sample (Nguezet *et al*, 2013).

3.2.2 Data Sources

Data was collected in 2016 from farmers who were members of Common Interest Groups (CIGs) in Kisii and Nyamira Counties. To obtain a representative sample, the researchers considered the fact that most farmers in Nyanza region are organized in CIGs. These groups are registered with the State Department of Social Services and are considered the primary entry points for development interventions. With the assistance of Africa Harvest, the researchers compiled a list of all existing CIGs in the area and randomly selected 48 groups from the list. Between 15 and 20 respondents (depending on group sizes), were then selected randomly from the groups, resulting in a sample size of 661 respondents.

Out of the 48 groups listed, 36 of them had been selected for participation in the promotion activities undertaken by Africa Harvest. Although selection for participation in promotion had been done randomly, this could not totally eliminate bias because the group members lived in the same locale, typically neighbours with no restrictions to access information from each other. In addition, not all members of selected CIGs attended the training sessions with Africa Harvest. It was possible that farmers who attended sessions could pass the same information to members of other groups that had not been selected to participate in the project.

The selected households were personally interviewed in local languages by trained enumerators using carefully structured and tested questionnaire. The questionnaire included sections on farm production characteristics, other household economic activities, awareness of KK15 and knowledge of nutrition benefits, and adoption and consumption of the variety.

3.2.3 Measurement of variables

3.2.3.1 Dependent variables

The dependent variables in this study are variety awareness, nutrition knowledge and adoption. There exist different methods of measuring awareness and knowledge, with different merits and demerits. The most commonly used measurement is recall and self-reporting. Recall data collected through self-reports does not suffer from major bias, even after lengthy periods (Beegle *et al*, 2012). Some inaccuracies that result from long recall period can be eliminated by applying ‘know by name’ method, whereby researchers prompt by reading the names of the techniques to farmers when collecting data, as opposed to relying solely on the memory of respondents (Kondylis *et at*, 2015).

This study uses the self-reported data on awareness of variety and knowledge of nutritional benefits, as opposed to relying on membership to groups that had participated in promotion activities, or contact with the program. This is because not all members of selected groups attended sessions and the fact that information and knowledge would have diffused beyond the selected groups, which were not restricted. As the study focused only on one variety, the accuracy of data was improved through name prompting (‘know by name’), whereby enumerators mentioned the variety by name. In the first stage, respondents were asked whether they knew about KK15 bean variety; the answer was binary and is denoted in by r in this study ($r=1$ if ‘yes’ and $r=0$ if ‘no’).

Only the farmers who answered in the affirmative to the first question were asked the second/follow-up question. The follow-up question sought to know whether the respondent had knowledge of the unique nutritional attributes of the variety, in this case, rich in iron and zinc. The answer to the follow-up question was also binary, denoted in this study by k ($k=1$ if ‘yes’ and $k=0$ if ‘no’). To reduce the bias caused by false reporting, the answer to the nutrition knowledge question was only entered as affirmative if the respondent could mention the specific nutritional attributes. Kondylis *et al,* (2015) find that jargon can affect farmers reporting of knowledge even when they are familiar with a practice or attribute. Iron and zinc do not have direct local translations in Nyanza region, and some farmers could not pronounce them in English. Such farmers reported on the effects on consumption on their health, which is, increasing blood levels for iron and boosting immunity for zinc. To obtain the adoption data, farmers were asked the quantity in kilograms that they had planted in the previous season.

3.2.3.2 Measurement of other key variables

Adoption was regressed against key variables that may affect it, after controlling for awareness of variety and knowledge of nutrition attributes. The variables included social networks, distance to produce markets, farm diversity, wealth, access to extension, education, the gender of household head, and age of the household head. Similar to Jäckering *et al*

(2018), the researchers created a social network index from counting the number of other persons the farmer interacts with on topics related to food and agriculture within the CIG. Jäckering *et al,* (2018) find that such informal social networks are an important channel for the flow of agricultural and nutrition information in rural Kenya. The distance in kilometres to the produce markets where farmers sell agricultural commodities and purchase farm inputs is also considered. This is typically the nearest big town.

Farm production diversity in this paper was measured as a count of the species of crops that the farmer already has on their farm, following Sibhatu *et al,* (2015). The crop species were counted regardless of the scale of production or whether it was a food crop or cash crop. The current level of farm production diversity may affect farmer’s decision on whether or not to add an extra crop variety in the farm. Access to extension services was measured by the number of times the farmer interacted with extension officers. Land size is also expected to influence adoption positively, as farmers with smaller portions may have exhausted farm space unless they displace other crops. The principal component analysis method was used to calculate a wealth index to represent the household's wealth. The higher the index, the wealthier the household was. During the survey, farmers were asked about their perception of KK15 beans and its attributes. The researchers created a Likert scale for farmer’s perception of the performance of KK15 beans on pre-listed attributes compared to his/her preferred local variety. The attributes considered included early maturity, yield, pest and disease resistance, marketability, cost of planting materials, prices, and taste. The scale ranged from better, worse, to no difference.

3.4 Results

3.4.1 Descriptive Results for Household Socio-economic Factors

Table 3.1 presents descriptive results of the household socioeconomic characteristics disaggregated by adoption status. A *t*-test of the difference of means was carried out to determine differences in the characteristics between the two categories.

Table 3.1: Descriptive Results for household socio-economic by adoption status

Variables	Means			t-test
	Adopters (N=137)	Non-adopters (N=534)	Total Sample (N=661)	
Proportion of male farmers (%)	73.7	74.7	74.5	0.24
Age of HH head (years) [a]	53	49.8	50.5	-2.68***
Education of HH head (years)	9.1	8.9	8.9	-0.58
Age of female spouse (years) [a]	48	44.6	45.3	-2.81***
Education of female spouse (years) [a]	7.7	8.3	8.1	1.76*
Size of land owned (acres)	1.6	1.4	1.5	-1.17
Number of extension visits [a]	6.2	2.6	3.3	-9.86***
Household size	5.5	5.4	5.5	-0.38
Distance to village market (Kms)	2	1.9	1.9	-0.53
Distance to agricultural produce market (Kms)	3.9	4.5	4.4	1.46
Distance to tarmac road (Kms)	3	3.4	3.3	0.81
Farm diversity (crop count) [a]	12.4	11.1	11.3	-4.06***
On farm income (1000 Kshs) [a]	68.7	10.6	76.5	-2.72***
Off farm income (1000 Kshs)	132.9	116.6	120	-1.11

[a] Notes: ∗∗∗, ∗∗, and ∗ show that mean values for KK15 adopters are significantly different from those of non-adopters at the 1%, 5%, and 10% respectively. Exchange rate US $1 = K.shs 103.

The results reveal that there are no significant differences between adopters and non-adopters in regards to the gender of household head. The average age of adopters is significantly higher than that of non-adopters. Nutrition requirements change as individuals advance in age, thus adoption is expected to vary with age if the new varieties are adopted for nutrition. The differences in the average age of female spouse for adopters and non-adopters are also significant. Observed differences between levels of education of household heads of adopters and non-adopters are not significant. The mean education years of adopters is slightly higher than that of non-adopters. However, differences in the education levels of female spouses between adopters and non-adopters are significant.

The study does observe significant differences between adopters and non-adopters in the size of land owned. On average, adopters had more interaction with agricultural agents, relative to non-adopters, implying that as expected, interaction with extension agents is associated with the decision to adopt improved varieties.

3.4.2 Perception of KK15 beans

Table 3.2 presents results for perceptions of farmers on KK15 beans on maturity period, yields, pest and disease resistance, marketability and taste. Results of a chi-square test to determine differences in perceptions between adopters and non-adopters are also presented. The numbers of farmers are reported for each category and percent of farmers shown in parenthesis.

A majority of farmers perceived KK15 beans as similar or superior to other varieties in the attributes that were considered. This was true for both adopters and non-adopters (Table 3.2). As such, it was expected that farmer’s adoption decisions could not have been substantially affected by the perception of inferior attributes of the variety. It was also expected that nutrition knowledge would result in increased adoption rates as reported in previous studies (Holtz *et al,* 2011; De Groote, 2016). With this result in mind, the researchers evaluated the effect of variety awareness and knowledge of nutrition attributes of the variety on probability of adoption and adoption rates. The results are presented in the sections that follow.

Table 3.2: Farmer perceptions about KK15 beans attributes

Characteristic	Adoption status	Better	Worse	No difference	Don't know	Pearson Chi2
Maturity period	Total	347 (86)	3 (1)	14 (3)	37 (9)	18.7 ***
	Adopters [b]	128 (96)	1 (1)	3 (2)	1 (1)	
	Non-adopters	217 (82)	2 (1)	11 (4)	36 (13)	
Yield	Total	334 (82)	13 (3)	13 (3)	43 (10)	15.3 ***
	Adopters [b]	122 (91)	4 (3)	5 (4)	3 (2)	
	Non-adopters	212 (79)	8 (3)	7 (3)	40 (15)	
Pest & disease Resistance	Total	211 (52)	28 (7)	74 (18)	90 (22)	33.9 ***
	Adopters [b]	90 (67)	12 (9)	24 (18)	8 (6)	
	Non-adopters	120 (45)	16 (6)	49 (18)	82 (31)	
Marketability	Total	118 (29)	96 (23)	32 (7)	157 (38)	18.1 ***
	Adopters [b]	46 (34)	44 (33)	9 (7)	35 (26)	
	Non-adopters	71 (27)	51 (19)	23 (9)	122 (46)	
Taste	Total	238 (59)	12 (3)	17 (4)	136 (34)	79.7 ***
	Adopters [b]	120 (90)	2 (1)	4 (3)	8 (6)	
	Non-adopters	117 (44)	10 (4)	13 (5)	127 (48)	

[b] Notes: ∗∗∗, ∗∗, and ∗ show perceptions of KK15 bean variety adopters are significantly different from those of non-adopters at 1%, 5%, and 10% respectively. Figures in parenthesis show percent of respondents.

3.4.3 Econometric Results and Discussion

3.4.3.1 Adoption Rates of KK15 Beans Variety

The parametric estimates of the ATE model are presented in Table 3.3. The study estimates parameters for binary adoption variable and also for the quantity of seed grown in Kgs. All estimated parameters are significant at the one percent level. The results based on the binary adoption variable are interpreted as percentages.

Table 3.3: Average Treatment Effect parametric estimation of population adoption rates

	Linear Models		Probit models	
	Variety awareness unconstrained	Nutrition knowledge unconstrained	Variety awareness unconstrained	Nutrition knowledge unconstrained
Average Treatment Effect [d]	0.626*** (0.101)	0.882*** (0.122)	0.297*** (0.021)	0.381*** (0.025)
Average Treatment Effect 1[d]	0.731*** (0.101)	0.949*** (0.134)	0.325*** (0.021)	0.389*** (0.025)
Average Treatment Effect 0[d]	0.441*** (0.119)	0.597*** (0.128)	0.246*** (0.026)	0.346*** (0.029)
Joint Exposure and Adoption [d]	0.465*** (0.065)	0.772*** (0.109)	0.208*** (0.014)	0.318*** (0.020)
GAP [d]	-0.162*** (0.043)	-0.110*** (0.024)	-0.089*** (0.010)	-0.063*** (0.005)
Population Selection Bias [d]	0.104*** (0.030)	0.066*** (0.025)	0.028*** (0.007)	0.008*** (0.003)
Observed				
Exposure rate			0.638*** (0.019)	0.818*** (0.019)
Adoption rate			0.207*** (0.016)	0.317*** (0.023)
Adoption rate among exposed [d]	0.727*** (0.108)	0.945*** (0.145)	0.325*** (0.025)	0.387*** (0.028)
mean adoption levels				
Number of obs.	640	398	661	407
Number of exposed	407	324	442	333
Number of adopters	130	125	137	129

[d] Notes: *** and ** denote statistical significance at the 1% and 5% level, respectively. Robust standard errors reported in parenthesis

Only 64 percent of the respondents we aware about the KK15 bean variety. Of those aware, only 82 percent had knowledge about the nutrition benefits of the variety. The observed adoption rate is 21 percent when awareness of variety is not a constraint, and 32 percent when knowledge of nutrition attributes is not a constraint. The Joint Exposure and Adoption (JEA) corresponds to the actual adoption rate at 21 percent. However, the JEA and observed adoption rates are not accurate indicators of adoption due to non-exposure bias (Diagne and

Demont, 2007). The true population adoption rate corresponds to the ATE which is the predicted adoption rate after adjusting for heterogeneous information exposure.

The predicted population adoption rate (ATE) when awareness of the variety is not a constraint is 30 percent and 38 percent when knowledge of nutrition attributes is not a constraint. This shows an estimated adoption gap of 8 percent, which can be interpreted as nutrition attribute knowledge gap. The ATE as measured by the quantity of seed grown was 0.6 Kg for awareness unconstrained group and 0.9 Kg for awareness and nutrition knowledge unconstrained group. Therefore, it follows that the average demand for KK15 bean seeds would have been 0.6 Kg if all farmers were aware of the variety and 0.9 Kg if all farmers were aware of the variety and knew the nutritional benefits.

The estimated adoption rate among the variety awareness unconstrained subpopulation ($ATE'T_r$) and variety awareness and nutrition knowledge unconstrained subpopulation ($ATE'T_k$) is 33 percent and 38 percent respectively. When measured by the amount of seed grown, the estimated *ATE’Tr* and *ATE’Tk* is 0.73 and 0.95 respectively. The *ATE’Tr* is less than *ATE’Tk* by only 5 percentage points. The *ATE’T* is consistently higher than ATE, indicating a positive and statistically significant Population Selection Bias (PSB) for the variety aware group as well as nutrition knowledge group. The PSB for variety aware is 2.8 percent and 0.8 percent for the farmers with knowledge on KK15 nutrition benefits. The potential adoption rate among farmers who had not been exposed to the variety and those who had not been exposed to nutrition knowledge of the variety was 25 percent and 35 percent respectively. The KK15 variety awareness exposure gap is 9 percent, while the nutrition knowledge gap is 6 percent.

3.4.3.2 Determinants of KK15 Adoption

Table 3.4 and 3.5 present regression results for the determinants of KK15 bean variety adoption among farmers in Nyanza region. Table 3.4 presents 3.5 model specifications for parametric linear regression results that are estimated using the quantity of seed that a farmer grew in the previous season as the dependent variable. Model 1 presents results for respondents who were aware of the variety, while results for respondents who possessed knowledge of nutrition attributes are presented in model 2.

Table 3.4: Parametric Linear Regression Results for Determinants of KK15 Adoption

	(1) Variety awareness		(2) Nutrition knowledge	
	1 (a) Classic	1 (b) ATE	2 (a) Classic	2 (b) ATE
Variables	Coefficient	Coefficient	Coefficient	Coefficient
Social Network Index ^{e}	0.014*	0.022**	0.021*	0.026*
	(0.007)	(0.011)	(0.011)	(0.013)
Distance to produce market ^{e}	-0.021**	-0.041**	-0.049**	-0.055**
	(0.011)	(0.018)	(0.021)	(0.024)
Wealth index ^{e}	0.120*	0.204**	0.175*	0.204
	(0.062)	(0.101)	(0.105)	(0.125)
Gender of HH head	0.015	0.058	0.024	-0.057
	(0.128)	(0.188)	(0.196)	(0.243)
Size of land owned (acres)	-0.044	-0.077	0.124	0.142
	(0.070)	(0.096)	(0.200)	(0.225)
Age of HH head (years) ^{e}	-0.140	-0.238*	-0.263*	-0.342*
	(0.087)	(0.136)	(0.139)	(0.181)
Farm diversity (crop count)	0.018	0.032	0.023	0.044
	(0.015)	(0.023)	(0.027)	(0.033)
Ease of acquiring credit (dummy) ^{e}	0.182**	0.330**	0.369**	0.481**
	(0.091)	(0.159)	(0.177)	(0.226)
No. of extension visits ^{e}	0.115***	0.094***	0.126**	0.120**
	(0.023)	(0.027)	(0.052)	(0.057)
Education of HH head	-0.001	-0.001	0.004	0.007
	(0.013)	(0.022)	(0.025)	(0.030)
Household size	-0.010	0.002	0.029	-0.033
	(0.026)	(0.043)	(0.057)	(0.070)
Number of obs.	627	401	392	318
F(9, 618)	7.47	7.91	6.86	7.05
Prob > F	0.00	0.00	0.00	0.00

^{e} Notes: ***, ** and * denote statistical significance at the 1%, 5% and 10% respectively. Robust standard errors reported in parenthesis

Table 3.5 similarly presents 4 model specifications for parametric probit regression results using binary adoption variable as the dependent variable; ‘yes’ if farmer adopted and ‘no’ if the farmer did not adopt.

