Tef technology Adoption, Extension, Innovation System, and Food Security in Central Ethiopia: The Case of Selected *Tef* Growing Areas

Mekonnen Hailu

A Dissertation Submitted To the Center for Food Security Studies, College of Development Studies

Presented in Fulfillment of the Requirement for the Degree of Doctor of Philosophy in Development Studies (Food Security and Development)

Addis Ababa University
Addis Ababa, Ethiopia
June, 2021

Addis Ababa University

College of Development Studies

Center for Food Security Studies

Tef technology Adoption, Extension, Innovation System, and Food Security in Central Ethiopia: The Case of Selected *Tef* Growing Areas

Mekonnen Hailu

A Dissertation Submitted To the Center for Food Security Studies, College of Development Studies

Presented in Fulfillment of the Requirement for the Degree of Doctor of Philosophy in Development Studies (Food Security and Development)

Supervisors: Degefa Tolossa (Prof)

Belay Kassa (Prof)

Anteneh Girma (PhD)

Addis Ababa University

Addis Ababa, Ethiopia

June, 2021

Declaration

By my signature below, I declare that this dissertation is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation, have been fully recognized.

Name: Mekonnen Hailu

Signature: ________________

Date: ________________

Place: ________________

DISSERTATION APPROVAL

This is to certify that the dissertation prepared by Mekonnen Hailu entitled ***Tef* technology Adoption, Extension, Innovation System, and Food Security in Central Ethiopia: The Case of Selected *Tef* Growing Areas** and submitted in fulfillments for the requirements for the Degree of Doctor of Philosophy (Food Security and Development) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee

______________________	______________	______________
Chairperson, Examining Committee	Signature	Date
______________________	______________	______________
External Examiner	Signature	Date
______________________	______________	______________
Internal Examiner	Signature	Date
Degefa Tolossa (Prof.)	______________	______________
Supervisor	Signature	Date
Belay Kassa (Prof.)	______________	______________
Supervisor	Signature	Date
Anteneh Girma (PhD)	______________	______________
Supervisor	Signature	Date

Abstract

Tef is a hugely important crop in Ethiopia in terms of both production and consumption. Demand for *tef* has risen and is expected to continue to rise due to population growth, average incomes, and urbanization. However, the *tef* production system is at a rudimentary stage and largely relies on traditional methods. As a result, the crop yield has not reached at the desired level to achieve household food security. Therefore, this study investigated the *tef* technology adoption, extension, innovation systems and household food security in Central Ethiopia. Given the multidisciplinary existence and various research units ranging from national to the individual level, different data collection and analysis methods were employed. A pragmatist approach was used that incorporated both quantitative and qualitative methods with multiple techniques for data collection and analysis. Additionally, secondary data were carefully reviewed and employed to supplement the firsthand data. Descriptive statistics and inferential statistics such as one-way ANOVA, t-test, and Chi-square tests were used to analyze quantitative data. Moreover, econometric models such as endogenous switching regression model (ESR), multivariate probit model (MVP), ordered probit model, Tobit model, and binary logistic regression model were employed. The Household Food Balance Model (HFBM) and other food security measurement techniques such as household dietary energy supply (DES), dietary diversity score (HDDS), and food consumption score (FCS) were used.

Results revealed that the *tef* innovation system is not well-developed to support the livelihoods of smallholders due to systemic constraints in the innovation system. Limited capacity of existing actors, weak interactions among actors, weak enforcement of institutions, and inadequate infrastructure are the structural elements that have constrained the development of *tef* innovation system. The weaknesses in the innovation system have limited the development of innovation functions such as technology development, technology diffusion, entrepreneurship, market formation, resource mobilization, and legitimacy creation. Results further show that performance of the extension service delivery was significantly affected by weak enforcement of performance targets, limited interactions among actors, lack of rewards and sanctions, weak supervision and politically biased evaluation, limited involvement of DAs and other key actors in planning, evaluation, and decision-making process, weak technical competence and work motivation of DAs, lack of adequate facilities for Farmers Training Centers (FTCs), and lack of motorbikes.

Results also indicate that improved *tef* technologies have the greatest impact on household food security when adopted in combinations rather than in isolation. Although combination of improved *tef* technologies has the greatest effect on household food security, the adoption rate was found to be low due to various determinants. The study identified education, household size, livestock holding, cooperative membership, credit, extension contacts, farmers' confidence with the skills of DAs, perception on economic return, and perception on participation in the extension service provision positively and significantly influence the adoption of a combination of improved technologies. While distance to the nearby extension office and distance to the output market has a negative and significant effect on the adoption of a combination of technologies. The study, furthermore, found that the number of improved technologies adopted is positively associated with education, livestock ownership, farm size, cooperatives membership, credit, extension contacts, training, farmers' confidence with the skills of DAs, farmers' perception on economic return, farmers' perception on participation in the extension service delivery. It is inversely related to distance to nearby extension offices and distance to market.

It is concluded that the *tef* production system was not transformed for developing the *tef* sub-sector. Transforming smallholders' production system without addressing the systemic barriers of the *tef* R&D and the factors impeding performance of the extension system inhibits innovation. This situation calls for urgent institutional innovation in research, extension, NGOs, and other private actors. Therefore, a combination of technological, institutional, and technical intervention would be paramount to tackle the systemic constraints that impeded the development of the *tef* sub-sector. Besides, policymakers should be committed to the active participation of other non-state actors through policy support to make research, extension, and innovation processes viable and well-functioning and to have more interaction and work in a coordinated manner. Moreover, actors should have typically promoted the adoption of a combination of technologies through designing possible interventions for those factors that impede the use of a combination of improved technologies.