Table 3.5: Parametric Probit Regression Results for Determinants of KK15 Adoption

	(3) Variety awareness		(4) Nutrition knowledge	
	3 (a) Classic	3 (b) ATE	4 (a) Classic	4 (b) ATE
Variables	Coefficient	Coefficient	Coefficient	Coefficient
Social Network Index	0.002	0.004	0.003	0.004
	(0.006)	(0.007)	(0.007)	(0.008)
Distance to produce market [f]	-0.036**	-0.042**	-0.033*	-0.031*
	(0.017)	(0.018)	(0.018)	(0.018)
Wealth index [f]	0.084*	0.122**	0.137***	0.140**
	(0.045)	(0.051)	(0.053)	(0.057)
Gender of HH head (dummy)	-0.029	0.138	0.147	0.152
	(0.148)	(0.168)	(0.173)	(0.184)
Size of land owned (acres) [f]	-0.057	-0.093*	-0.096*	-0.095*
	(0.049)	(0.048)	(0.049)	(0.051)
Age of HH head (years) [f]	-0.344***	-0.315***	-0.355***	-0.357***
	(0.079)	(0.085)	(0.091)	(0.103)
Farm diversity (crop count) [f]	0.051***	0.060***	0.059***	0.086***
	(0.018)	(0.020)	(0.020)	(0.023)
Ease of acquiring credit (dummy)	-0.011	0.005	0.109	0.112
	(0.173)	(0.195)	(0.207)	(0.226)
No. of extension visits [f]	0.121***	0.079***	0.085***	0.070***
	(0.022)	(0.020)	(0.022)	(0.023)
Education of HH head [f]	-0.043**	-0.044**	-0.048**	-0.053**
	(0.017)	(0.020)	(0.020)	(0.022)
Household size	-0.032	-0.016	-0.019	-0.029
	(0.031)	(0.035)	(0.036)	(0.039)
Number of Obs.	645	415	400	326
Wald chi2(11)	258.3	85.35	86.37	48.11
Prob > chi2	0.00	0.00	0.00	0.00
Log likelihood	-286.13	-238.61	-225.59	-196.80

[f] Notes: ***, ** and * denote statistical significance at the 1%, 5% and 10% respectively. Robust standard errors reported in parenthesis

The coefficient estimates for the classic models are smaller than those for the ATE corrected models. The results also differ in level significance, which is higher for the ATE results than the classic model for some of the variables. A few differences in significance and direction of influence are also observed between the classic and ATE model results. For the purpose of this study therefore, only ATE results will be interpreted.

The quantity of seeds that a farmer grew increased with the size of the social network (number of fellow CIG members that they engaged on issues of agriculture and nutrition) a farmer had. Although the direction is positive, social networks do not appear to significantly affect the probability of adoption (model 3). In keeping with *apriori* expectations, interaction with extension agents and access to credit increased the likelihood of a farmer adopting KK15 beans. Wealth index is significant at 1 percent for the quantity of KK15 bean seeds grown for the variety aware unconstrained group but not the nutrition knowledge unconstrained group. The level of significance is however almost equal as the P>chi is 0.104 for nutrition knowledge and 0.097 for variety aware. Wealth index is significant at 5 percent for the probability of adoption as shown in model 3 and 4.

Distance to produce market and age of the household head negatively affect the probability of adoption and quantity of KK15 beans seeds grown, while farm diversity as measured by a count of crop species that a farmer grew had a positive and significant effect on the probability of adopting KK15 beans. A farmer who already grew a larger number of different crops were also more likely to adopt and grow the new variety of beans. The farmers who already grew diverse crops probably did so for nutrition and food sufficiency purposes and therefore were willing to adopt more for a similar purpose.

The quantity of KK15 beans grown increased with farmer’s perception of ease of acquiring credit. Farmers who perceived that they could easily acquire credit grew more seeds relative to those who perceived credit services as difficult to access. This is expected, as the farmers who perceived access to credit as easy are either wealthy and creditworthy, or willing to take risk. Access to credit is also as a result of supply-side effects. Previous studies have found an association between access to credit and adoption of new varieties (Zeller *et al,* 1998; Matuschke *et al*, 2007).

3.5 Discussion

The findings of the study demonstrate that not all farmers were aware of the KK15 bean variety. In addition, not all farmers who were aware of the variety had knowledge of the nutrition attributes of the variety. These findings demonstrate an incomplete diffusion of information in the population. This, therefore, justifies the use of the ATE framework so as to eliminate bias that could result from exposure bias and selection bias. The implication of the incomplete information diffusion is confirmed by the positive PSB for variety awareness and nutrition attribute knowledge. Thus, the adoption rate among the targeted subpopulation was most likely to overestimate the true population adoption rate. This finding agrees with results from studies by Diagne and Demont (2007), Donstop-Nguezet *et al* (2013) and Kabunga *et al* (2012) on the implication of selection bias and exposure bias on adoption estimation.

Because the PSB is positive and statistically significant for variety awareness, the null hypothesis that KK15 variety aware sub-population was equally likely to adopt as the general population is therefore rejected. The implication is that the probability of adoption for farmer selected from the variety aware sub-population was different than for a farmer randomly selected from the general population. The null hypothesis that the subpopulation with nutrition knowledge on KK15 variety was equally likely to adopt the variety as the general population is also rejected. Because the PSB is positive and significant, the study concludes that a farmer selected from the subpopulation of farmers who had knowledge of the nutrition benefits of KK15 had a higher probability of adopting than a farmer randomly picked from the general population. This confirms the positive effect of nutrition information on the adoption of biofortified crops and agrees with findings of previous studies on (Chowdhury *et al*, 2010; Holtz *et al*, 2011; De Groote, 2016).

The ATE estimation shows a positive adoption gap of 8 percent or 0.3 kg between those aware of the variety and those with knowledge of nutrition benefits. This gap, which is interpreted as nutrition attribute knowledge gap represents the potential adoption loss due to lack of knowledge of the nutritional benefits of KK15 beans. Thus, adoption would have increased by 8 percent if all farmers were aware of the nutrition attributes of the variety. In addition, the study finds a positive variety awareness gap and nutrition attribute knowledge gap. The implication is that there is still potential for increasing adoption of KK15 bean variety by increasing awareness of the variety and knowledge of its nutrition benefits.

Regarding the factors that influence adoption, especially for biofortified crops, our findings agree with the results of some previous studies, with some unique findings. Social networks influence adoption rates for farmers who have already adopted but did not influence the probability to adopt in this study. This is an indication of information flow on the new varieties among farmers and its implication in enhancing adoption. Similarly, Jäckering et al. (2018) find that social networks are important channels for the flow of information on agriculture and nutrition.

Extension agents are also important channels of agricultural information. Farmers who had increased interaction with extension agents were more likely to adopt the new varieties. This is expected, as these farmers were more likely to access information of the new varieties, as well as the necessary agronomic practices. Numerous studies have previously shown the positive role of extension services for adoption of new varieties (Feleke & Zegeye, 2006;

Donstop-Nguezet et al, 2013; Elias *et al*, 2013). This finding indicates that extension agents could also be an important channel of passing nutrition information of biofortified crops to farmers.

Similar to Shikuku *et al.* (2014) and Okello *et al.* (2014), we find that younger farmers, relative to the older ones, were more likely to adopt KK15 beans. Younger farmers are more likely to be in the child bearing age and with young children. Kaguongo *et al.* (2010) found that presence of children less than five years of age in the households increased the intensity of adoption of orange-fleshed sweet potatoes in Kenya. These farmers would similarly find it more beneficial to adopt the bean varieties for nutrition purposes.

Contrary to *apriori* expectations, education of the household head negatively affected the probability of adoption of KK15 bean varieties. This is not totally implausible. It could be that more educated farmers are aware of alternative nutrition sources that they are able to acquire from market sources. They are therefore not likely to grow the new variety whose target is nutritional. Additionally, more educated farmers are more likely to be engaged in off-farm employment and therefore not readily available to access the information through available information channels for the specific technology.

The findings record that access to markets influences adoption. The market is an important source of planting materials, a market for produced commodities, and information on the new varieties. Therefore, farmers who are located in remote areas, far away from these markets, could lack both access and information on the new varieties. Previous studies have shown the importance of access to planting materials for adoption to occur (Kabunga *et al.*, 2012). Distance to market is also a proxy for transaction costs which reduce adoption.

3.6 Conclusions and Policy Recommendations

The ATE framework is employed in this study to control for incomplete diffusion of information on KK15 beans and knowledge of nutrition attributes in the population. The results show that among farmers who were aware of the variety, a majority perceived KK15 beans as better than other varieties in the attributes considered. This therefore indicates that non-adoption that may result from any perceived inferior quality of the variety relative to other varieties was substantially eliminated.

The study finds that not all farmers that were aware of the variety had knowledge of its nutrition attributes. Farmers who had knowledge of the nutrition attributes of KK15 beans were more likely to adopt, relative to farmers who were only aware of the variety. This indicates the positive impact of nutrition knowledge on adoption of biofortified crops. There is therefore need to embed nutrition information in information packages disseminated to farmers when promoting adoption of biofortified crops. In addition, nutrition efforts can benefit from making extension services offered by usual services providers, including government more ‘nutrition sensitive’. This can be done by including nutrition information in extension information offered to farmers.

CHAPTER FOUR

FARM PRODUCTION DIVERSITY AND ITS ASSOCIATION WITH DIETARY DIVERSITY IN KENYA[2]

Abstract

Agriculture has the potential to improve dietary diversity through farm production diversity if farming households consume what they produce. However, the linkages between a household's own agricultural production and dietary diversity are not well understood. This study uses a count of crop species, animal species, production diversity score, and the Simpson's index as measures of farm production diversity to assess the effect of production diversity on the dietary diversity of households, women and children. A Poison model was employed on a sample of 779 farming households selected using a multistage sampling technique in a household survey representative at the County level in Kisii and Nyamira Counties, Kenya. The findings of the study indicate that farm production diversity is significantly associated with the dietary diversity of women and that of the entire household, but is not associated with the dietary diversity of children. The count of the animal species has the highest magnitude of association with dietery diversity in this study. Every additional animal species kept leads to a 0.33 and 0.13 increase in household dietery diversity and the dietery diversity of women respectively. Children's dietary diversity is significantly associated with the education of the mother, household size and age of the child. The study highlights the need to consider individual dietary requirements when developing nutrition interventions and policy, as opposed to general dietary interventions targeting the entire household.

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4.1. Introduction

Close to one billion people in the world are undernourished (FAO *et al*, 2019). According to FAO (2018), a majority of the people who are undernourished live in the rural areas of low-income countries in Africa and Asia. In Kenya, approximately 24.2 percent of the population is undernourished (FAO 2018). Undernutrition causes severe economic losses at the individual, household and national levels (World Health Organization [WHO] 2006; Gödecke *et al,* 2018). The annual cost of micronutrient deficiencies in low-income countries has been estimated at between 2.4 and 10 percent of Gross Domestic Product (GDP) (Horton and Ross 2003; Stein and Qaim 2007; Freijer *et al,* 2013; Freijer *et al,* 2018). Women and children are more vulnerable to the effects of undernutrition because of their high nutritional requirements for growth and development, different physiological requirements, and contribution to the intergenerational cycle of undernutrition and ill health (Blössner *et al.* 2005; Kim *et al,* 2017; Merchant and Kurz, 2018).

Besides enhanced access to sufficient quantities of food, better dietary diversity and quality of diets are central components of nutrition security. Dietary diversity is a qualitative measure of food consumption that reflects household access to a variety of foods, and is also a proxy for nutrient adequacy of the diet of individuals (Kennedy *et al*, 2011). Studies have shown that dietary diversity is correlated with nutrient adequacy of the diet, micronutrient adequacy and indicators of growth and nutritional status of women and children (Steyn *et al,* 2006; Kennedy *et al,* 2007; Arimond *et al,* 2010; Fongar *et al,* 2018). Nutrient adequacy results from consumption of energy and essential nutrients, including micronutrients, in sufficient amounts over time. Micronutrient adequacy plays an important role in preventing deficiency diseases, improving immune function, physical work capacity, cognitive development and learning capacity in children, as well as preventing diet-related chronic diseases (WHO, 2003; Black *et al*, 2008). Overall, individual dietary indicators are good proxies for individual dietary quality and micronutrient adequacy. Promotion of dietary diversity is thus an effective approach to improving micronutrient and dietary quality for women and children. The household-level dietary diversity is an indicator of household economic access to diverse food and includes purchased foods such as sugars and sweets (Swindale and Bilinsky 2005; Kennedy *et al*, 2011; Verger *et al*, 2017).

Despite increased global food availability, undernutrition remains an increasingly difficult challenge in low-income countries (Black *et al*, 2008; FAO, 2018). A majority of the people who are undernourished live in the rural areas of low-income countries and depend on agriculture as a source of food and livelihood (FAO *et al*, 2017). Thus, nutrition interventions would be expected to focus on enabling these households to meet their nutrition requirements from the food they produce. However, there has been little nexus between nutrition and agricultural interventions and policy.

Most of the policy interventions in agriculture have focused on improving the quantity of food staples produced, resulting in commercialization and intensification of staple food production systems, rather than quality and diversity of diets (Fanzo *et al,* 2013; Larochelle and Alwang 2014; Pingali, 2015; Magrini and Vigani 2016). Nonetheless, farm commercialization and market access can substitute for own production through selling surplus farm produce and purchasing food items not produced in the farm (Sibhatu *et al,* 2015; Hoddinott *et al,* 2015; Koppmair *et al,* 2017; Sibhatu and Qaim, 2017). However, studies have shown little effect of commercialization and intensification of staple food production systems on the nutritional status of vulnerable groups such as the poor, women and children (Berti *et al*, 2004; Hawkes and Ruel, 2008; Masset *et al*, 2012). This is because commercialization and intensification of staple food production systems crowd out traditional non-staple foods that are rich in essential micronutrients (Pingali 2015). For subsistence households that consume mainly what is produced from their own farms, this transition may deprive them of diverse diets and micronutrient-rich vegetables, fruits, and animal-source foods.

At national levels, a positive correlation between income growth and nutrition has been documented in the literature (Haddad *et al,* 2003; Webb and Block, 2012). At the household level, income can be used to purchase diverse foods (Koppmair *et al,* 2017). However, income is a viable pathway only if households have access to markets to sell farm produce and purchase food, a persistent challenge for many households in rural areas of low-income countries (Binswanger and McCalla, 2010; Jayne *et al,* 2010; Sibhatu *et al*, 2015; Koppmair *et al,* 2017). Consequently, the nutrition of the vulnerable categories of the population in developing countries benefits least from interventions that target economic growth in the short term (Dubé *et al*, 2012). Haddad *et al* (2003) found that although increases in income at the household and national levels are correlated with a decrease in overall undernutrition, this growth alone does not reduce the prevalence of undernutrition in children.

According to Hawkes and Ruel (2008), the subsistence production pathway is one of the most fundamental solutions to food insecurity for the poor and pre-transition countries. Some recent interventions are promoting “nutrition-sensitive” agriculture which aims to make agriculture more responsive to nutrition needs of small scale households. Farm production diversification is one of the components of “nutrition-sensitive” agriculture (FAO, 2014; Ruel *et al*, 2018). Since most of the households facing undernutrition depend on subsistence farming as a source of food, having a variety of crops or animals on the farm could translate to a diverse diet. Production of staples should result in greater access to and consumption of energy, while production of fruit, vegetables, and animal source foods (dairy, eggs, fish, and meat) should result to greater access to energy, protein, and fat, as well as improved quality and micronutrient content of diets.