Keywords: Adoption, agricultural technology, food security, innovation, tef

Acknowledgements

In the course of my study, I owe my unique gratitude and appreciation to many people and organizations from which I have received various types of assistance. I am pleased to take advantage of this opportunity to express my gratitude to them. First and foremost, I would like to express my sincere gratitude and appreciation to my supervisors, Professor Degefa Tolossa, Professor Belay Kassa, and Dr. Anteneh Girma, for their valuable guidance and advice from the proposal stage with the supervision concerned, during all phases of the study. They have put full effort into directing me during this research as supervisors of this work. From the initial design and development of the project proposal, they have been instrumental. I have gained immensely from their comments and suggestions on methods and tools for fieldwork.

I thank the Ethiopian Institute of Agricultural Research (EIAR), the Agricultural Growth Project (AGP) and Addis Ababa University for providing me with financial support to carry out this research. For their kindness, hospitality, and taking their time out to answer my many questions, I would like to thank all the people of Minjar Shenkora and Ada'a Woredas. Desalegn Wakeyo, Aklili Gebeyehu, Addis Azene, Tesfaye Teferi, and Abebe Ararsa are also indebted to me for their assistance in collecting data. I am also grateful to the administration offices of Minjar Shenkora and Ada'a Woredas for facilitating administrative ties with farmers for data collection and further support. I also acknowledge Tadele Mamo's support for the implementation of the questionnaire and the organization of the CAPI field survey.

Throughout my studies, the motivation and guidance from my family has always been with me. Tensaye Abate, my beloved wife, is a wonderful partner who always inspires me and enthusiastically follows up on the success of my work. I also very much appreciate the patience and affection of our daughters, Aklesiya Mekonnen, Liya Mekonnen, and Melose Mekonnen. I would like to thank Dr. Solomon Hailu, my brother, and Dr. Sintayehu Kassaye, for reading the dissertation chapters and offering suggestions for improvement. It was truly unforgettable to have the inspiration and moral support of my family and friends.

Dedication

This thesis foremost dedicated to smallholder *tef* producers in Central Ethiopia who struggle to survive with traditional and backward farming practices

Table of contents

List of Figures

List of Tables

List of Acronyms

ADE	Adult Equivalent
ADLI	Agricultural Development Led Industrialization
ADPLAC	Agricultural Development Partners’ Linkage Advisory Council
AEOs	Agriculture Extension Organizations
AGP	Agricultural Growth Project
AIS	Agricultural Innovation System
AKIS	Agricultural knowledge and information systems
ANOVA	Analysis of Variance
ARDU	Arsi Rural Development Unit
ATA	Agricultural Transformation Agency
ATE	Average Treatment Effect
ATT	Average Treatment on the Treated
ATU	Average Treatment on the Untreated
ATVET	Agricultural Technical and Vocational Education and Training
AU	African Union
AWAO	Ada’a Woreda Agriculture Office
BoA	Bureau of Agricultural
CAPI	Computer Assisted Personal Interview
CGIAR	Centers of Consultative Group on International Agricultural Research
CPP	Comprehensive Package Program
CSA	Central Statistics Agency
DAs	Development Agents
DES	Dietary Energy Supply
DIT	Diffusion of Innovations Theory
EARC	Ethiopian Agricultural Research Council
EARO	Ethiopian Agricultural Research Organization
ETB	Ethiopian Birr
EDRI	Ethiopian Development Research Institute
EEA	Ethiopian Economic Commission
EHNRI	Ethiopian Health and Nutrition Research Institute

EIAR	Ethiopian Institute of Agricultural Research
EIC	Ethiopian Investment Commission
EPRDF	Ethiopian People's Revolutionary Democratic Front
ESR	Endogenous Switching Regression
FAO	Food and Agricultural Organization of the United Nations
FCS	Food Consumption Score
FTCs	Farmers Training Centers
GDP	Gross Domestic Product
GFSI	Global Food Security Index
GoE	Government of Ethiopia
GTP	Growth and Transformation Plan
HDDS	Household Dietary Diversity Score
HDI	Human Development Index
HFBM	Household Food Balance Model
HLIs	Higher Learning Institutions
IAR	Institute of Agricultural Research
IAEA	International Atomic Energy Agency
ICT	Information Communication Technology
IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
Kcal	Kilo Calorie
Kgs	Kilograms
MoA	Ministry of Agriculture
MoANR	Ministry of Agriculture and Natural Resources
MoARD	Ministry of Agriculture and Rural Development
MoF	Ministry of Finance
MoFED	Ministry of Finance and Economic Development
MoT	Ministry of Trade
MPP	Minimum Package Programs
MSWAO	Minjar Shenkora Woreda Agriculture Office
MVP	Multivariate Probit Model

NAF	Net Available Food
NARS	National Agricultural Research System
NBE	National Bank of Ethiopia
NGOs	Nongovernmental Organizations
NPC	National Plan Commission
PADETES	Participatory Demonstration and Training Extension Systems
R&D	Research and Development
RARIs	Regional Agricultural Research Institutions
SG-2000	SaSakawa Global 2000
TAM	Technology Acceptance Model
TLU	Tropical Livestock Unit
TPB	Theory of Planned Behavior
TRA	Theory of Reasonable Action
TTF	Theory of Task-technology Fit
UNDP	United Nations Development Program
USD	United States of America Dollar
USAID	United States Agency for International Development
WFP	World Food Program

List of published and unpublished papers

This dissertation is comprised of the following research papers:

Paper I. Under review as Mekonnen Hailu, Degefa Tolossa, Anteneh Girma, & Belay Kassa (2020). Exploration of systemic constraints to *Tef* sector development in Central Ethiopia: A structural–functional innovation systems analysis. *Journal of Innovation and Knowledge*

Paper II. Published as Mekonnen Hailu, Degefa Tolossa, Belay Kassa & Anteneh Girma (2020). Understanding factors affecting the performance of agricultural extension system in Ethiopia. *Ethiopian Journal of Agricultural Science, 30*(4), 237-263.

Paper III. Published as Mekonnen Hailu, Degefa Tolossa, Anteneh Girma, & Belay Kassa (2020). The impact of agricultural technologies adoption on household food security of smallholders in Ethiopia: An endogenous switching estimation. *World Food Policy*

Paper IV. Under review as Mekonnen Hailu, Degefa Tolossa, Anteneh Girma & Belay Kassa (2020). Determinants of multiple agricultural technologies adoption in smallholders' agriculture: Micro evidence from major *tef* growing areas of Ethiopia. *Outlook on Agriculture*

1. INTRODUCTION

"Economic growth originating in Agriculture can have a particularly strong impact in reducing poverty and food insecurity" (FAO)

1.1 Background

The world's greatest challenge is to secure physical, social, and economic access to sufficient, safe, and nutritious food for all people at all times for an active and healthy life, in an environmentally sustainable manner (Burchi et al., 2011; FAO, 1996). Great strides have been made in the reduction of poverty and food insecurity. Despite global efforts, overall food insecurity has been steadily rising, owing primarily to a rise in moderate food insecurity. Nearly 750 million people are currently facing severe food insecurity, and more than 1.25 billion people have faced moderate food insecurity. Hence, about two billion people, or 26% of the global population, experienced hunger or did not have regular access to nutritious and sufficient food (FAO, IFAD, UNICEF, WFP and WHO, 2020). Thus, the world is not on track to achieve Zero Hunger by 2030 and contradicts the International Declaration of Human Rights (1948), which states that "every person has a right to adequate food" (Maxwell and Smith, 1992).

The vast majority of people who are food insecure live in developing countries such as Asia (51.5%), Africa (33.8%), and Latin America and the Caribbean (10.3%) (FAO, IFAD, UNICEF, WFP and WHO, 2020). Sub-Saharan Africa is one of the main regions where severe food insecurity is on the rise, as well as the region with the highest food insecurity rate. This region, according to van Ittersum et al. (2016), is the most vulnerable to food insecurity due to low agricultural productivity, rapid population growth, and its current dependence on cereal imports. Ethiopia is one of the many countries in Sub-Saharan Africa that have suffered from long-term food shortages and famine over the years. Poverty and food insecurity are still major issues in the country (Dube et al., 2019). About 25% of individuals, this directly translates into 26 million people estimated to be food insecure (CSA and WFP, 2019). More than 20 million Ethiopians now depend on long-term welfare transfer programs (Getachew, 2018). According to the Global Food Security Index 2020 report, Ethiopia ranked 108 out of 113 countries; it was 91 last year (GFSI, 2020).

Agriculture is the primary source of livelihood for the large majority of people live in rural areas of Ethiopia. It provides a living for around 17.7 million Ethiopian smallholders (CSA, 2020). Despite the share of agriculture to the total GDP declining to 32.7% in recent years, its GDP contribution has increased from 499.8 billion ETB in 2013/14 to 650.3 billion ETB in 2019/20 (MoA, 2020; NBE, 2019/20). The sector also provides 72.7 % of employment opportunities, 90% of export earnings, and 90% of raw materials for manufacturing industries (CSA and WFP, 2019). Hence, agriculture has played and continues to play a fundamental role in the government's policy and development strategies. It is unlikely, even unrealistic; to assume that there could be successful development of industrial and service sectors without effective interactions and transformation of the agriculture sector (Getachew, 2018). Therefore, the overall economic growth of the country and the fight against poverty would depend on the gains or losses of the agricultural sector. Although Ethiopia has made considerable progress in agriculture, the sector has been unable to achieve the desired change, as poverty and food insecurity remain major problems facing the country (Dube et al., 2019). Given the high prevalence of rural poverty and the large productivity gap, increasing the productivity of smallholders is Ethiopia's top priority (Demese et al., 2010). Hence, agricultural development is an essential tool for increasing productivity and, eventually, for food security (Mulubrhan et al., 2017; Usman et al., 2017; Fuglie, 2016; Avila and Evenson, 2010; Habtemariam, 2008).

By increasing productivity through the generation of technologies and increasing technological diffusion, agricultural research and extension systems play a key role in agricultural development and total factor productivity (NPC, 2016; Maiangwa, 2010). The effectiveness of the agricultural research and extension system is thus measured by the progress and achievements made in the development of agriculture (Fentahun, 2015). Agricultural development, however, needs and depends on innovation and innovation systems (Juma, 2009). It is an important component of the success of agricultural development (Anandajayasekeram et al., 2009). Innovation system has gained so much attention because it is expected that greater consideration of the innovation system would increase the positive impacts of agricultural development and subsequently improve the livelihoods of those who depend entirely on agriculture. It is generally acknowledged as a significant source of increased productivity and economic growth, as well as a significant contributor to income generation, poverty alleviation, and social development

(Rapela, 2019). Agriculture innovation is typically the result of a dynamic interaction between multiple actors involved in the technology development, diffusion, processing, packaging, distribution, and consumption of agricultural products (Rao et al., 2017; World Bank, 2011). Instead of being passive recipients of technology developed elsewhere, all actors in an innovation system have a stake in their development and diffusion (Musiolik, 2012; Klerkx et al., 2010). The Agricultural Development Led Industrialization (ADLI) strategy favored innovations to transform agriculture, despite several factors restricted the innovation system in Ethiopia.