However, the current empirical evidence on the association of farm production diversity with dietary diversity is not conclusive (Sibhatu and Qaim, 2018). A review of recent studies by Sibhatu and Qaim (2018) using meta-analysis reveals mixed evidence. Only a small proportion of studies find a positive and significant association between production diversity and dietary diversity and/or nutrition across various indicators and sub-samples, while a majority of studies report significant associations only for certain indicators or subsamples, or no association at all (Sibhatu and Qaim, 2018). However, most of the studies analyze the associations only for specific indicators or sub-samples. Consequently, the findings are context specific and not generalizable across sub samples within the population (Sibhatu and Qaim, 2018). This study contributes to the existing literature by using the same data set to compute dietary diversity scores for children, women and household and analyzing the scores against different indicators of farm production diversity to evaluate the linkages thereof. The study aims to provide evidence on the suitability of farm production diversification as a strategy of improving diet diversity of households and individuals.

Diet diversity of individuals is measured differently from household dietary diversity to capture specific individual nutritional needs. For example, women of reproductive age are more vulnerable due to physiological demands of pregnancy and lactation and have a higher requirement for iron than men (FAO and FHI 360, 2016). For children, vitamin A is essential to support rapid growth, prevent blindness and prevent mortality and morbidity caused by infections such as diarrhea, measles, and respiratory infections (Villamo and Fawzi, 2000; West and Keith, 2002; Mayo-Wilson *et al,* 2011). Dietary diversity measurements for individuals are designed to include foods that meet these nutrition-specific requirements.

Using both individual and household level measures of dietary diversity in the study provides an opportunity to analyze, compare and report on the effects at both levels. Analyzing this association at both the individual and household level is important in illustrating the effect of farm production diversity on the nutrition of vulnerable groups in the household, such as women and children. We tested the hypotheses that: (i) an increase in the farm production diversity does not have an effect on household dietary diversity; (ii) an increase in the farm production diversity does not have an effect on dietary diversity of women; and, (iii) an increase in the farm production diversity does not have an effect on dietary diversity of children.

4.2 Study Methods

4.2.1 Data Sources

This study uses primary data collected between October and December in 2015 from a survey of 779 farming households in Kisii and Nyamira Counties of Kenya. The two Counties are located in a highland equatorial climate region that receives rainfall in all months of the year. There are two main rainfall seasons, the long rain season occurring between February and June and the short rain season occurring between September and early December. The two Counties are suitable for agricultural production, farmers grow a wide range of food crops such as maize, beans, indigenous vegetables, sorghum, millet, and cash crops such as tea. In spite of the favourable agricultural potential, the two counties are characterized by high levels of undernutrition. More than one-quarter of children below 5 years of age are stunted, while close to 10 percent are underweight (Kenya National Bureau of Statistics 2014). Paradoxically, a vibrant agriculture sector in the two Counties seems to co-exist with high levels of undernutrition, suggesting a failure to match the agricultural potential of the region with its nutrition needs.

A multistage sampling technique was used to select the respondents in the field survey. The first stage involved the development of a sampling frame by listing all existing Common Interest Groups (CIGs) in Kisii and Nyamira Counties with assistance from Africa Harvest Biotech Foundation International, a non-governmental organization working in the region. In this study, CIGs are defined as groups of farmers from the same area who voluntarily agree to cooperate on agricultural activities and are registered with the State Department of Social Services. In the second stage, a simple random sampling technique with a probability proportionate to the total number of CIGs was used to select 48 groups (32 and 16 groups were selected from Kisii and Nyamira Counties respectively) from the sampling frame. In the third stage, a sample of 20 households was selected from each group through a simple random sampling technique. In groups that had 20 or fewer members, all members were selected. Interviews were conducted in local languages by trained enumerators who were supervised by the researchers. After dropping 29 questionnaires that had incomplete information, a sample of 779 households was used for the analysis. Within the 779 households, data from 570 women within the childbearing age of 18-45 years and 263 children who were between 6-59 months of age was also analyzed.

4.2.2 Analytical Model

This study employs the Poisson regression model to estimate the effect of farm production diversity on dietary diversity. A total of 12 bivariate Poisson regression equations were estimated with the dietary diversity scores as the dependent variable while the five measures of farm production diversity constituted the independent variables. The Poisson regression model is suitable for analyzing data in cases where the dependent variable takes the form of a non-negative integer 0, 1, 2, which is in form of count data (Cameron and Trivedi 2005; Greene 2007). The model is suitable for this study since the dependent variables are measured as a count of food groups to be analyzed against a set of covariates (x). Count data can be analyzed using Ordinary Least Squares (OLS) as found in Jones *et al*, (2014), but can yield biased results due to among other reasons; the inability of OLS to account for the zero truncated data, heteroscedasticity, and non-normality (Sturman 1999; Greene 2007).

The Poisson model assumes equidispersion, that is the variance of y_i is equal to its mean. The likelihood ratio test for equidispersion is conducted by running the negative binomial regression and interpreting the overdispersion parameter, alpha, which becomes zero when the data does not suffer from overdispersion (StataCorp 2009). Although the Poisson model is nonlinear, it can be estimated by the maximum likelihood method as the observations $(y_i | x_i)$ are independent. The coefficient estimates of a Poisson model are interpreted as semi-elasticities while the marginal effects, which are presented in this study, are interpreted as the change in the dietary diversity score when the explanatory variable changes by one unit. The model has been applied in similar studies on diet diversity recently (Sibhatu *et al*, 2015; Koppmair *et al,* 2017). All the models were estimated with standard errors corrected for group clusters to eliminate possible error term correlation within common interest groups (Cameron and Miller, 2015).

4.2.3 Empirical Model

The Poisson regression model in this study was estimated in two forms. First, the effect of Farm Production Diversity (PD) on the Dietary Diversity Scores (DDS) is analyzed. The models are specified in equation 1 as follows:

$$DDS_{ij} = \alpha_0 + \alpha_1 PD_i + \ell_{ij} \quad \text{………………..……………………………………………..(4.1)}$$

Where the DDS of household *i* or individual *j* is a function of farm production diversity of the farm cultivated by household *i*. The terms α and ℓ denotes the coefficients to be estimated and random error term respectively. Different forms of this model are estimated using various measures of farm production diversity (Simpson's Index, animal species count, crop species count and production diversity score) against household and individual dietary diversity scores as the dependent variables in each model.

Since dietary diversity depends not just on the sources of the food, but also on the ability of the household to produce the food or obtain it from other sources, the models are estimated again, but this time adjusted for market access and market participation (farm commercialization) factors and socioeconomic factors. The adjusted models are specified in equation 2 as follows;

$$DDS_{ij} = \alpha_0 + \alpha_1 FD_i + \alpha_2 MA_i + \alpha_3 MP_i + \alpha_4 SE_{ij} + \ell_{ij} \quad \text{…...……………………………….…..(4.2)}$$

In the adjusted models, the DDS of household *i* or individual *j* is a function of farm production diversity (PD), market access (MA) and market participation or farm commercialization (MP) factors, and individual and household socio-economic factors (SE).

4.2.4 Definition and Measurement of Variables

The dependent variables in this study are the dietary diversities of the household and individuals. The explanatory variables include farm production diversity, market access, market participation, and socioeconomic factors.

4.2.4.1 Dietary Diversity

Dietary diversity is defined as "a qualitative measure of food consumption that reflects household access to a variety of foods and is also a proxy for nutrient adequacy of the diet of individuals" (Kennedy *et al*, 2011). This study uses three measures of dietary diversity namely; Household Diet Diversity Score (HDDS), Child Dietary Diversity Score (CDDS) and Women Dietary Diversity Score (WDDS) (Table 4.1). The HDDS and WDDS are computed following FAO (2011) guidelines (Kennedy *et al*, 2011) while the CDDS is computed following WHO (2010) guidelines for children aged 6-23 months. The age of children in this study was extended to 6-59 months to cover the first five years of life when children are most susceptible to negative impacts of undernutrition (Grantham-McGregor et al, 2007). The scores are a count of the number of different food groups consumed over a certain period of time, usually 7 days or 24 hours, for either the household or for individual members. Studies have shown that the individual dietary diversity scores are significantly correlated with more comprehensive measures of diets and nutrition (Fongar *et al*, 2018; Headey and Ecker, 2013) and are thus appropriate for research as they are easy to measure.

The HDDS was computed using data on 12 food groups from a 7-day food consumption recall. Individual dietary diversity scores were computed for women (WDDS) and children (CDDS) using a 24-hour dietary recall data. Recall data for WDDS was collected twice on two non-consecutive days. Special days such as celebrations and holidays were excluded. The WDDS was calculated using 9 food groups, while the CDDS was calculated for children aged 6-59 months using 7 food groups. The food group classes for all three scores are shown in Table 4.1.

Table 4.1: Food group classification for different dietary diversity scores

No	Household dietary diversity score (HDDS)	Women's dietary diversity score (WDDS)	Child dietary diversity score (CDDS)
1	Cereals	Starchy staples	Grains, roots, and tubers
2	White roots and tubers	Dark green leafy vegetables	Legumes and nuts
3	Vegetables	Other vitamin A rich fruits and vegetables	Dairy products (milk, yogurt, cheese)
4	Fruits	Other fruits and vegetables	Flesh foods (meat, fish, poultry, and liver/organ meats)
5	Meat	Organ meat	Eggs
6	Eggs	Meat and fish	Vitamin A rich fruits and vegetables
7	Fish	Eggs	Other fruits and vegetables
8	Legumes, nuts, and seeds	Legumes, nuts, and seeds	
9	Milk	Milk and milk products	
10	Oils and fat		
11	Sugar and sweets		
12	Spices, condiments, beverages		

Seasonality of agricultural production can cause variation in diet diversity across the year due to associated effects on food security (Hirvonen et al, 2016). The data used in this study was collected in the month of November and early December, just before harvesting of maize which is a major staple food. Although this would be considered a lean season (Hirvonen et al, 2016), Kisii and Nyamira Counties receive rainfall in all months of the year, thus would be expected to be comparatively less vulnerable to effects of seasonality.

4.2.4.2 Farm Production Diversity

Farm production diversity is defined in this study as the variety of crop species grown and animal species kept on the farm in the previous 12 months. Farm production diversity is measured using four methods: Simpson's Index; crop species count; animal species count and production diversity score. The use of multiple measurements allowed for the comparison of results and to test for consistency of the association between farm production diversity and dietary diversity.

The Simpson's Index is a weighted index that takes into account the number of species (richness), as well as the relative abundance of each species (evenness) (Jones *et al*, 2014; Simpson 1949). The crop species count, animal species count, and production diversity score is an unweighted count of the different animal species and/or plant species that are kept or grown within the farm. The production diversity score adopts a dietary approach in measuring farm production diversity by mapping crop and animal species produced on the farm on the number of food groups used to compute dietary diversity (Berti, 2015; Koppmair et al. 2017, Sibhatu and Qaim, 2018).

According to Sibhatu and Qaim (2018), a major disadvantage of the production diversity score method is that it counts species that deliver products in two different food groups twice (for example, chicken is a source of eggs and meat). This study overcomes the double-counting problem by adopting the 16 broad food groups from which dietary diversity scores are derived as found in FAO (2011) guidelines (Table 3). This ensured that species were not counted in two food groups (for example, eggs are only counted if they were actually produced, while chicken was only counted as a source of meat). Industrial cash crops were excluded from the production diversity score as household do not consume them from the farm but were included in the crop species count.

4.2.4.3 Market Access and Market Participation (Farm Commercialization)

This study uses a commercialization index as a proxy for market participation and farm commercialization. Following Carletto *et al* (2017) and Ogutu and Qaim (2019), the index was calculated as the value of farm produce sold divided by the value of total farm produce. Commercialized households were expected to consume more diversified diets. Similarly, households that are able to access employment off-farm could also access diversified diets from the market (Sibhatu *et al,* 2015). Such farmers may, however, be constrained by physical access to the market. This study defines market access as the geographic distance in kilometres from the home to the nearest market where households purchase or sell food. Households located close to these markets were expected to have more diversified diets.

The models were also adjusted for socioeconomic and demographic factors that were expected to influence dietary diversity such as household size, education of household head and female spouse, as well as age and gender of the household head.

4.3 Results and Discussions

4.3.1 Descriptive Results

Table 4.2 presents the Descriptive Results for Household Socio-economic Factors for the key variables in the study. The average counts of crop species and animal species per household were nine and two respectively (Table 4.2). Farm sizes in Kisii and Nyamira Counties were

1.6 acres on the average (Table 4.2). The most common plant species grown were maize, beans, bananas, millet, amaranths and local vegetables (black nightshade, spider plant and jute mallow). Other crops included tea, coffee, avocado, kale, cowpeas, sugarcane, pumpkins, and onions. The most common livestock species kept were cattle, goats, chicken, sheep and rabbits. The dietary diversity scores on the average were 9, 4 and 5 for HDDS, WDDS and CDDS respectively (Table 4.2).

Table 4.2: Descriptive Results for Household Socio-economic Factors of sampled farm households (N=779)

Variable	**Description**	**Mean**	**Std deviation**
Crop species count	Number of crop species grown by the household	9.20	3.40
Animal species count	Number of animal species kept by the household	1.81	0.91
Simpson's Index	Index calculated from all crop species grown by the household	0.72	0.16
Production diversity score	Count of crop and animal species mapped over food groups	7.88	1.72
HDDS	Household Dietary Diversity Score	9.17	1.47
WDDS	Women Dietary Diversity Score	4.15	0.93
CDDS	Child Dietary Diversity Score	5.04	1.02
Age of household head	Age in years of the household head	49.31	12.56
Education of household head	Number of formal education years completed by household head	8.96	3.78
Household head is male	Percentage of households with male head	77	
Education of the woman	Number of formal education years completed by the woman	8.3	3.7
Farm revenue	Gross annual income in 1000 KShs. from selling farm produce	96.02	211.44
Off-farm income	Annual income in 1000 KShs earned from off-farm sources	96.02	150.11
Household size	Number of household members	7	2.45
Distance to the village market	Distance in kilometres to the nearest village market	1.59	1.31

Notes: 1 dollar is equivalent to Kshs.100 as at 22nd December 2019; source, Central Bank of Kenya

Annual farm revenues on the average were Kenya Shillings 96,020. Households are relatively large in Kisii and Nyamira Counties, with 7 members being the average size (Table 4.2).

4.3.2 Econometric Results

Table 4.3 presents the results of 12 bivariate Poisson regression models between the measures of dietary diversity as dependent variables and farm diversity as independent variables. The chi-squared statistic for the likelihood ratio test in all models was not significant, thus we fail to reject the hypothesis that alpha = 0 and conclude that the negative binomial regression results are equal to the Poisson regression results. The data, therefore, do not suffer from overdispersion.

Table 4.3: Diet diversity scores and Farm Production Diversity

	HDDS	WDDS	CDDS
Production diversity score	0.194***	0.125***	0.028
	(0.026)	(0.028)	(0.042)
Animal species count	0.325***	0.130***	- 0.014
	(0.057)	(0.042)	(0.104)
Crop species count	0.073***	0.046***	0.024
	(0.018)	(0.014)	(0.021)
Simpson’s Index	0.038	0.042**	0.016
	(0.028)	(0.018)	(0.031)

Notes: ∗∗∗, ∗∗ and ∗ denote statistical significance at the 1%, 5% and 10 % level, respectively. Cluster corrected standard errors reported in parentheses. The parameter estimates indicate the change in the dietary diversity score when the explanatory variable changes by one unit.

Results presented in Table 4.3 show that for every additional food group that the household produced, HDDS and WDDS increased by 0.19 and 0.13 respectively. Animal species count has the highest association with diet diversity in this study. Every additional animal species kept leads to a 0.33 and 0.13 increase in HDDS and WDDS respectively (Table 4.3). When farm production diversity is measured only as a crop species count, every additional crop grown leads to an increase of 0.07 and 0.05 in the number of food groups consumed by the household and women respectively (Table 4.3). The WDDS is significantly associated with all indicators of farm production diversity. In contrast, none of the indicators of farm production diversity is significantly associated with CDDS.

Tables 4.4, 4.5, 4.6 and 4.7 present the results of the Poisson regression estimates adjusted for market access, market participation (farm commercialization) and socioeconomic factors.