In the agricultural economy of Ethiopia, *tef* is an important staple crop. *Tef [Eragrostis tef* (Zucc.) Trotter] is a cereal crop endemic to Ethiopia that belongs to the grass family and widely cultivated in the country for centuries (Yiferu and Hailu, 2005). *Tef* is a hugely important crop in terms of both production and consumption (Minten et al., 2016; Bekabil et al., 2011; Vandercasteelen et al., 2013). During the 2019/20 farming season, more than 7.1 million farmers allocated 24.1% of the national grain area to *tef*. *Tef* ranked first in terms of area coverage and is second to maize in terms of volume of production among cereals, accounting for 17.1% of the total production in the category (CSA, 2020). It is the country's most staple food with excellent nutritional value (high protein and fiber content, complex carbohydrates, and gluten-free) (Vandercasteelen et al., 2013, 2016). Besides, it accounts for about 15% of all calories consumed and provides about 66% of daily protein intake in Ethiopia (Crymes, 2015; ATA, 2013; Guush et al., 2011; Bekabil et al., 2011). *Tef* has gained popularity as wellness and healthy food on the global market in recent years. Since the grains are gluten-free, they are suitable as a food for people who suffer from celiac disease, a type of gluten protein allergy (Cafer and Rikoon, 2017; Spaenij-Dekking et al., 2005). In reality, it is superior in many minerals, including high iron, calcium, magnesium, and zinc content. Hence, per capita consumption has risen and is expected to continue to grow due to increases in average incomes, population growth, and urbanization (Lee, 2018; ATA, 2013). *Tef* has remained an important crop for Ethiopian farmers: the straw used as a nutritious feed for cattle, the price is higher than other cereals, no disease epidemic has threatened its performance, and grain can be stored for a long time without being attacked by weevils (Melaku, 2020; Seyfu, 1989).

Tef can be grown under diverse agro-ecological conditions in almost all regions of Ethiopia (Yazachew, 2020; Vandercasteelen et al., 2013). However, Amhara and Oromia are the two major *tef* producing regions, and collectively the two regions account for 87.1% of the total *tef* production and 85.3% of the *tef* cultivated area (CSA, 2020). Minjar Shenkora and Ada'a *woredas* are the two major producing areas for *tef* production in Amhara and Oromia Regional States, respectively. The two regions have better experiences in using improved technologies including improved *tef* variety, row planting practice, and chemical fertilizer. *Tef* is one of the selected crops since the country adopted the Participatory Demonstration and Training Extension Systems (PADETES) to promote the technological packages of improved technologies including *tef* (Misigana, 2018; Belay, 2003).

1.2 Statement of the problem

Transforming a country's agriculture sector can help to alleviate poverty and improve food security, as well as increase incomes, create jobs, and jump-start the economy (Boettiger et al., 2019; Otchia, 2014). Through the generation of improved technologies and technological diffusion, agricultural research, extension, and innovation systems is at the heart of agricultural transformation. They are key movers in the economic transformation. Today's investments in research, extension, and innovations will be helpful for future agricultural transformation and will have a positive effect on productivity as a result of technological change (Pardey et al., 2013). Over the last five decades, the *tef* research and extension systems, and other development actors have worked a lot to improve smallholders' *tef* production system in particular and transform the agriculture sector in general. The national *tef* research program has been released more than 44 improved varieties along with production packages (MoA, 2019). As a result, the average yield of *tef* has been significantly increased from 8 qt/ha in 2000/01 to 18.5 qt/ha in 2019/20 (CSA, 2019). Moreover, the land covered by the *tef* extension package has been increased from 7% in 2002 to 35.5% in 2017/18 (CSA, 2018). Efforts also made in the last half-century to implement different agro-techniques and tools in order to improve the *tef* production system. Important changes have also occurred in the *tef* innovation systems and value chain both at the production level and on the consumption side. Besides, demands are on the rise among *tef* consumers, and the *tef* marketing system is becoming more efficient (Minten et al., 2018).

Despite the fact that changes are happening, the transformation of the *tef* production system is still in its infancy (Minten et al., 2018; Reardon and Timmer, 2007). Moreover, the *tef* production system is at a rudimentary stage and largely relies on traditional methods (Lee, 2018; Minten et al., 2016; FAO, 2015). This problem can be explained by the fact that efforts in changing the *tef* production system is influenced by many constraints that need to be addressed to facilitate further transformation of the *tef* production system. According to Bekabil et al. (2011), pre-and post-harvest losses, inefficient agronomic practices, the low adoption rate, fragmentation of the value chains, and limited value addition are the major factors influencing smallholders' *tef* production system. For example, the *tef* losses are estimated at 25-30% both before and after harvest and reduce the quantity of grain by up to 50%. In addition, agricultural mechanization is almost absent, and post-harvest loss is substantial (Minten et al., 2016; FAO, 2015). Lack of mechanization for row planting, harvesting, and threshing are the major constraints to transform smallholders' production system and increase productivity. The traditional sowing method has been used at a rate of 25–50 kg per hectare (ATA, 2013) and this practice reduces yields because of the uneven distribution of the seeds, higher competition between plants for inputs, and difficult weeding once the plants have matured (Bekabil et al., 2011). Farmers are more likely to use machines during land preparation but less likely during harvesting and threshing (Guush et al., 2016). According to this study, mechanized threshing was reported by only 3% and harvesting by 2% of *tef* producers.