Table 4.4: Diet diversity scores and PD (production diversity score) adjusted for Market Access, Market Participation and Socioeconomic factors

Variable	HDDS	WDDS	CDDS
production diversity score	0.145***	0.103***	0.007
	(0.026)	(0.028)	(0.042)
Farm commercialization	0.551**	0.015	-0.019
	(0.259)	(0.173)	(0.312)
Off-farm income	0.044***	0.003	-0.001
	(0.012)	(0.010)	(0.015)
Household head is male	0.228**	0.027	0.167
	(0.110)	(0.081)	(0.127)
Education level of HH head	0.036**	-0.002	-0.039*
	(0.017)	(0.013)	(0.023)
Age of HH head	-0.062	-0.256**	0.392
	(0.195)	(0.135)	(0.277)
Education level of woman	0.024	0.055***	0.065***
	(0.017)	(0.015)	(0.022)
Distance to market (kilometres)	0.202**	0.038	0.018
	(0.103)	(0.024)	(0.042)
Distance to market (kilometres) squared	-0.022 (0.015)		
Household size	-0.018	0.136*	-0.072**
	(0.026)	(0.077)	(0.036)
Household size squared		-0.006	
		(0.005)	
Age of child			0.250**
			(0.123)
Number of observations	779	570	263

Notes: ***, ** and * denote statistical significance at the 1%, 5% and 10 % level, respectively. Cluster corrected standard errors reported in parentheses. The parameter estimates indicate the change in the dietary diversity score when the explanatory variable changes by one unit.

Table 4.5: Diet diversity scores and PD (Animal species count) adjusted for Market Access, Market Participation and Socioeconomic factors

Variable	HDDS	WDDS	CDDS
Animal species count	0.281***	0.103**	0.027
	(0.058)	(0.042)	(0.095)
Farm commercialization	0.641**	0.080	0.014
	(0.254)	(0.171)	(0.307)
Off farm income	0.051***	0.008	0.000
	(0.012)	(0.009)	(0.015)
Household head is male	0.231**	0.062	0.170
	(0.115)	(0.085)	(0.123)
Education level of HH head	0.034**	-0.001	-0.040*
	(0.017)	(0.013)	(0.023)
Age of HH head	0.044	-0.233	0.397
	(0.199)	(0.145)	(0.275)
Education level of woman	0.027	0.056***	0.066***
	(0.017)	(0.015)	(0.022)
Distance to market (kilometres)	0.219**	0.045	0.018
	(0.102)	(0.025)	(0.042)
Distance to market (kilometres) squared	-0.021 (0.015)		
Household size	-0.018	0.151*	-0.073**
	(0.026)	(0.077)	(0.036)
Household size squared		-0.007*	
		(0.005)	
Age of child in months			0.253**
			(0.126)
Number of observations	779	570	263

Notes: ***, ** and * denote statistical significance at the 1%, 5% and 10 % level, respectively. Cluster corrected standard errors reported in parentheses. The parameter estimates indicate the change in the dietary diversity score when the explanatory variable changes by one unit.

Table 4.6: Diet diversity scores and PD (Crop species count) adjusted for Market Access, Market Participation and Socioeconomic factors

Variable	HDDS	WDDS	CDDS
Crop species count	0.050***	0.038**	0.019
	(0.019)	(0.014)	(0.022)
Farm commercialization	0.578**	0.008	-0.029
	(0.256)	(0.181)	(0.316)
Off farm income	0.044***	0.003	-0.004
	(0.013)	(0.009)	(0.016)
Household head is male	0.278**	0.064	0.159
	(0.123)	(0.081)	(0.126)
Education level of HH head	0.037**	-0.001	-0.039*
	(0.017)	(0.013)	(0.023)
Age of HH head	-0.090	-0.280*	0.344
	(0.222)	(0.148)	(0.279)
Education level of woman	0.027	0.055***	0.064***
	(0.018)	(0.015)	(0.022)
Distance to market (kilometres)	0.193*	0.039	0.015
	(0.107)	(0.025)	(0.043)
Distance to market (kilometres) squared	-0.018		
	(0.016)		
Household size	-0.013	0.149*	-0.070**
	(0.028)	(0.076)	(0.036)
Household size squared		-0.007*	
		(0.005)	
Age of child in months			0.254**
			(0.124)
Number of observations	779	570	263

Notes: ***, ** and * denote statistical significance at the 1%, 5% and 10 % level, respectively. Cluster corrected standard errors reported in parentheses. The parameter estimates indicate the change in the dietary diversity score when the explanatory variable changes by one unit.

Table 4.7: Diet diversity scores and PD (Simpson's Index) adjusted for Market Access, Market Participation and Socioeconomic factors

Variable	HDDS	WDDS	CDDS
Simpson's Index	0.020	0.037*	0.016
	(0.027)	(0.019)	(0.032)
Farm commercialization	0.630**	0.050	-0.023
	(0.260)	(0.179)	(0.314)
Off farm income	0.049***	0.007	-0.001
	(0.013)	(0.009)	(0.015)
Household head is male	0.317***	0.093	0.174
	(0.118)	(0.080)	(0.126)
Education level of HH head	0.037**	0.002	-0.039*
	(0.017)	(0.013)	(0.022)
Age of HH head	-0.006	-0.226	0.373
	(0.215)	(0.150)	(0.280)
Education level of woman	0.031*	0.060***	0.065***
	(0.018)	(0.015)	(0.022)
Distance to market (kilometres)	0.216**	0.048*	0.019
	(0.107)	(0.026)	(0.042)
Distance to market (kilometres) squared	-0.020		
	(0.017)		
Household size	-0.010	0.150*	-0.070*
	(0.027)	(0.077)	(0.036)
Household size squared		-0.007	
		(0.005)	
Age of child in months			0.254**
			(0.124)
Number of observations	779	570	263

Notes: ***, ** and * denote statistical significance at the 1%, 5% and 10 % level, respectively. Cluster corrected standard errors reported in parentheses. The parameter estimates indicate the change in the dietary diversity score when the explanatory variable changes by one unit.

The full model results show that farm diversity has an independent association with HDDS and WDDS. The magnitude does not change considerably from the findings in Table 4.3 and the results are consistent across all the models. When the model is adjusted for market access, farm commercialization and socioeconomic factors, we find that WDDS is not significantly associated with the Simpson's Index. Other factors that are positively associated with HDDS include off-farm income, market access, farm commercialization, gender and education level of household head (Table 4.4, 4.5, 4.6 and 4.7).

Off-farm income is not significantly associated with increased dietary diversity for women and children. Similarly, farm commercialization was significantly associated with increased HDDS, but not WDDS and CDDS. Contrary to expectations, larger households were associated with increased WDDS. The association, however, turned negative for the squared term, indicating a non-linear relationship. Using the formula $-\beta_t/2\beta_q$, we determine the turning point to be 10 household members. Thus, as household size increased beyond 10 members, the diet diversity of women begun to decline.

The education level of the woman was positively associated with CDDS. Maternal education was expected to have a positive association with diet diversity because women are the primary family caregivers in the majority of households, this was confirmed herein as women were the majority respondents of the dietary recall questionnaires. As expected, the age of the child was significantly associated with diet diversity of children (Table 4.4, 4.5, 4.6 and 4.7).

4.3.3 Discussion of Key Findings

One of the key findings of this study is that the magnitude of the association between farm production diversity and dietary diversity first depends on the method used to measure farm production diversity. When measured as an unweighted crop species count, animal species account and production diversity score, farm production diversity is significantly associated with HDDS and WDDS but not with CDDS. The magnitude of the effect is however small but higher for HDDS than WDDS. When measured as a Simpson’s Index, farm production diversity is only significantly associated with WDDS. The magnitude of the association is smallest for the crop species count and highest for the animal species count. Similar to Koppmair *et al.,* (2017), the results show a larger effect of farm production diversity on dietary diversity scores when measured as production diversity score, relative to crop species count. Most previous studies report a magnitude of association in the range of 0.05 to 0.20 (Bellon *et al*, 2016; Koppmair et al, 2017; Sibhatu and Qaim, 2018), which compares favourably with our findings. Jones *et al,* (2014) reported higher effects while using the OLS method instead of a Poisson model that is applied in this study. We find a higher magnitude effect for the animal count, which has not been analyzed separately by any of the previous studies.

The hypotheses that an increase in farm production diversity has no effect on household dietary diversity is rejected. Similarly, the hypothesis that an increase in farm production diversity has no effect on women dietary diversity is rejected. Our findings are consistent with findings from previous studies by Sibhatu *et al,* (2015) and Jones *et al,* (2014) that farm production diversity is independently associated with household dietary diversity. Sibhatu *et al,* (2015) however argue that this association is only true in specific conditions, and can turn negative as farm production diversity exceeds a certain threshold because households may lose the economic benefits of specialization. Overall, the Poisson model results show that as households diversify in the farm, their economic access to diverse diets follows a similar pattern.

As would be expected, other factors that contribute to the household economic status, such as farm commercialization, off-farm income and education level of household head are significantly associated with HDDS. Households that practiced commercialized farming relative to subsistence had more diversified diets. This is however not the case for diets of women and children. It is plausible that off-farm income and farm commercialization is only significantly associated with HDDS, since unlike individual diet diversity; HDDS is an indication of the household’s economic access to diverse diets. HDDS includes food groups that are obtained only from the market to measure the economic ability of the household to acquire diverse diets. Nevertheless, the finding is in agreement with previous studies that report little effect of commercialization and intensification of staple food production systems on the nutritional status of vulnerable groups such as the poor, women and children (Berti *et al*, 2004; Hawkes and Ruel, 2008; Masset *et al*, 2012; Pingali, 2015). Thus, even when farm commercialization and incomes are increasing, some degree of farm production diversity is still vital for diet diversity of women and of households that are constrained by income.

Farm production diversity is not associated with dietary diversity of children in this study. Based on these findings, we fail to reject the hypothesis that increase in farm production diversity has no effect on children dietary diversity. Though positive, the association between farm production diversity and dietary diversity of children is not significant. The results here do not agree with results from some other recent studies undertaken in various regions using other measures of farm diversity. For instance, Hirvonen and Hoddinott (2017), found that CDDS among children in Ethiopia is strongly correlated with farm production diversity computed by mapping farm diversity over the 7 food groups used to compute CDDS. However, findings from previous studies have shown little change in children nutrition as a result of interventions in agriculture (Berti *et al,* 2004; Masset *et al,* 2012).

Across all models, our findings show that children's dietary diversity is associated with maternal education, household size and age of the child. These findings agree with previous studies, that maternal education leads to improved children nutrition outcomes (Kabubo-Mariara *et al,* 2008; Ruel *et al,* 2013). Schooling improves nutrition through nutrition knowledge, empowerment, optimization of time and physical and mental health which is observed through diet choices and attitude (Ruel *et al,* 2013). We also find that as children grow older, their diets become more diversified. This confirms similar results reported from the region by Harvey *et al* (2017), that older children were more likely to attain minimum acceptable diet and dietary diversity. Obviously, new types of foods are introduced as the child grows older. However, this is an indication that the dietary requirements of younger children, especially those who are not breastfeeding, are possibly not met.

Seasonality of agricultural production affects the diets of rural households (Bellon *et al,* 2016). One limitation of this study is the failure to capture the possible seasonal changes in the linkages between farm production diversity and dietary diversity as it would have required further rounds of data collection. However, Kisii and Nyamira Counties receive rainfall in all the months of the year, thus farm production happens all year round, accordingly the seasonal variation in food production and consumption is minimal.

4.4 Conclusion and Policy Implications

This study evaluates the linkages between farm production diversity and dietary diversity of the household, women and children and uses different measures of farm production diversity to compare the results. Overall, the study's findings are consistent with previous studies, yet offer some new insights. It can, therefore, be concluded that the association between farm production diversity and dietary diversity in Kenya is diverse, context-specific and depends on factors such as the market participation (farm commercialization), income sources and proximity to markets. Although the magnitude of association varies, the direction of association between farm production diversity and dietary diversity is consistent across the different measures of farm diversity except for the Simpson's Index. The positive association between farm production diversity and dietary diversity though small in magnitude has important nutrition policy implications for government and development partners than can stem the high levels of undernutrition in Kenya.

Given that farm production diversity is significantly associated with the dietary diversity of the household and women, but not for children, there is need to target nutrition policy interventions at individuals such as women and children rather than developing programs for the entire household. This study recommends the expansion of child nutrition education programs that target to educate mothers and/or caregivers on the nutrition requirements of children.

The finding that factors contributing to household economic status such as farm commercialization, off-farm income and education are significantly associated with HDDS has important policy implication for improving household's nutrition. This study recommends the implementation of policies that target improving market access for farm produce and providing opportunities for off-farm employment since they will be more effective in improving household's access to diverse diets.

CHAPTER FIVE

SUBSISTENCE PRODUCTION, MARKETS, AND DIETARY DIVERSITY IN THE KENYAN SMALL FARM SECTOR[3]

Abstract

Undernutrition and low dietary quality remain widespread problems in poor population segments, especially among smallholder farmers in sub-Saharan Africa. Hence, the question how smallholder systems can be made more nutrition-sensitive is of particular relevance for research and policy. Recent studies analyzed whether increasing farm production diversity may help to improve nutrition, with a popular finding that a positive but small average effect on dietary diversity exists. The underlying mechanisms were not examined in detail. This paper tests the hypothesis that the effect of farm diversity on nutrition is small because production diversity is positively associated with dietary diversity obtained from subsistence production but negatively associated with dietary diversity obtained from the market. This hypothesis is confirmed with data from Kenya, using different indicators of production diversity and dietary diversity scores at household and individual levels. The results underline the important role of markets for smallholder diets and nutrition. Hence, strengthening markets and improving market access should be a key strategy to make smallholder systems more nutrition-sensitive.

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5.1 Introduction

Undernutrition is a widespread problem in many developing countries. While the proportion of undernourished people declined significantly during the last few decades, the number of people with insufficient access to food remains high and even increased recently in sub-Saharan Africa (FAO, 2019). Beyond food quantity, dietary diversity is important for healthy and balanced nutrition. Measures of dietary diversity consider the different types of foods consumed by households and individuals and have recently become popular indicators in the food security and nutrition literature (Fongar *et al.*, 2019; Verger *et al.*, 2019). At the household level, dietary diversity scores are easy-to-measure indicators of food security (Headey and Ecker, 2013). At the individual level, dietary diversity scores are proxies of dietary quality and nutrition, because they are significantly associated with micronutrient intakes and nutrition status (Arimond and Ruel, 2004; Fongar *et al.*, 2019). Undernutrition and micronutrient malnutrition remain the leading risk factors for child mortality and other serious health issues in Africa (Gödecke *et al*., 2018; Development Initiatives, 2018).

Many of the people affected by undernutrition and micronutrient malnutrition are smallholder farmers. Hence, the question how smallholder systems can be made more nutrition-sensitive has received considerable attention in the recent literature (Carletto *et al.*, 2015; Ruel *et al.*, 2018). One common recommendation is to increase farm production diversity, meaning that farmers should be encouraged to produce a larger number of different crop and livestock species (Fanzo *et al.*, 2013; Jones, 2017). As smallholder households typically consume large proportions of what they produce at home, higher farm production diversity may also lead to higher dietary diversity. Indeed, several recent studies found a positive relationship between farm production diversity and dietary diversity in the small farm sector of different developing countries (; Jones *et al.*, 2014; Sibhatu *et al.*, 2015; Romeo et al., 2016; Bellon *et* *al*., 2016; Koppmair *et al*., 2017; Hirvonen and Hoddinott 2017; Ecker, 2018). However, the effect of increasing production diversity on dietary diversity was found to be small in many cases, which could mean that introducing additional species may not be the most effective strategy to improve diets and nutrition in smallholder households. A few authors argued that the small size of the effects might be due to measurement issues and that the picture could change if other indicators were used (Berti, 2015; Verger *et al*., 2017). But recent reviews showed that the mean effects of increased production diversity on diets and nutrition remain small even when alternative indicators are used (Sibhatu and Qaim, 2018a, 2018b).

Smallholder households obtain the food that they consume from different sources, the most important of which are (i) own production (subsistence pathway) and (ii) market purchases (market pathway). When smallholder households increase their production diversity, then both the subsistence and the market pathway may be affected. Here, we hypothesize that the association between farm production diversity and overall dietary diversity is small because production diversity may have a positive partial effect on diets through the subsistence pathway, but a negative partial effect through the market pathway. Even though smallholder farmers tend to be subsistence-oriented, recent research showed that a sizeable share of their diets is typically obtained from the market (Luckett *et al*., 2015; Frelat *et al*., 2016; GLOPAN, 2016; Sibhatu and Qaim, 2017).