Furthermore, although the adoption of improved *tef* technologies has been improved, the rate of adoption of improved *tef* varieties is low and limited to only a few varieties (Yazachew et al., 2020; Minten et al., 2018; Dejene and Bekele, 2015; Debelo, 2015; Negera and Getachew, 2014; Kebebew et al., 2013). Studies conducted by Minten et al. (2018) and Yang et al. (2013) show that the quantities of chemical fertilizers that are being used are below the recommended levels, and mechanization, which is quickly happening in other emerging economies, is mostly absent. As a result, the level of productivity has not reached at the desired level and its maximum potential. Yet, through scientific research, the productivity of the crop can be improved by addressing its predicaments for higher yield and stability. According to the National *Tef* Strategy document (2000-2015), at the experimental plot level with the appropriate package, *tef* yields up to 34 qt/ha in the presence of lodging that reduces yield by 17-25%. Research conducted under non-lodging conditions has shown that up to 46 qt/ha of yield can be further increased. In addition, a record of 50 qt/ha has also been noted in some research plots. We can witness that a good level of productivity of other major cereals such as maize, wheat, sorghum, etc., despite the crop nature (Kebebew et al., 2013). For example, the productivity of maize is 42.4 qt/ha, wheat 29.7 qt/ha, and sorghum 28.8 qt/ha (CSA, 2020). In addition, the *tef* innovation system and value addition are not well-developed to support smallholder farmers' livelihoods and have not reached their full potential (Lee, 2018; Bekabil et al., 2011).

Several studies on *tef* R&D, extension, technology adoption, and innovation systems have been undertaken in Ethiopia. A large number of these studies have looked at the factors that influence the adoption of improved *tef* technologies and innovations (Deresse and Teklu, 2019; Etsehiwot, 2018; Efa et al., 2016; Dejene and Bekele, 2015; Debelo, 2015; Negera and Getachew, 2014; Kebebew et al., 2013; Vandercasteelen et al., 2013). Moreover, a study by Gerba (2018); Gerba et al. (2017); Faure et al. (2016); Ragasa et al. (2016) and Birner et al. (2009) assessed the agricultural extension system in Ethiopia and elsewhere. There are also empirical analysis of the performance of development agents (DAs) and analyzed factor affecting the performance of DAs (Yaghoubi-Farani et al., 2015; Ifenkwe, 2012). Numerous studies have also analyzed the *tef* marketing and value addition analysis by identifying systemic constraints along the value chains and possible interventions (Tariku, 2021; ATA, MoA and EIAR, 2013). Besides, studies have been conducted to analyze the impact of *tef* technologies, extension and advisory services, and innovation systems (Ragassa et al., 2016; Vandercasteelen et al., 2013; Okoboi, 2013).

However, the current study differs from the previous studies in the following ways. First, the challenges of the *tef* production system under consideration differ as this study focuses on the R&D, the extension system, and the innovation systems together in a single study. Most previous studies on the *tef* R&D, extension and innovation systems have been undertaken separately. Thus, it is important for designing a combination of possible interventions to address the challenges together. Second, most previous adoption studies have focused on the analysis of a single technology (Mengistu, 2015; Debelo, 2015; Negera and Getachew, 2014; Vandercasteelen et al., 2013). Improved technologies are frequently advised to be used in combination, and their full potential can only be achieved when they are combined with other complimentary inputs. To capture useful economic information included in simultaneous adoption decisions, modeling technology adoption and impact analysis in multiple technology choices is important (Dorfman, 1996). Third, the employed econometric models also widely differ. Most of the previous studies employed the propensity score matching, multinomial logit model, uni- and bivariate probit model (see, for instance, Deresse and Teklu, 2019; Efa et al., 2016; Hailu, 2008). Little is known about the econometric models such as endogenous switching regression models (ESR). Fourth, the combination of technologies under consideration differs as this research focuses on *tef* seed, chemical fertilizer, and row planting. These technologies are properly selected because farmers in the study areas have adopted and considered to be adopted.

Therefore, the current study will shed some light by addressing the aforementioned gaps in the *tef* R&D, extension, and innovation systems. Why the *tef* R&D, extension, and innovation systems were unable to transform smallholders' *tef* production systems and increase productivity to produce sufficient agricultural food production for ensuring household food security? It's important to investigate the systemic constraints in the *tef* innovation systems, as well as the factors impeding the performance of the extension system that restricts the transformation of the *tef* production systems. The study also identified the factors that affect household decisions and the number of technologies adopted by smallholder farmers. Therefore, the general objective of this study is investigates the systemic constraints in the *tef* innovation system, assess the performance of the extension and advisory service delivery and factors explaining it and the determinants of improved *tef* technology adoption.

1.3 Objectives

The overall objective of the study was investigated the *tef* technology adoption, extension, innovation systems and food security in Central Ethiopia. Specifically, the study first aimed to explore the systemic constraints of the *tef* sector development through the innovation system approach, by taking the case study of Central Ethiopia (**Paper I**). Second, the study intended to assess the performance of agricultural extension system and advisory services and identify the factors explaining it (**Paper II**). The third specific objective of the study was to analyze the impact of a combination of improved *tef* technologies on household food security by considering smallholders' *tef* producers' (**Paper III**). The primary aim of the fourth study was to identify the determinants of a combination of technology adoption of *tef* technologies (**Paper IV**).

1.4 Research questions

This research answers the following research questions in the Ethiopian farming households' context:

1. What are the major systemic constraint in the *tef* innovation system that constrained the development of the *tef* sub-sector **(Paper I)**
2. What explains the low performance of Ethiopia's agricultural extension system and what possible options are there for improving such performance? **(Paper II)**
3. What are the impacts of multiple combinations of agricultural technologies' adoption on yield and household food security? **(Paper III)**
4. What are the determinants affecting adoption of multiple combinations of improved *tef* technologies? **(Paper IV)**

1.5 Context and the study areas setting

Agriculture is the most important economic sector in the country. Agriculture's contribution to the country's economic development spans a wide range of sectors. Ethiopia is Africa's second-most populous country and the world's most populous landlocked country, after Nigeria, which has a population of 97.6 million people (NBE, 2019/20). Poverty has long been a problem in the country, with many people still living in poverty (MoA, 2020). Agriculture remains the primary source of income for many households, especially those in rural areas (CSA, 2020). The vast majority of them; however, are smallholder farmers with less than one hectare of land. Ethiopia's agricultural potential is immense. For example, only about 12.86 million ha of Ethiopia's total potential cultivated land is currently cultivated, accounting for about 15% of the total arable area (CSA, 2020; NBE, 2019/20). Ethiopia is a country with a wide range of terrain, including varying climates, soils, natural vegetation, and settlement patterns.