Increasing farm production diversity can lead to a substitution of home-produced food for market purchases, so that the total effect of production diversity on dietary diversity may be reduced. While the important role of markets for smallholder diets was highlighted in previous research (Barrett, 2008; Koppmair *et al*., 2017; Hirvonen and Hoddinott, 2017; Ogutu *et al*., 2020), we are not aware of studies that explicitly differentiated between subsistence and market pathways when analyzing the role of farm production diversity. We address this research gap with data from smallholder farm households in Kenya.

In particular, the association between farm production diversity and overall dietary diversity is examined, as other studies did, but then the analysis is extended by separately looking at dietary diversity obtained through the subsistence pathway and dietary diversity obtained through the market pathway. This analysis can help to better understand the underlying mechanisms and develop effective strategies towards making smallholder systems more nutrition-sensitive. The robustness of the results is also tested by using various indicators of production diversity and dietary diversity with household-level and individual-level data for women and children. Data were collected in Kisii and Nyamira Counties, where farms are mostly very small and subsistence-oriented. These are typical conditions for sub-Saharan Africa. Hence, the results may offer some broader lessons also beyond the concrete empirical setting.

5.1.1 Conceptual Framework

Existing studies on farm production diversity and dietary diversity (Jones *et al.*, 2014; Sibhatu *et al.*, 2015; Romeo *et al.*, 2016; Bellon *et al.*, 2016; Hirvonen and Hoddinott 2017; Koppmair *et al.*, 2017; Ecker, 2018) implicitly assumed a direct link between these two variables by estimating regression models of the following type:

$$DD = \alpha_0 + \alpha_1 PD + \alpha_2 \boldsymbol{X} + \varepsilon \tag{5.1}$$

where DD is an indicator of dietary diversity, PD is an indicator of farm production diversity, $\boldsymbol{X}$ is a vector of control variables, and ε is a random error term. However, in reality, the relationship is less direct because households obtain their food from different sources, including subsistence production and market purchases.[4] Hence, overall dietary diversity is a function of dietary diversity obtained from subsistence and dietary diversity obtained from the market, as shown in Figure 5.1.

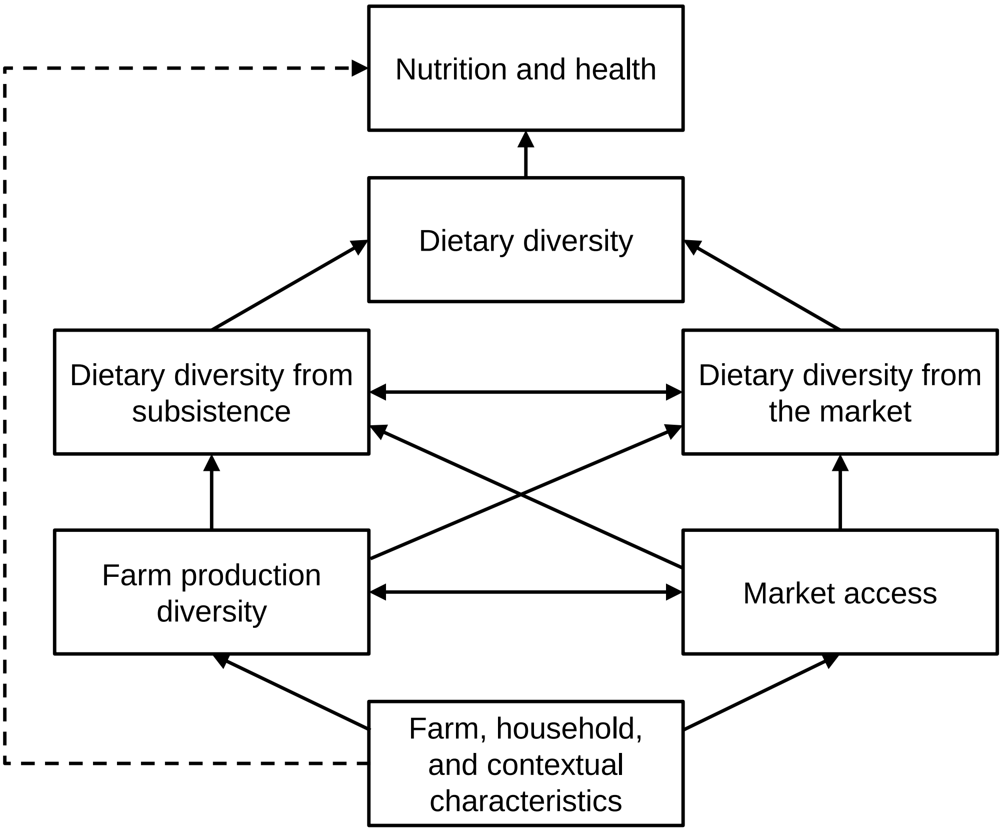

Figure 5.1: Links between farm production diversity and dietary diversity through subsistence and market pathways

Farm production diversity has a direct partial effect on dietary diversity from subsistence, which is expected to be positive. But farm production diversity may also affect dietary diversity from the market, and this partial effect may be negative. Up to a certain extent, a negative partial effect may simply be due to dietary substitution: if a household produces certain food items itself, there may be no need to obtain the same foods also from the market.

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[4] Subsistence production represents foods obtained from the own farm, while market purchases represent foods that the household purchases from local markets. Other sources can include the collection of wild foods, gifts, and transfers, but subsistence production and market purchases are generally the most important ones (Sibhatu and Qaim, 2017).

However, increasing farm production diversity may also affect household income and thus the ability to buy food in the market (Dzanku and Mawunyo, 2018). If production diversification is a response to market incentives, then it may result in increased household income, which could lead to higher dietary diversity through the market pathway. For instance, Hirvonen and Headey (2018) showed that rural households in Ethiopia are more likely to grow vegetables in home gardens when they are located close to the market, probably because market closeness allows these households to also sell some of the vegetables produced. Similarly, Bellon *et al.* (2016) found that better market opportunities were associated with higher levels of farm diversification in one region in Benin. More typically, however, the opposite is true: farms with poor market access are more diversified and subsistence-oriented (de Janvry *et al.*, 1991; GLOPAN, 2016; Sibhatu and Qaim, 2017; Ruel et al., 2018).

Against this background, we hypothesize that farm production diversity is positively associated with dietary diversity from subsistence (DD_{sub}), but negatively associated with dietary diversity from the market (DD_{mar}). This hypothesis is tested using the following regression models:

$$DD_{sub} = \beta_0 + \beta_1 PD + \beta_2 \boldsymbol{X} + \varepsilon \tag{5.2}$$

$$DD_{mar} = \gamma_0 + \gamma_1 PD + \gamma_2 \boldsymbol{X} + \varepsilon \tag{5.3}$$

where β_1 is expected to be positive, and γ_1 is expected to be negative. A negative γ_1 might also explain why the combined effect of production diversity on total dietary diversity (DD_{tot}) is often smaller than expected. These partial effects were not analyzed in previous research. We will use equation (5.1) to estimate the combined effect and equations (5.2) and (5.3) to estimate the partial effects, with appropriate control variables included. As shown in Figure 1, control variables that may also affect dietary diversity include farm, household, and contextual characteristics.

5.2 Materials and Methods

5.2.1 Household Survey

Data for this study were collected from farm households in the counties of Kisii and Nyamira in Nyanza region through a survey that was implemented in November and December 2016. Kisii and Nyamira are characterized by high population density, very small farm sizes (mostly below 2 acres), and favorable agricultural potential (GoK, 2014). With over 1000 mm of annual rainfall spread over two extended rainy seasons, agricultural production takes place all the year around. As a result, there is relatively little seasonal variation in food production and consumption (Fongar *et al.*, 2019), which is advantageous for our analysis, because data were only collected during a two-month period. In spite of the favorable agricultural conditions, undernutrition is widespread in the study region. According to official statistics, 25% of the children in Kisii and Nyamira are stunted (low height-for-age), which is the most common indicator of child undernutrition (KNBS, 2014).

To get a representative sample of farm households in the absence of recent census data, we exploited the fact that the majority of farm households in the study region are organized in farmer groups. These groups are registered with the Ministry of Social Services. Based on the Ministry list of farmer groups and with the help of Africa Harvest, a local non-governmental organization active in the region, we identified the existing groups in Kisii and Nyamira and randomly sampled 48 groups that were spread over 8 different sub-counties. In each of these 48 groups, we randomly selected 15-20 households (depending on group size), resulting in a total sample of 755 farm households.

In addition to collecting household-level data, in the 755 households we also collected individual-level data from 550 women (either the household head or the spouse) and 205 children aged 6-59 months. We were not able to collect individual-level data in all of the households. Also, many of the households did not have small children. If a household had more than one child aged 6-59 months, we selected one of the children randomly.

The selected households were personally interviewed with a structured questionnaire, which was carefully designed and pre-tested. Households were interviewed on dietary patterns and farm production practices, including types of crops produced or livestock kept, and how the farm produce was utilized. The household-level dietary section of the questionnaire was answered by the person responsible for food preparation in the household. The individual-level dietary section for women was answered by the respective woman herself; for children the section was answered by the mother or caregiver. Food consumption at the household level was captured through a 7-day recall. Individual food intakes were captured through a 24-hour dietary recall.

5.2.1.1 Measurement of Dietary Diversity

We compute three types of dietary diversity scores, as shown in Table 1. Dietary diversity scores count the number of different food groups consumed over a certain period of time. The first score that we use is the household dietary diversity score (HDDS) with a total of 12 food groups (FAO, 2011). We calculate the HDDS based on data from the 7-day food consumption recall. HDDS is a good proxy of a household’s economic access to food and food security, as households typically diversify their food consumption patterns with rising incomes and when they have achieved certain minimum levels of calorie sufficiency (Headey and Ecker, 2013). However, HDDS is not necessarily a good indicator of dietary quality for at least two reasons. First, HDDS also counts certain less healthy food groups that may contribute to diversity but not to dietary quality, such as sugar, sweets, and soft drinks (Table 5.1). Second, dietary diversity scores at the household level do not account for intra-household food distribution and may therefore not fully reflect what individual household members actually eat (Verger *et al.*, 2019).

Table 5.1: Food group classification for different dietary diversity scores

Number	Household dietary diversity score (HDDS)	Women's dietary diversity score (WDDS)	Child dietary diversity score (CDDS)
1	Cereals	Starchy staples	Grains, roots, and tubers
2	White roots and tubers	Dark green leafy vegetables	Legumes and nuts
3	Vegetables	Other vitamin A rich fruits and vegetables	Dairy products (milk, yoghurt, cheese)
4	Fruits	Other fruits and vegetables	Flesh foods (meat, fish, poultry, and liver/organ meats)
5	Meat	Organ meat	Eggs
6	Eggs	Meat and fish	Vitamin A rich fruits and vegetables
7	Fish	Eggs	Other fruits and vegetables
8	Legumes, nuts, and seeds	Legumes, nuts, and seeds	
9	Milk	Milk and milk products	
10	Oils and fat		
11	Sugar and sweets		
12	Spices, condiments, beverages		

Dietary quality is better captured with individual-level data. Various studies showed that individual-level dietary diversity scores are significantly correlated with micronutrient intakes and nutritional status (Arimond and Ruel, 2004; Fongar *et al.*, 2019). Therefore, the other two scores are calculated at the individual level for women and children aged 6-59 months, using the 24-hour dietary recall data. Women and children are of particular interest because they are typically most affected by undernutrition and micronutrient malnutrition

(Development Initiatives, 2018). For women, we calculate the Women's Dietary Diversity Score (WDDS) using 9 food groups (FAO, 2011). For children, we calculate a Child Dietary Diversity Score (CDDS), using the 7 food groups recommended by WHO (2008) for assessing the minimum dietary diversity of small children.[5] The food group classifications for all three scores are shown in Table 5.1.

All three dietary diversity scores are first calculated considering all foods consumed by households and individuals, regardless of the particular food source. In a second step, we re-calculate two additional versions of all three dietary diversity scores by (i) only considering the foods obtained from subsistence production ($\mathrm{HDDS}_{\mathrm{sub}}$, $\mathrm{WDDS}_{\mathrm{sub}}$, $\mathrm{CDDS}_{\mathrm{sub}}$) and (ii) only considering the foods obtained from the market ($\mathrm{HDDS}_{\mathrm{mar}}$, $\mathrm{WDDS}_{\mathrm{mar}}$, $\mathrm{CDDS}_{\mathrm{mar}}$). Note that the total dietary diversity scores are not necessarily the sum of the scores from the two sources, because certain food groups may be obtained from subsistence and from markets (or other sources) simultaneously.

5.2.1.2 Measurement of Farm Production Diversity

Farm production diversity can be measured in different ways. One common approach is to simply count all the different crop and animal species produced by the farm household, regardless of whether these are produced for food or other purposes (Jones *et al.*, 2014; Sibhatu *et al.*, 2015). We use such a species count of the crops grown in the previous planting season and the livestock kept as one measure of farm production diversity.

However, this simple species count also includes non-food cash crops that cannot contribute to dietary diversity through the subsistence pathway. Moreover, different crop species that

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[5] The CDDS was primarily developed and validated for young children aged 6–23 months, but recent research suggests that it can also be used for older children up to 59 months (Fongar *et al.*, 2019), as we do here.

belong to the same food group – such as different types of cereals – may not add to diets when these are assessed with dietary diversity scores (Berti, 2015). Therefore, as an alternative measure of production diversity, we also calculate so-called production diversity scores, which count the number of different food groups produced, using the same food group classification as for the HDDS. Production diversity scores were also calculated and used in other recent research analyzing the association between production diversity and dietary diversity (Koppmair *et al.*, 2017; Hirvonen and Hoddinott, 2017; Sibhatu and Qaim, 2018b).

5.2.1.3 Measurement of other Key Variables

Dietary diversity in smallholder farm households cannot only be influenced by farm production diversity, but also by a number of other farm, household, and contextual characteristics. Some of these characteristics may be correlated with farm production diversity, so we need to control for them in the regression models to avoid estimation bias. We control for farm size, household size, as well as gender, age, and education of the household head. These are all variables that were shown to influence household diets and nutrition in previous studies (Jones *et al.*, 2014; Sibhatu *et al.*, 2015; Ogutu *et al.*, 2020).

Household wealth or living standard is also expected to be an important determinant of diets and nutrition. In general, income or expenditures are commonly used indicators of living standard, but including income or expenditures in our models would be problematic because of endogeneity. Simultaneity may be an issue, because diets and nutrition can influence people's labor productivity, and thus also income and expenditures. Also, income (and expenditures) may be affected by farm production diversity (Sibhatu and Qaim, 2018b). As income is likely one of the key mechanisms for the association between production diversity and dietary diversity from the market, including income as a control variable could lead to serious estimation bias. Finding an instrument for income in our models was not possible, because all variables that affect income also affect diets and nutrition. Instead, we control for the value of household assets (vehicles, television, other major appliances, etc.), which is another indicator of household wealth and much less prone to endogeneity than income or expenditures.

Market distance may also matter, as farm households use markets to sell farm produce and buy food items that they do not produce themselves (Hirvonen and Hoddinott, 2017; Koppmair *et al.*, 2017). We include a variable that measures the distance from the household to the closest village market. These village markets are typically small and used frequently by farmers for regular transactions. Furthermore, recent research showed that informal social networks can be important channels for the flow of agricultural and nutrition information in rural communities (Jäckering *et al*., 2019). In our regression models, we control for farmers' social networks through a variable that counts the number of other persons within the group that the farmer interacts with on topics related to food and agriculture.

Finally, in the individual-level models for women and children we also control for a few individual characteristics. In the models for women's dietary diversity, we control for the women's age and education level. In the child models, we control for the child's age and the number of siblings living in the household, which may be an important factor for intra-household food distribution. For the siblings, we count all children up to the age of 14 years, as this is the age until which children in Kenya are expected to attend primary school.

5.2.2 Regression Estimators

As explained above, we estimate the models shown in equations (1) to (3) to analyze the association between farm production diversity and dietary diversity. In these models, the dependent variables are dietary diversity scores, which are count variables. Count data models are typically estimated with a Poisson estimator (Greene, 2007). The standard Poisson estimator assumes equidispersion in the data, implying that the variance of the outcome variable is equal to its mean. We tested the equidispersion assumption in our data and found that the variance of all dietary diversity scores is significantly lower than the mean, indicating the presence of under-dispersion. Against this background, instead of the standard Poisson estimator we use the generalized Poisson model, which is more suitable to analyze under-dispersed data (Harris and Young, 2012). We use the generalized Poisson estimates to calculate marginal effects for all variables, which are straightforward to interpret. All models are estimated with clustered standard errors at the farmer group level to deal with possible heteroscedasticity (Cameron and Miller, 2015).