The study is intended to look at why agricultural research and extension systems were unable to transform smallholders' *tef* production by unlocking the potential of innovation systems so as to produce sufficient agricultural food production for ensuring food security in Central Ethiopia by taking a case study of Minjar Shenkora and Ada'a *woredas* (Figure 1.1). One of the *woredas* in the North Shewa Zone of the Amhara Regional State of Ethiopia is Minjar Shenkora. The *woreda's* administrative center is Arerti and is located approximately 135 km south-east of Addis Ababa. It is bordered in the North by Hagere Maryam and Berehet *woredas*, in the South by Boset *woreda*, in the West by Gimbichu and Lome, and in the East by Fentale in the Region of Oromia. A total of 30 *kebeles*, 27 rural kebeles, and the remaining urban kebeles make up the *woreda*. The *woreda* extended astronomically between $8^0$42'46'' N and $9^0$7'37'' N latitudes and from $39^0$12'57'' E to $39^0$46'53'' E longitudes. It covers an area of 1,509.93 square kilometers. *Tef*, wheat, sorghum, and maize are among the cereal crops and chickpea, and lentil among pulses grown in the study area. The study area is composed of three agro-climatic zones; *Dega*, *Weina Dega*, *and Kolla*. According to MSWAO (2017), the *woreda* has the mean annual maximum temperature varies from 27 to 29^0c and the mean annual minimum temperature varies from 10 to 13^0c. Minjar Shenkora has the largest population size in the North Shewa zone of Amhara Regional State with a total population of 156,040, according to the CSA (2017) population estimate at the *woreda* level. In rural areas, 86% and 14% are urban residents.

Ada'a is one of the *woredas* in Oromia Regional State's East Shewa Zone. The administrative town of the *woreda* is Bishoftu, situated 45 km east of Addis Ababa. Ada'a is bordered by Dugda Bora to the south, Akaki to the northwest, Gimbichu to the northeast, and Lome to the east. Altitudes range from 1500 to over 2000 meters above sea level in this *woreda*. Ada'a is an area of mixed farming activity, crop production, and livestock production. The area has two cropping seasons: *belg* short rainy season extends from March to April and *meher* (main rainy season) from June to September. Crops grown in the *woreda* are *tef*, wheat, barley, maize sorghum, chickpea, horse bean, groundnut, root crops, and vegetables (AWAO, 2017). CSA (2017) population estimate at the *woreda* level, Ada'a *woreda* has a total population of 165,729.

The selected woredas are potential areas for *tef* production in the country. They are located very close to the agricultural research center of Debrezeit (DZARC). DZARC is the national center of excellence within the Ethiopian Institute of Agricultural Research (EIAR) for *tef* research. Therefore, the two possible areas are strongly anticipated to take advantage of enhanced technology packages as opposed to other areas. Despite these realities, a significant number of farming households still use low genetic potential and local seeds. Besides, the productivity level has not been achieved at the desired level due to various constraints in the research and extension. This enables the major constraints and factors that hinder the performance of the R&D and extension systems to be investigated.