5.3 Results

5.3.1 Descriptive Results for Household Socio-economic Factors

Descriptive results for household socio-economic variables used in this study are shown in Table 5.2. The farms are small in size (average land holding of 1.45 acres) and quite diverse in their production patterns. On average, farms produce 13.4 different crop and livestock species, including maize, sorghum, millet, beans, bananas, different types of vegetables, as well as cash crops such as tea and coffee. Many households also keep sheep, goats, chicken, and sometimes cattle. The average production diversity score is 5.8, meaning that households produce more than five different food groups on their farms.

The lower part of Table 5.2 shows the different dietary diversity scores.

Table 5.2: Descriptive Results for Household Socio-economic variables

Variable	Description	Mean	SD
Socioeconomic characteristics			
Farm size	Land area owned (acres)	1.45	1.19
Household size	Number of household members	5.49	2.04
Male head	Household head is male (dummy for male=1)	0.76	0.43
Age head	Age of household head in years	50.31	12.43
Education head	Years of education of household head	8.74	3.60
Age woman	Age of woman interviewed in years	45.31	12.28
Education woman	Years of education of woman interviewed	8.16	3.62
Age of child	Age of child in months	46.85	12.54
Distance to market	Distance to closest village market (km)	1.90	2.02
Assets	Value of assets owned (thousand $)	2.80	7.16
Social network	Number of people farmer shares information with	6.54	4.36
Farm production diversity			
Species count	Number of crop and animal species produced	13.37	3.74
Crop count	Count of crop species grown on farm	11.31	3.41
Animal count	Count of animal species kept on farm	2.06	1.13
Production diversity score	Number of food groups produced	5.81	1.07
Dietary diversity			
HDDS	Household dietary diversity score	9.72	1.31
$HDDS_{sub}$	HDDS from subsistence	4.75	1.58
$HDDS_{mar}$	HDDS from the market	7.37	1.55
WDDS	Women's dietary diversity score	4.17	0.82
$WDDS_{sub}$	WDDS from subsistence	2.86	1.36
$WDDS_{mar}$	WDDS from the market	2.31	1.06
CDDS	Child dietary diversity score	4.13	0.73
$CDDS_{sub}$	CDDS from subsistence	2.95	1.28
$CDDS_{mar}$	CDDS from the market	2.34	1.05

Note: The sample contains observations from 755 households, 550 women, and 205 children.

The HDDS is larger than the WDDS and the CDDS, which is plausible for three reasons. First, the HDDS includes a larger number of food groups than the other two scores. Second, the HDDS considers the foods consumed by all household members, whereas the WDDS and CDDS only include the foods consumed by individual women and children. Third, for the calculation of HDDS we used data from the 7-day food recall, meaning that all foods consumed over a 7-day period were considered, whereas the WDDS and CDDS were calculated using 24-hour dietary recall data.

Households obtain a larger part of their food diversity from the market than from subsistence production (Table 5.2). This is in line with recent results from other African contexts (Hirvonen and Hoddinott, 2017; Sibhatu and Qaim, 2017). The picture is somewhat different for the WDDS and CDDS disaggregation, where subsistence and market sources both account for about half of total dietary diversity. The larger role of markets for HDDS is due to the fact that the HDDS also includes food groups such as oils and fats, sweets, and other processed foods that are only purchased in the market.

Interesting to note is that the average number of food groups produced on the farms is larger than the number of food groups consumed from subsistence. Seasonality may potentially play a role here because the HDDS only considers foods consumed during the last 7 days. On the other hand, there are also certain foods that farms produce and sell without consuming them on a regular basis. This is especially true for certain types of vegetables, but also for eggs and other animal products. For instance, 80% of the sample households produced eggs, while only 34% of them consumed eggs from their own farm during the 7-day recall period.

In Table 5.3, we compare more specifically which of the food groups are produced by many farm households and what shares of total consumption are obtained from subsistence and from the market.[6] Almost all households produced cereals, especially maize, but at the same time almost all households also purchased cereal products from the market. Around 40% of

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[6] For some of the food groups, the subsistence and market shares do not add up to 100%, because small quantities are also obtained from other sources, such as collection of wild foods, gifts, and transfers. However, subsistence and markets account for over 95% of the quantities consumed in most cases.

all cereal foods consumed in the farm households were obtained from the market, which often involves semi-processed products such as maize and wheat flour. Similarly, almost all households grew vegetables and fruits, but the majority also purchased items from these food groups in the market. For instance, a household may grow kale and bananas, but may buy other items such as tomatoes and papaya. This means that most households specialize in producing certain species rather than trying to produce everything that they would like to consume. Most of the roots and tubers, meat, fish, and highly processed food products are obtained from the market, as one would expect.

Table 5.3: Food group production and consumption from different sources

		Household consumption		
	Households producing (%)	Total quantity (kg)	From subsistence (%)	From the market (%)
Cereals	97	4.19 (4.78)	53	40
Roots and tubers	16	3.50 (3.36)	21	68
Vegetables	98	3.04 (4.07)	65	30
Fruits	95	10.27 (10.24)	61	31
Meat	97	1.04 (0.87)	31	68
Eggs	80	5.82 (4.06)	75	24
Fish	0.4	0.64 (0.58)	2	92
Legumes, nuts, seeds	31	1.4 (1.44)	78	19
Milk/milk products	67	6.8 (5.83)	77	22
Oils and fats	0	0.7 (0.46)	0	99
Sugar and sweets	0	1.44 (0.84)	0	97
Spices, condiments, beverages	0	0.29 (0.27)	0	97

Notes: The sample contains observations from 755 households. Consumption refers to mean quantities consumed by households over a 7-day recall period with standard deviations shown in parentheses. For fruits and eggs, quantity is measured in terms of pieces consumed.

5.3.2 Comparisons between Different Types of Farms

In Table 5.4, we compare mean dietary diversity and farm production diversity for different types of farms to get a better understanding of the patterns observed. All farms in our sample are very small, fairly diversified, and produce to a large extent for subsistence. Nevertheless, they differ somewhat in terms of their market orientation. For comparative purposes, we subdivide the total sample into two subsamples of equal size according to their level of commercialization, using the proportion of farm output sold as the distinguishing variable. Households in the less commercialized subsample sell less than 40% of their farm output, meaning that more than 60% is kept for home consumption. Accordingly, households in the more commercialized subsample sell more than 40% of their output. A second typology we use is households with and without the production of cash crops, such as tea and coffee. Two-thirds of the households in our sample grow cash crops, whereas one-third does not (Table 4).

Table 5.4: Dietary diversity scores in different farming systems

	Less commercialized (n=377) [a]	More commercialized (n=378) [a]	Without cash crops (n=249) [a]	With cash crops (n=506) [a]
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Dietary diversity scores				
HDDS	9.58 (1.36)	9.85** (1.24)	9.72 (1.28)	9.71 (1.32)
HDDS_{sub}	4.50 (1.59)	4.99*** (1.52)	4.62 (1.57)	4.80 (1.57)
HDDS_{mar}	7.27 (1.55)	7.46 (1.55)	7.58 (1.61)	7.25 (1.51)
WDDS	4.12 (0.83)	4.21* (0.78)	4.28* (0.84)	4.11 (0.78)
WDDS_{sub}	2.71 (1.34)	3.01** (1.33)	2.80 (1.45)	2.89 (1.29)
WDDS_{mar}	2.34 (1.09)	2.32 (1.02)	2.52*** (1.17)	2.24 (0.98)
CDDS	4.19 (0.74)	4.07 (0.72)	4.32*** (0.73)	4.02 (0.72)
CDDS_{sub}	2.90 (1.25)	2.99 (1.32)	2.87 (1.32)	2.99 (1.26)
CDDS_{mar}	2.36 (1.10)	2.32 (1.01)	2.51* (1.11)	2.24 (1.01)
Farm production diversity				
Species count	13.12 (3.80)	13.70* (3.61)	12.25 (3.54)	13.98*** (3.67)
Production diversity score	5.73 (1.05)	5.90* (1.06)	5.70 (1.09)	5.87* (1.03)

Notes: The total sample contains observations from 755 households, 550 women, and 205 children. [a] This sample size refers to the number of household observations in each category. Mean differences between categories were tested for statistical significance. * $p<0.1$; ** $p<0.05$; *** $p<0.01$

More commercialized households have higher HDDS and WDDS than less commercialized households (Table 5.4). Usually one would expect that more commercialized households are more specialized in their production patterns and obtain more of the foods consumed from the market. Strikingly, however, the more commercialized households in our sample have an even higher farm production diversity than the less commercialized households. The comparisons in Table 5.4 also suggest that farm commercialization is more strongly associated with dietary diversity from subsistence than with dietary diversity from the market. For CDDS, no significant differences can be observed between more and less commercialized households.

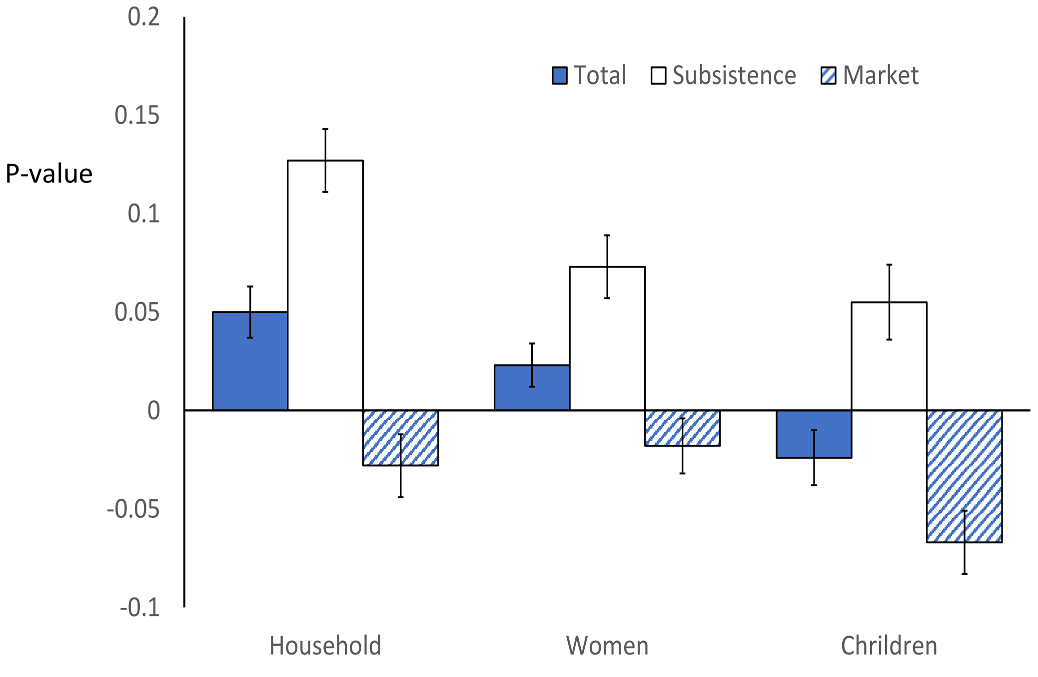
Comparing the households with and without cash crop production, no significant differences are observed in terms of HDDS (Table 5.4). Interestingly, however, WDDS and CDDS are somewhat higher in the households without cash crop production, and this in spite of a lower production diversity score. This may possibly be related to the fact the income from cash crops is primarily controlled by male household members, who are often less concerned about dietary quality and child nutrition than female household members (Malapit *et al.*, 2015). In any case, the observed patterns underline the complex relationships between farm production, household and individual consumption, and market participation.

5.3.3 Regression Results

The estimated associations between farm production diversity and dietary diversity at household and individual levels are summarized in Figure 5.2. Details of the underlying regression models are shown in Tables 5.5-5.7. Table 5.5 presents the regression results for the household-level models, meaning that HDDS is the dependent variable. For each model, we estimated two versions; first, using the simple species count as the production diversity indicator (columns 1-3 in Table 5.5 and panel ‘a’ in Figure 5.2), and second, using the production diversity score (columns 4-6 in Table 5.5 and panel b in Figure 5.2).

Farm production diversity is positively associated with total HDDS, but the magnitude of the association is relatively small. The marginal effect of 0.05 in column (1) of Table 5.5 suggests that each additional species produced on the farm is associated with a 0.05 increase in the number of food groups consumed. In other words, households would have to produce 20 additional species in order to increase HDDS by one food group. The association is larger when the production diversity score is used (column 4), as was also demonstrated in previous research (Sibhatu and Qaim, 2018b). But the marginal effect remains relatively small: the value of 0.18 implies that more than five additional food groups would have to be produced in order to increase HDDS by one food group.

(a) Production diversity measured with species count



(b) Production diversity measured with production diversity score

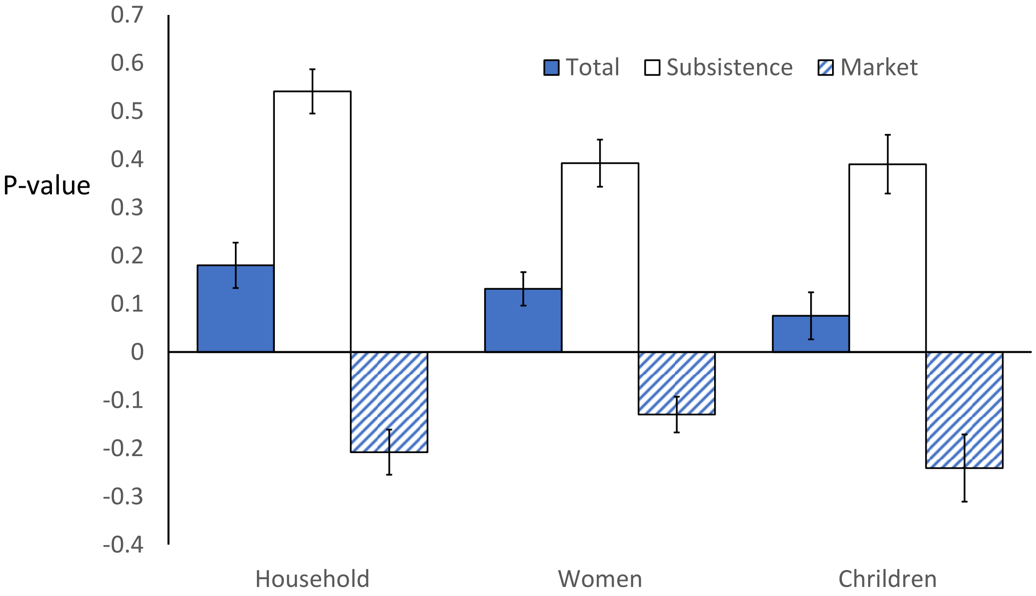


Figure 5.2: Association between farm production diversity and dietary diversity (summary results)

Notes: Marginal effects of production diversity on household and individual dietary diversity scores are shown with standard error bars. Estimates are based on the regression models shown in Tables 5-7, controlling for confounding factors.

The results for HDDS_{sub} and HDDS_{mar} in Table 5.5 reveal the pathways that were outlined in the conceptual framework. The estimates confirm our main hypothesis, namely that farm production diversity is positively associated with dietary diversity obtained from subsistence, but negatively associated with dietary diversity obtained from the market (also see Figure 5.2). As expected, the partial effects through the subsistence pathway are larger than the total effects. Interesting to note, however, is that even when the production diversity score is used, the effect on dietary diversity from subsistence remains significantly smaller than one (0.54 in column 5 of Table 5.5). Hence, the production of one additional food group on the farm does not necessarily mean that this additional food group is also consumed by the farm household. This is in line with the above-mentioned finding that certain foods are produced primarily for the market and not consumed by the farm households on a regular basis.