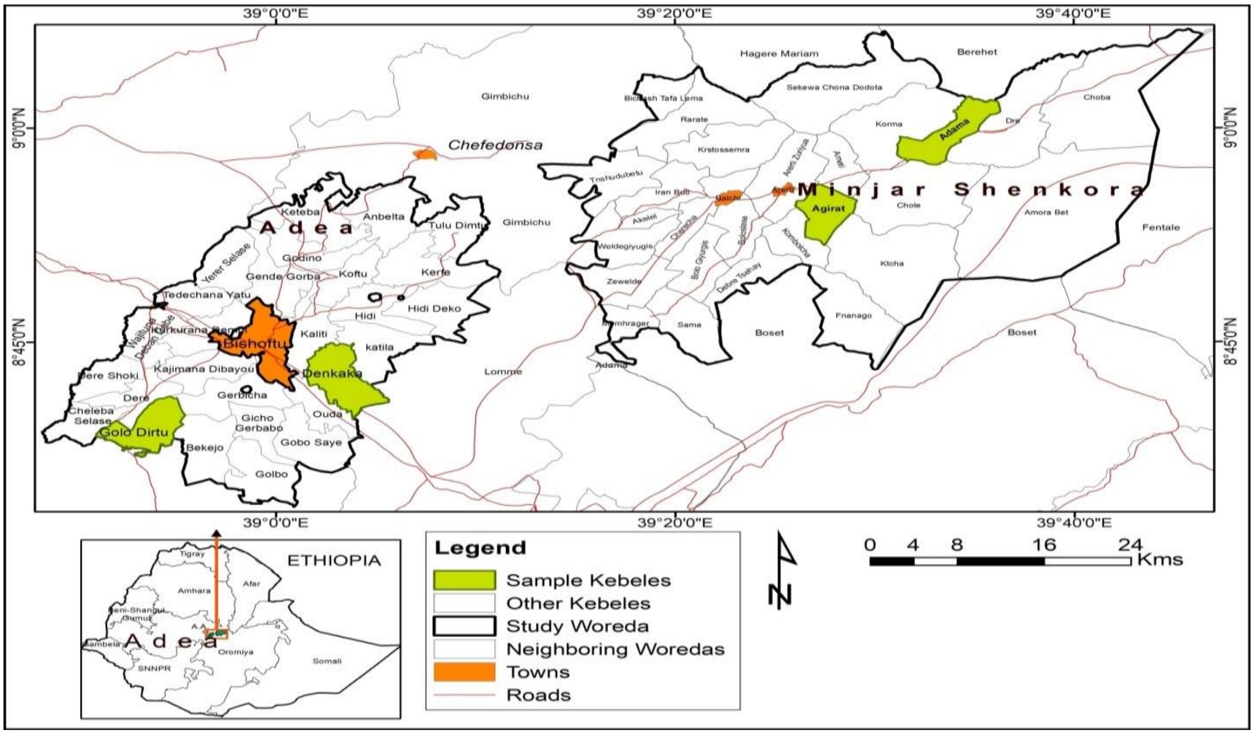


Figure 1.1 Location maps of Minjar Shenkora and Ada'a *woredas*

Source: EIAR

1.6 Research Philosophy & Methodological approach

The sources, nature, and development of knowledge are all themes in research philosophy (Bajpai, 2011). It's a viewpoint on how data should be gathered, analyzed, and interpreted in the case of a phenomenon. The way they see the world and how they do research is influenced by their philosophical positions. Although there are three important research philosophies in social sciences (positivism, interpretivism, and pragmatism), this study is a result of the pragmatist paradigm that combines qualitative and quantitative methods with multiple techniques for data collection and analysis. Unlike positivism and interpretivism research philosophies, pragmatism research philosophy can integrate more than one research approach and research strategies within the same study. Only concepts that assist action are considered relevant by the pragmatist research philosophy. Pragmatics understand that there are numerous ways to perceive the world and conduct research, that no single point of view can ever provide the complete picture, and that various realities may exist (Saunders et al., 2012).

Since the 1980s, two important points have emerged from the development of the methodological approach in social science research. One is the widespread acceptance of methods from each other by the proponents of different approaches. The second is the move from the single method approach, either qualitative or quantitative, to mixed methods. A mixed-method is an approach that combines the qualitative and quantitative approaches into a single study or multi-phased study. The need for a more thorough analysis drove the decision to use a mixed-method approach, as both are unsuccessful at capturing the details of a case (Ivankova et al., 2006). The multidisciplinary nature of agricultural research, extension, and innovation has forced the use of multiple primary data collection techniques at the same time or separately. This approach is known by different names, including triangulation, composite, and multiple names (Degefa, 2005).

The quantitative method examines the relationship between variables to test objective hypotheses. These variables can then be measured using instruments, resulting in numerical data that can be analyzed using statistical procedures (Creswell, 2002). It was primarily concerned with data collection through a structured questionnaire survey and experiments. Using Minjar Shenkora and Ada'a woredas as a case study, the method aimed to provide evidence on why agriculture research, extension, and innovation systems were limited to transform the smallholders' *tef* production system to contribute in endeavors of generating adequate food production in Ethiopia. Variables were collected on the general household characteristics, resource endowments, institution, extension and market related, and farmers' perception variables. Variables on general household characteristics, resource endowments, institutional, extension, and market-related, and perception variables of farmers were collected.

Qualitative research is rich in data and consists of detailed descriptions, in-depth investigations, and the insights and experiences of people (Creswell and Creswell, 2017). By using a qualitative approach, it is possible to see the research issue in detail. The assumption that a pre-existing environment can be understood, unlike the quantitative method, does not start with the assumption that. The qualitative approach includes a variety of data collection materials such as key informant interviews, focus group discussions, informal interviews, and personal observations (Reta, 2018). The in-depth interviews were conducted with agricultural researchers, agricultural experts, DAs, policy-makers, traders, model farmers, farmers and elders of the community. Focus group discussions were conducted with farmers, development agents, and community elders to collect information on their views and perceptions of agricultural issues in terms of improved technology and the availability and accessibility of extension services. There were also informal discussions with members of the farming community from various households and farmers who are members of cooperatives. Close observations were carried out in the farm fields as well as in the community households. This allows us to get firsthand information on farming households' food security and agriculture-related issues. Various checklists were used during qualitative data collection time; the discussions were documented, transcribed, and compared with field notes.

Various analysis methods have been used to analyze the data collected from quantitative and qualitative sources using various tools. Using STATA 14 and SPSS version 20 software the quantitative data was cleaned, coded, entered, sorted, and analyzed. To interpret quantitative data, descriptive and inferential statistics were used. The descriptive analysis includes frequency, percentage, mean, standard deviation, and cross-tabulation. Continuous data were analyzed via one-way ANOVA and t-test in inferential statistical analyses, while categorical data were analyzed using the Chi-square test. To analyze the quantitative data, econometric models such as the endogenous switching regression (ESR) model, multivariate probit (MVP) model, ordered probit model, tobit model, and binary logistic regression model was used. The Household Food Balance Model (HFBM) was also utilized to measure the food security of the sample households. They thematically summarized, narrated, and then analyzed and discussed qualitative data produced from in-depth interviews, focused group discussions, observations, and document analysis. Moreover, to analyze the structural and functional elements of the innovation system, the AIS framework was adapted.

1.7 Limitation of the study

There were four main limitations of this study. First, the study only considered three agricultural technologies (improved *tef* varieties, chemical fertilizer and row planting practice). Since the *tef* technology package may include other technologies such as manure, pesticides, mechanization, etc., the study's findings may be too limited to be applied to all technologies. Yet, it may be contributing to further research and may provide valuable information in development planning for areas with similar agro-ecological, socio-economic and geographical context with the study *woredas*. Second, the study attempted to analyze the impact of multiple combinations of improved technologies adoption on household food security but did not successfully capture and analyze the welfare implications of the adoption of various combinations of technologies to bridge the knowledge gap and influence agriculture policies. Therefore, further research that studies the welfare implications of the adoption of individual and combinations of improved technologies are required.