Table 5.5: Association between farm production diversity and household dietary diversity

	(1) HDDS	(2) HDDS_{sub}	(3) HDDS_{mar}	(4) HDDS	(5) HDDS_{sub}	(6) HDDS_{mar}
	Species count			Production diversity score		
Farm production diversity	0.050***	0.127***	-0.028*	0.180***	0.541***	-0.208***
	(0.013)	(0.016)	(0.016)	(0.047)	(0.046)	(0.047)
Farm size (acres)	0.078*	0.114***	-0.013	0.084**	0.117***	0.000
	(0.042)	(0.039)	(0.050)	(0.042)	(0.034)	(0.052)
Household size	0.049**	0.011	0.040	0.046**	0.005	0.049*
	(0.022)	(0.025)	(0.030)	(0.022)	(0.024)	(0.029)
Male head (male=1)	0.323**	0.400***	0.207	0.305**	0.348***	0.244
	(0.132)	(0.126)	(0.158)	(0.140)	(0.133)	(0.149)
Age head (years)	-0.010**	0.003	-0.016***	-0.008*	0.008**	-0.017***
	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.005)
Education head (years)	-0.002	0.023	-0.001	0.001	0.030**	-0.001
	(0.014)	(0.015)	(0.016)	(0.013)	(0.013)	(0.016)
Distance to market (km)	0.053***	0.088***	0.011	0.046**	0.074***	0.015
	(0.020)	(0.026)	(0.029)	(0.019)	(0.027)	(0.029)
Assets (value)	0.001	0.002	-0.000	0.001	0.001	0.001
	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
Social network index	0.042***	0.060***	0.009	0.035**	0.044***	0.015
	(0.015)	(0.018)	(0.021)	(0.015)	(0.017)	(0.021)
Number of observations	755	755	755	755	755	755

Notes: Marginal effects of generalized Poisson models are shown with cluster corrected standard errors in parentheses. * $p<0.1$; ** $p<0.05$; *** $p<0.01$

Results for women's dietary diversity, with WDDS as dependent variable, are presented in Table 5.6. They are generally similar to what we also found at the household level: farm production diversity is positively associated with dietary diversity obtained from subsistence but negatively associated with dietary diversity obtained from the market. The combined effect is positive and relatively small, regardless of how exactly farm production diversity is measured. The marginal effects on WDDS are smaller than those on HDDS in absolute terms, which is due to the smaller number of food groups considered in calculating the WDDS.

Table 5.6: Association between farm production diversity and women's dietary diversity

	(1) WDDS	(2) WDDS_{sub}	(3) WDDS_{mar}	(4) WDDS	(5) WDDS_{sub}	(6) WDDS_{mar}
	Species count			Production diversity score		
Farm production diversity	0.023**	0.073***	-0.018	0.131***	0.392***	-0.130***
	(0.011)	(0.016)	(0.014)	(0.035)	(0.049)	(0.037)
Farm size (acres)	0.019	0.086**	-0.096***	0.016	0.085**	-0.096***
	(0.032)	(0.044)	(0.033)	(0.030)	(0.036)	(0.033)
Household size	0.022	-0.006	0.040	0.019	-0.019	0.040
	(0.017)	(0.028)	(0.027)	(0.017)	(0.027)	(0.026)
Male head (male=1)	0.119	0.288**	0.039	0.095	0.233	0.092
	(0.074)	(0.147)	(0.117)	(0.075)	(0.147)	(0.106)
Age head (years)	-0.010*	-0.007	-0.000	-0.009	-0.002	-0.004
	(0.006)	(0.011)	(0.008)	(0.006)	(0.011)	(0.008)
Education head (years)	0.005	-0.001	0.006	0.007	0.003	0.002
	(0.011)	(0.022)	(0.018)	(0.011)	(0.023)	(0.018)
Age woman (years)	0.004	0.012	-0.009	0.003	0.008	-0.006
	(0.007)	(0.010)	(0.008)	(0.006)	(0.011)	(0.008)
Education woman (years)	0.013	0.053**	-0.024	0.011	0.050**	-0.021
	(0.013)	(0.027)	(0.018)	(0.013)	(0.023)	(0.017)
Distance to market (km)	0.031**	0.054**	0.001	0.028*	0.041*	0.004
	(0.015)	(0.024)	(0.021)	(0.015)	(0.022)	(0.021)
Assets (value)	0.001	0.003	0.000	0.001	0.002	0.001
	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
Social network index	0.012	0.040**	-0.014	0.008	0.029	-0.011
	(0.014)	(0.020)	(0.020)	(0.014)	(0.019)	(0.020)
Number of observations	550	550	550	550	550	550

Notes: Marginal effects of generalized Poisson models are shown with cluster corrected standard errors in parentheses. * $p<0.1$; ** $p<0.05$; *** $p<0.01$

Results for children's dietary diversity, with CDDS as dependent variable, are shown in Table 5.7. Here, we also find positive effects of production diversity on dietary diversity obtained from subsistence, and negative effects on dietary diversity from the market. But as both these partial effects are similar in terms of their absolute magnitude, they balance out so the combined effect is not significantly different from zero (column 4 of Table 5.7). When production diversity is measured with the simple species count, the combined effect is even negative (column 1), meaning that producing additional species on the farm tends to reduce child dietary diversity.

Table 5.7: Association between farm production diversity and child dietary diversity

	(1) CDDS	(2) CDDS_{sub}	(3) CDDS_{mar}	(4) CDDS	(5) CDDS_{sub}	(6) CDDS_{mar}
	Species count			production diversity score		
Farm production diversity	-0.024*	0.055***	-0.067***	0.075	0.390***	-0.242***
	(0.014)	(0.019)	(0.016)	(0.049)	(0.061)	(0.070)
Farm size (acres)	-0.043	0.072	-0.084	-0.063*	0.053	-0.089
	(0.031)	(0.051)	(0.059)	(0.034)	(0.047)	(0.058)
Household size	0.020	-0.024	0.064	0.014	0.000	0.048
	(0.031)	(0.068)	(0.058)	(0.031)	(0.068)	(0.054)
Male head (dummy)	0.268**	0.264	0.069	0.233*	0.197	0.150
	(0.120)	(0.167)	(0.156)	(0.125)	(0.174)	(0.152)
Age head (years)	0.004	0.009	-0.007	0.001	0.005	-0.009*
	(0.005)	(0.006)	(0.005)	(0.005)	(0.006)	(0.005)
Education head (years)	0.030*	0.037	0.021	0.025*	0.036*	0.010
	(0.016)	(0.024)	(0.018)	(0.015)	(0.021)	(0.017)
Age child (months)	0.011**	0.007	-0.000	0.011**	0.006	-0.000
	(0.004)	(0.008)	(0.004)	(0.005)	(0.007)	(0.004)
Number of siblings	-0.093	-0.041	-0.161**	-0.093	-0.070	-0.158*
	(0.061)	(0.082)	(0.081)	(0.063)	(0.085)	(0.083)
Distance to market (km)	0.009	0.070*	0.008	0.017	0.062*	0.032
	(0.021)	(0.036)	(0.024)	(0.021)	(0.034)	(0.025)
Assets (value)	-0.001	-0.001	0.001	-0.001	-0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
Social network index	-0.010	0.043	-0.040	-0.017	0.023	-0.032
	(0.020)	(0.028)	(0.026)	(0.020)	(0.027)	(0.024)
Number of observations	205	205	205	205	205	205

Notes: Marginal effects of generalized Poisson models are shown with cluster corrected standard errors in parentheses. * $p<0.1$; ** $p<0.05$; *** $p<0.01$

Beyond the effects of farm production diversity, the estimates for the control variables in Tables 5.5-5.7 are also of interest, as they help to better understand dietary diversity outcomes. Farm size is positively associated with dietary diversity at the household level (HDDS in Table 5.5), which is unsurprising given that a larger farm size allows more production for home consumption and for markets. The effect of farm size on HDDS is particularly channeled through the subsistence pathway. Interestingly, the combined effect of farm size on women's dietary diversity is not significant (Table 5.6), and it is even negative for children's dietary diversity (column 4 of Table 5.7).

The results in Table 5.5 further show that male-headed households have a higher dietary diversity than female-headed households. These gendered effects are probably driven by households with male household heads having higher incomes on average. Female-headed households are often those where the male household head died or left, which tends to reduce the income-earning opportunities for the rest of the family.

Education of the household head has positive marginal effects in several of the models. This is unsurprising, because diets are also determined by nutrition knowledge, and nutrition knowledge tends to increase with rising educational levels. The important role of knowledge and access to information is also stressed by the positive marginal effects of the social network indicator, especially in the household-level models in Table 5.5. As was shown in recent research, informal social networks can play an important role for the spread of agricultural and nutrition information in rural communities of Africa (Jäckering *et al*., 2019).

Distance to market has positive marginal effects on dietary diversity in many of the models, which is surprising on first sight, because longer distances are normally expected to worsen access to diverse foods from the market. However, as can be seen, the positive effects of market distance are primarily channeled through the subsistence pathway. This is plausible, since households with limited market access are often more oriented towards subsistence production (Hirvonen and Hoddinott, 2017; de Janvry *et al.*, 1991).

In a final analysis, we test whether the role of farm production diversity for household and individual dietary diversity differs between households at different levels of market orientation. For this analysis we return to the commercialization typology introduced above and re-estimate all models for two subsamples, namely the less commercialized and the more commercialized households. The estimation results are summarized in Table 5.8.

Table 5.8: Association between farm production diversity and dietary diversity in more and less commercialized households

	(1) DDS	(2) DDS_{sub}	(3) DDS_{mar}	(4) DDS	(5) DDS_{sub}	(6) DDS_{mar}
	Less commercialized households (n=377)			More commercialized households (n=378)		
Household DDS	0.060***	0.137***	-0.026	0.041**	0.119***	-0.026
	(0.020)	(0.023)	(0.023)	(0.016)	(0.021)	(0.019)
Women’s DDS	0.020	0.084***	-0.017	0.029**	0.068***	-0.018
	(0.014)	(0.024)	(0.019)	(0.013)	(0.020)	(1.02)
Children’s DDS	-0.032	0.070*	-0.089***	-0.011	0.052**	-0.036*
	(0.020)	(0.036)	(0.021)	(0.018)	(0.025)	(0.022)

Notes: Marginal effects of production diversity (measured with the simple species count) on dietary diversity scores (DDS) estimated with generalized Poisson models are shown with cluster corrected standard errors in parentheses. The same control variables as shown in Tables 5-7 were included in estimation but are not shown here for brevity. The total sample contains observations from 755 households, 550 women, and 205 children. * $p<0.1$; ** $p<0.05$; *** $p<0.01$

We observe the same patterns for both subsamples. The overall effect of production diversity on dietary diversity is small, and it combines a positive partial effect through the subsistence pathway and a negative partial effect through the market pathway. In the household-level estimates, the total effect of production diversity on dietary diversity is somewhat larger in the less commercialized households than in the more commercialized ones, which is plausible because in the less commercialized households the subsistence pathway plays a more important role. Also, in the individual-level models for women and children, we observe that the effects of production diversity on dietary diversity through the subsistence pathway are somewhat larger in the less commercialized households. But overall, the differences between the two subsamples are small, suggesting that the main findings hold for all types of smallholder farm households in the study region.

5.4 Conclusions and Policy Implications

Smallholder farmers in sub-Saharan Africa remain one of the population groups most affected by undernutrition and low dietary quality. Hence, there is an urgent need to make smallholder production systems more nutrition-sensitive. Several recent studies analyzed whether further increasing farm production diversity might be a useful strategy to improve diets and nutrition. Most of these studies identified a positive relationship between production diversity and dietary diversity, even though the average magnitude of the effect was found to be small. Reasons for the small effect were hardly examined in detail, a research gap which we addressed in this paper with data from smallholder farmers in Nyanza region.

Farm production can affect smallholder diets through different pathways, especially the subsistence pathway and the market pathway. We tested the hypothesis that farm production diversity is positively associated with dietary diversity obtained from subsistence and negatively associated with dietary diversity obtained from the market. This hypothesis was confirmed, using various indicators of production diversity and dietary diversity, also after controlling for possible confounding factors. In addition to household-level dietary diversity scores, we also calculated individual-level dietary diversity scores for women and children with the same overall conclusions.

To some extent, the negative partial effect through the market pathway can be explained by a simple substitution of own-produced foods for foods purchased in the market. However, high farm production diversity and a focus on subsistence can also be associated with lower household income and thus lower economic ability to access higher-value and more nutritious foods from the market. In any case, the negative partial effect through the market pathway counteracts the positive effect through the subsistence pathway, so that the combined overall effect of production diversity on dietary diversity is small.

The results underline the important role of markets for the diets of smallholder farmers, even in subsistence-oriented settings. Overall, about half of all the foods consumed in the sample households were purchased in the market. While the role of food sources varies by food group, for 9 out of the 12 food groups used to calculate household dietary diversity scores the market-derived quantities were found to be 30% or more. These numbers are in line with previous studies carried out in other parts of sub-Saharan Africa (GLOPAN, 2016; Koppmair *et al.*, 2017; Hirvonen and Hoddinott, 2017; Sibhatu and Qaim, 2017).

One important policy implication is that promoting farm diversification may not be the most effective strategy to improve diets and nutrition in smallholder farm households. African smallholder farms are often quite diverse anyway. In our study region, the average farm produces more than 13 different species on less than 1.5 acres of land. Further diversification may foster subsistence and reduce the opportunities to participate in markets as sellers and buyers. Strengthening markets and improving market access for smallholders seems to be a more promising strategy.

Strengthening markets and improving market access requires improved roads as well as storage and market infrastructure. Higher-value nutritious foods, such as fruits, vegetables, and animal-source products, are more perishable than grains and most other staple foods, so that good infrastructure and efficient logistics are especially important. Obviously, these higher-value foods are of particular relevance to improve dietary quality and nutrition and should receive particular policy attention. In addition to general infrastructure improvements, the establishment of nutrient-preserving processing facilities could also help to improve market functioning for perishable foods. This plea for strengthening markets does not mean that certain forms of production diversification in the small farm sector may not be useful in particular contexts. But, unless markets are completely absent, diversification should build on market incentives rather than focusing on subsistence alone.

The results presented here on subsistence and market pathways refer to farm households in Nyanza region. However, the situation in Nyanza region is quite typical for the African small farm sector, so that the general findings may also apply to other contexts. Of course, follow up research in different settings will be useful to better understand the complex linkages between agricultural production patterns, markets, diets, and nutrition in smallholder farm households.

CHAPTER SIX

GENERAL CONCLUSIONS AND POLICY RECOMMENDATIONS

6.1 Conclusions

The study evaluated the effect of farm production diversity on nutrition of smallholders in Kisii and Nyamira Counties. The study used cross sectional survey data collected in from 779 households. A multistage sampling procedure was used to select respondents. The study addressed three objectives.

The first objective sought to assess the impact of variety awareness and nutrition knowledge on adoption of biofortified crop varieties. The results show that among farmers who were aware of the variety, a majority perceived KK15 beans as better than other varieties in the attributes considered. This, therefore, indicates that non-adoption that may result from any perceived inferior quality of the variety relative to other varieties was substantially eliminated. The study finds that not all farmers that were aware of the variety had knowledge of its nutrition attributes. Farmers who had knowledge of the nutrition attributes of KK15 beans were more likely to adopt, relative to farmers who were only aware of the variety. The study therefore concludes that nutrition knowledge had a positive impact on adoption of biofortified crops.

The second objective sought to evaluate the association between farm diversification and dietary diversity of the household and individuals within the home. The study found that the association between farm diversity and dietary diversity first depends on the method used to measure farm diversity. When measured as unweighted crop count, animal account, and crop count plus animal count, farm diversity is significantly associated with HDDS and WDDS but not with CDDS. The magnitude of the effect is however small and higher for HDDS than

WDDS. The animal count has the largest magnitude of association with diet diversity. Farm diversity is significantly associated with diet diversity of the household and women, but not for children. The study thus concludes that targeting farm production diversity to improve dietary diversity is a positive direction for household economic access to diversified diets and diet diversity of women, although it may not be effective in improving diet diversity for children.

The third objective aimed to assess the role of subsistence and market food sourcing on dietary diversity in the Kenyan small farm sector. The findings indicate that overall, about half of all the foods consumed in sample households were purchased in the market. While the role of food sources varies by food group, for 9 out of the 12 food groups used to calculate household dietary diversity scores the market-derived quantities were found to be 30% or more. The study therefore concludes that promoting farm diversification may not be the most effective strategy to improve diets and nutrition in smallholder farm households. African smallholder farms are often quite diverse anyway. Further diversification may foster subsistence and reduce the opportunities to participate in markets as sellers and buyers.

6.2 Policy Recommendations

The findings from paper one suggest that there is need to embed nutrition information in information packages disseminated to farmers when promoting adoption of biofortified crops. In addition, nutrition efforts can benefit from making extension services offered by usual services providers, including government more ‘nutrition sensitive’. This can be done by including nutrition information in extension information offered to farmers.

Findings from paper two suggest that there is need to consider and incorporate individual nutrition requirements when developing policy and nutrition interventions, as opposed to general interventions targeting entire households. Policy and interventions, therefore, could be made more effective if a multi-faceted approach targeting education and nutrition knowledge of caregivers and farm decision makers is adopted. Moreover, interventions such as commercialization and diversification of income sources to off-farm can increase household economic access to diverse diets. Policies that encourage smaller household sizes can also be a viable intervention, albeit in the long term.

Findings from paper three suggest that strengthening markets and improving market access for smallholders is a more promising strategy for reducing undernutrition, relative to further farm production diversification. Besides, farm sizes are small thus limiting the extent to which farmers can diversify. This is not to imply that certain forms of production diversification may not be useful in particular contexts. However, diversification should build on market incentives rather than focusing on subsistence alone, unless markets are completely absent.

6.3 Suggestions for Further Research

The results presented here refer to smallholder households in Kisii and Nyamira. However, the situation in the two Counties is quite similar to other regions in the Kenyan and African small farm sector, thus the general findings may also apply to other contexts. Follow up research that uses data sets collected in different seasons will be useful to better understand how the linkages between agricultural production patterns, markets, diets, and nutrition in smallholder farm households change over different seasons.

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APPENDICES

BUDGET

Table 3.0-1: Budget for the period 2015 - 2018 in Kenya shillings

Activity	Description	Unit	Rate	Sub-total
Studentship expenses				
School fees	1 student for three years	3	150,000	450,000
Monthly stipend	1 student for a total of 36 months	36	60,000	2,160,000
Equipment				
Purchase of one computer	1 computer for entire study period	1	50,000	50,000
Exchange visit for the globalfood programme in Germany				
Air ticket to Germany and back	1 return ticket to Germany	1	80,000	80,000
Accommodation while in Germany	5 nights accommodation for 1 student	5	7,000	35,000
Perdiem while in Germany	5 nights perdiem for 1 student	5	3,000	15,000
Data collection for the PhD research (baseline and follow-up)				
Enumerator payment for data collection	5 enumerators for 10 days each for 2 seasons	100	3,000	300,000
Daily supervisor accommodation during baseline data collection	20 nights for 1 supervisor for 2 seasons	40	1,000	40,000
Daily supervisor perdiem during baseline data collection	20 nights for 1 supervisor for 2 seasons	40	3,000	120,000
Stationery during baseline data collection	50 pencils, 2 eraser, 2 sharpener, 2 pens, 2 notebooks, 2 folders for 5 enumerators each	280	50	14,000
Questionnaires	150 questionnaires of 45 pages each for 2 seasons	13,500	5	67,500
Data entry clerks for baseline data	5 clerks for 5 days for 2 seasons	50	500	25,000
Proposal and thesis development				
Printing copies of the proposal	25 copies of 60 pages each	1,500	5	7,500
Spring binding of the proposal copies	25 copies for Ksh 50 each	25	50	1,250
Printing copies of the thesis	25 copies of 200 pages each	5,000	5	25,000
Binding copies of the proposal	25 copies for Ksh 250 each	25	250	6,250
TOTAL				**3,396,500**

Work Plan (2016 – 2019)

Table 3.0-2: Quarterly work plan for the period 2015 – 2019

Year/Quarter	2016		2017				2018				2019		
Activity (Milestone)	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Development of the proposal (Proposal approved)	▨	▨	▨	▨	▨								
Preparation for the baseline (Questionnaire developed and tested)		▨											
Implement baseline survey (Baseline data collected, entered and cleaned)		▨	▨										
Design and implement experiments (Treatments designed and implemented)			▨	▨	▨	▨							
Develop the first paper (Factors influencing uptake of pro-nutrition interventions in agriculture)						▨							
Develop a paper (Effect of farm diversity as a nutrition intervention on dietary diversity in rural households)							▨	▨					
Follow up survey (Follow up data collected, entered and cleaned)						▨	▨						
Data analysis (Factors influencing adoption of KK15 beans)								▨	▨	▨			
Data analysis (Association between farm diversification and diet diversification)								▨	▨	▨			
Compiling a thesis (PhD thesis submitted and defended)											▨	▨	
Graduate													▨

Questionnaire number (HHID) ___________________

QUESTIONNAIRE

HOUSEHOLD SURVEY 2016

AGRICULTURE AND DIETARY DIVERSITY IN AFRICA: AN APPLICATION OF RANDOMISED CONTROLLED TRIALS IN KISII AND NYAMIRA, KENYA.

Goettingen University-Germany and University of Nairobi-Kenya are, carrying out a research on different aspects of agricultural development. We are currently doing a survey which aims to provide more understanding about farmers' production and marketing decisions, and nutrition and health status. Your participation in answering these questions is very much appreciated. Your responses will be **COMPLETELY CONFIDENTIAL** and will only be used for research purpose. If you indicate your voluntary consent by participating in this interview, may we begi

Household ID: _________ code __________
Survey Date: (dd/mm/yyyy) __ __/____/ 2017
HH head Name (Full name) (HNAME) _______________________

Cell phone number (CELLNO) _________________________

MODULE 1: HOUSEHOLD DEMOGRAPHIC INFORMATION *(reference period between 1st Oct 2016 and 30th Sep 2017).*

1.1 Household composition details*: Please list all household members (All those who are under the care of household head in terms of food and shelter provision, those who normally live and eat their meals together), starting with the household head*

1. MEMID	2 Name of the HH member	3 Gender *M = 1; F= 0*	4 Relationship to HH head (*Use codes A below)*	5 Age in years	6 **Years** of formal education (*Highest level attained*)	7 Marital Status *(Use codes B below)*	8 # of Months in the last 12 months this person was away from home?	9 Main Occupation based on time spent *(Use codes C below)*	10 Number of months in the last 12 months have you been in this occ.?	12 Years of farming experience	13 Household farm labour contribution *Codes D*	14 Does this person own a cell phone? *1=YES; 0=NO*
1												
2												

Questionnaire number (HHID) ____________________

MODULE 2: CROPS GROWN

Plot code (number starting from plot nearest to house**)**	Plot size (Acres)	Crop grown *(Code C)*	Crop variety *(Code D)*	Crop Output	
				Qty	Units *(Codes E)*
Short Rains					
Long Rains					

Questionnaire number (HHID) ____________________

MODULE 2: VARIETY/BREED AWARENESS AND UP-TAKE

New breed/variety/technologies	Have you ever heard of this variety/breed? *(1=Yes; 0=No) If No skip*	Year you **first** knew or heard of the variety/breed?	Main sources of information on the new variety/breed? **Codes A**			Is this variety /breed 0. Local 1. Improved	Have you ever planted /kept this variety/breed?	If No, Why? **Codes C** *Rank 3 and skip to 12*			If Yes to Q5, which year did you **first** plant/keep the	What was the **main** source of breed kept/variety planted that year? **Codes B**	Number of seasons variety has been planted/breed kept	Did you plant this variety/keep breed in 2015?	What is the most desirable attribute of the variety/breed? **Codes D** *Rank 3*			Will you plant the variety/ keep the breed in future?	If No to Q12, why? **Codes C** *Rank 3*			Are you aware of the nutritional value of this variety or breed?	If yes to 14 what was the source of information? Code A
	1	**2**	**3**			**4**	**5**	**6**			**7**	**8**	**9**	**10**	**11**			**12**	**13**			**14**	**15**
Technology 1 (e.g. OFSP)																							
Technology 2 (e.g. Butternut)																							
Technology 2 (e.g. Kroiler chicken)																							

Code A	Code B	Code C	Code D
1= Farmer Coop/Union 2= Farmer group 3=Extension staff/office 4= Other farmers (neighbours/relative) 5= Market (e.g. Agro vet/stockist) 6=Radio programs 7=Research centre (trials/demos) (*name* _____ 7= NGO/CBO *(name ______* *8= Health centre/Practitioner* 9= Other*(specify ______)*	1= NGO free *(name ________)* 2= NGO subsidy *(sp_________)* 3= Extension staff demo plots 4= Other farmers 5= Market (Agrovet/local trader/stockist) 6=Farmer group/coop 7=Agricultural association/training centre 8= Other*(specify* ___________	1= Seed not available 2=Day old chicks not available 3=Lacked cash to buy seed/DOCs 4= Lacked credit to buy seed/DOCs 5= Prefer other varieties/breeds 6=Susceptible to diseases/pests 7=Poor taste 8=Low yielding/lays fewer eggs 9=Late maturing /longer maturity period 10=Low market prices/demand 11=High input requirements 12=Limited land to experiment/plant 13= Other*(specify _______)*	1=Preferred taste 2=High yielding 3=Resistant to diseases/pests 4=Has large grain 5=Lays more eggs 6=Early maturing 7=Fetches high market prices/has high demand 8=Right dry matter content 9=Other specify 9=low input requirements 10=Seed available 11=DOCs readily 12=Seed affordable 13=DOCs affordable 14=Nutritious 15= Requires less land 16= Other*(specify* _______

10.1 MODULE 3: LIVESTOCK PRODUCTION AND MARKETING

10.2 For the last **12 months *(01. Oct 2014 to 30. Sep 2015*)**, please give details of revenue and cost of livestock production?

(Please include all animals on the farm last year also those that were later sold or died) If no livestock is owned skip to next module.

Animal	Number owned in Oct 2014	Number of births and purchases	Number lost/died	Number consumed	Number sold	Number owned in Sept 2015	Average price of sale	Total revenue (Ksh)	Who decides sale? *MEM-ID)*	Who decides revenue use? *MEM-ID)*	Total Cost of Production (Ksh)			
											Fodder/ feeds	Labour *(hired labour)*	Veterinary care	Other costs, specify
Dairy cow												▨		
Other cow												▨		
Bulls												▨		
Trained												▨		
Heifer												▨		
Calves												▨		
Immature												▨		
Goat												▨		
Sheep												▨		
Chicken												▨		
Donkeys												▨		
Pigs												▨		
Rabbits												▨		

10.3 For the last **12 months *(01. Oct 2014 to 30. Sep 2015*)**, please give details of production and revenue of the following livestock products?

Animal product/services	Quantity produced		Quantity sold		Price per unit	Estimated sales value	Estimate cost of market access	Who decides sale? *(MEMID)*	Who decides revenue use? MEMID)
	Qty	Unit *(Code)*[a]	Qty	Unit *(Code A)*					
Milk									
Eggs									
Manure									
Honey									
Hide									
Others specify_________									

Code A: *UNIT CODE (1=litres, 2=millilitres, 3=Units/numbers, 4=Tray, 5=Kilogram, 6=50 kg bag , 7=90 kg bag, 8= Wheelbarrow, 9=Other (specify)________)*

MODULE 4: OTHER SOURCES OF INCOME AND TRANSFER

	Code	**Type of income received**	Did you or any household member earn income from This during last 12 monthsr? *(No=0, Yes=1)*	Number of units (days, weeks, …) worked per year	Average net income per unit		Total **net** income earned (Ksh)
					Cash (Ksh)	Payment in kind – cash equivalent (Ksh)	
Labour	1	Agricultural labour (*casual + permanent*)					
	2	Casual labour (*non-agricultural*)					
	3	Salary (*Permanent non-agricultural employment*)					
	4	Pension					
Transfers	5	Food aid					
	6	Remittances					
	7	Gifts e.g dowry					
Rent	8	Rent					
Small Business	9	Brick making					
	10	Carpentry					
	11	Construction					
	12	Grain mill					

	13	Other:					
Petty trade	14	Handicrafts					
	15	Food					
	16	Beverage, local brew					
	17	Sales in shop, petty trade and					
	18	Transport					
	19	Dividends (T-bills, bonds, shares)					
Sales of forest products Trade	20	Sale of wood and charcoal,					
	21	Sale of wild nuts/fruits					
Other agric income	22	Tea coffee bonuses					
	23	Sale of crop residues					
	24	Leasing out land					
	25	Renting out oxen for ploughing					

Module 18- Household Food Consumption

(Target Person: Women responsible for food preparation/decisions)

(Enumerators: Please ask the following questions to the person who is mainly responsible for preparing the food for the last 7 days in the household)

Code A

1	**Litre**	**5**	**5 kg bag**	**9**	**Debe**	**13**	**¼ kg tin**	**17**	**Cup (15)**
2	**Millilitre**	**6**	**25 kg bag**	**10**	**Bunch (Bananas)**	**14**	**½ kg tin**	**18**	**Others Specify**
3	**KGS**	**7**	**50 kg bag**	**11**	**Piece/Number**	**15**	**1 kg tin**		
4	**Grams**	**8**	**90 kg bag**	**12**	**Gorogoro**	**16**	**Bundles**		

	Food Items consumed in the past 7 DAYS	**How much in total did your household consume during the last 1 week?**	**Unit of quantities consumed** *(Use codes above A)*	**Source** *1= Own production 2=Purchased 3=Gift 4=Other, specify*	**Price per unit Ksh..**		**Food Items consumed in the past 7 DAYS**	**How much in total did your household consume during the last 1 week?**	**Unit of quantities consumed** ***(Use codes below)***	**Source** *1= Own production 2=Purchased 3=Gift 4=Other, specify*	**Price per unit Ksh..**
	Staple foods					25	Cooking banana				
1	Cassava Tuber						**Other staple foods**				
2	Cassava flour					26					
3	Cassava chips					27					
4	Yam Tuber					28					
5	Yam flour						**Vegetables**				
6	Yam chips					29	Okra				
7	Orange fleshed sweet potato					30	Tomato				
8	Other sweet potato					31	Pepper				
9	Sweet potato chips					32	Onion				
10	Irish potato					33	Carrot				
11	Irish potato chips					34	Eggplant (biringanya)				

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12	Arrowroots					35	Cabbage				
13	Maize green					38	Cucumber				
14	Maize grain					39	Pumpkin				
15	Maize flour					40	Butternut				
16	Sorghum grain					41	Spinach				
17	Sorghum Flour					42	Kales (Sukuma wiki)				
18	Millet grain					43	Amaranth leaves (terere) (Terere/Mchicha/ Dodo)				
19	Millet flour					44	Pumpkin leaves				
20	Brown rice					45	Sweet potato leaves				
21	White rice					46	Black night shade (managu/ Osuga)				
22	Wheat grain					47	Cow pea leaves (Kunde/Thoroko)				
23	Wheat flour					48	Stinging nettle				

Module 18- Household Food Consumption
(Target Person: Women responsible for food preparation/decisions)
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	brown						(thabai)				
24	Wheat flour white										
	Other vegetables (specify)					67	Ripe pawpaw				
49						68	Pineapple				
50						69	Apple				
51						70	Coconut				
	Nuts and Pulses					71	Guava				
52	Beans dry					72	Ripe bananas				
53	Beans fresh					73	Melon				
54	Black beans (Njahi)					74	Sugar cane				
55	Green grams (Ndengu)					75	Avocado				
56	Soybean						**Other fruits**				
57	Peas (incl					76					

Module 18- Household Food Consumption

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	cowpea, pigeon peas, green peas-minji)										
58	Lentils					77					
59	Groundnut					78					
60	Cashew nut (korosho)						**Meat and animal Products**				
61	Soya meat (e.g. Sossi)					79	Cow meat				
62	Soybean flour					80	Goat/ Sheep meat				
	Other pulses and nuts					81	Pork				
63						82	Chicken				
64						83	Bush meat (Game meat)				
	Fruits					84	Turkey (bata mzinga)				
65	Orange					85	Fish				
66	Ripe mango					86	Snail				

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						87	Crabs				
88	Chicken sausage						**Beverages**				
89	Beef sausage					107	Cocoa powder				
90	Pork Sausage					108	Tea (leaves)				
91	Eggs (pieces) with yolk					109	Coffee (powder)				
92	Eggs without yolk					110	Milo powder				
93	Liver (from any animal)					111	Soya powder				
94	Offal's (matumbo)					112	Drinking chocolate				
	Other meats						**Other beverages**				
95						113					
97							**Drinks**				
98						115	Soft drinks (coke/fanta/etc)				
	Dairy					116	Orange juice				

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	products										
99	Milk (cow/goat milk)					117	Apple juice				
100	Powdered milk					118	Pineapple juice				
101	Sour milk (mala)					119	Other juice (concentrates)				