Third, given the findings underscored in the thesis, the important challenge is not only generating improved *tef* technologies but also understanding the factors that facilitate or impede the adoption of technologies. One of the limitations of this study is that adoption and impact were analyzed using smaller numbers of farming households who adopted multiple combinations of improved technologies. This could limit the generalizability of the results from quantitative models across the population. Fourth, the study was undertaken only in Minjar Shenkora and Ada'a *woredas* due to time, financial, and circumstances constraints. As a result, the study was unable to include other major *tef*-growing *woredas* in the country in order to increase the sample size. Nevertheless, these limitations never affected the purpose and quality of this study, although they would merit analysis in their own right. Further research could address the variations among farming households and Regional States in different parts of *tef* growing areas.

1.8 *Tef* research, extension, technology adoption, innovation system, and food security

1.8.1 *Tef* research and development

Tef research began in Ethiopia in 1956 at the then Jimma Agricultural and Technical High School, now Jimma University (Hailu et al., 2001). In 1960, *tef* research was transferred to the then Central Experiment Station and now the Debre Zeit Agricultural Research Center (DZARC), mainly focused on breeding *tef* varieties to enhance production (Cheng et al., 2017; Minten et al., 2016; Berhanu and Hoekstra, 2008). Since 1960s DZARC is the center of excellence for *tef* research within the Ethiopian Institute of Agricultural Research (EIAR) involving four centers of excellence of *tef* research in the four major *tef* growing regions: Adet agricultural research center of Amhara Regional State; Bako agricultural research center of Oromia Regional State; Axum agricultural research center of Tigray Regional State and Areka agricultural research center of SNNPR Regional State. The public sector is the only responsible body to support the *tef* research program with very few international donors. The involvement of relevant actors in technology and knowledge development and dissemination is very limited and weak. It's a one-way communication approach in which information and technology move from researchers to end users via extension agents, similar to a conveyor belt (Belay et al., 2012). Agricultural innovation systems are inadequate to support the agricultural sector's development and smallholder farmers' livelihoods.

The *tef* breeding research has passed through five main phases for the last half century (Kebebew et al., 2011). During the first phase (1956–1974) the research focused largely on germplasm enhancement, genetic improvement relying entirely pure-line selection and initiation of induced mutation techniques. In the second phase (1975-1995) the tef research program discovered the crossing techniques. In the third stage (1995-1998) molecular approaches involving development of molecular markers was initiated and molecular genetic diversity analyzed. In the fourth phase (1998-2003), in vitro culture techniques and inter-specific hybridization were introduced, as well as a re-evaluation of induced mutagenesis, particularly for lodging and leaf rust disease resistance. In the last phase, since 2003 until now the research system introduced the participatory breeding approaches. The *tef* research program for the last half century has been mainly focused on breeding, with limited attention paid to mechanization, processing, irrigation, and storage (Bekabil et al., 2011).

1.8.2 Extension and advisory services

In 1953, the then Alemaya Imperial College of Agriculture and Mechanical Arts (IECAMA), now Haramaya University, began providing research-based agricultural extension services to the local communities (MoANR, 2017; Belay, 2003). At the end of 1963, the college's mission was completely transferred to the Ministry of Agriculture as a department, and the Ministry of Agriculture has since been responsible for leading national agricultural extension activities. Farmers' access to agricultural information empowers them and establishes long-term partnerships with service providers for better facilities, capacity building, and financial support. A good agricultural extension system can efficiently provide need-based extension and advisory services to as many farming households as possible. To help rural people have better livelihoods, the agricultural extension must concentrate on both technical advances and institutional aspects (organizational and leadership development) (Habtemariam, 2008).

Ethiopia's government is persuaded that an effective and efficient extension and advisory services is essential for transforming smallholder subsistence agriculture into a commercial agricultural production system by promoting the adoption and use of agricultural technologies that increase yield and quality. Ethiopia's extension system has a lot of potential for supporting farmers all over the country. So far, over 83,000 DAs have been educated and graduated, with about 56,000 employed in the agricultural extension system (MoANR, 2017). The government has also built nearly 12,500 FTCs that operate at various levels. Furthermore, the government established 25 ATVETs to produce DAs in various fields of expertise. The agricultural extension system faces a variety of obstacles, despite the state's commitments. The majority of these issues have persisted from one government to the next and year to year (Gerba et al., 2017). Several factors, including government expenditures in the sector, especially on extension services, a road network, higher levels of rural education, and favorable domestic and foreign price incentives have influenced the wider circulation of improved technologies (Fantu et al., 2017).

In terms of services delivered, Ethiopia's agricultural extension system remains largely public and unimodal. It occurs within a dynamic government bureaucratic system that includes a variety of interactions, as well as the unique characteristics of the agriculture sector (Guush et al., 2018). A robust and vibrant extension system is a vital policy tool for bringing about necessary behavioral and attitude improvements, as well as putting pressure on national agricultural extension programs (MoANR, 2017). Agriculture extension services are important for encouraging the adoption of more productive farm technologies. Development experts have stressed the importance of it in achieving agricultural development, poverty reduction, and food security. It is also important in the transformation of rural areas.

1.8.3 Agricultural innovation system

Innovation systems are not a modern phenomenon. Rather, it can be traced back to ideas expressed by various economists in the 1800s as they investigated the impact of technological change on productivity as well as the social and economic effects of technological change (Spielman, 2005). An innovation system is a network of organizations, businesses, and individuals dedicated to commercializing new goods, procedures, and organizational forms, as well as the institutions and policies that influence the actions and performance of the systems (Rajalahti et al., 2008). When applied to agriculture, the innovation system model has provided a framework for analyzing complex relationships and innovative processes that occur among multiple agents, institutions, and endogenously determined technological and institutional opportunities, adding value to the traditional, linear perspective on agricultural R&D (Spielman, 2005). If the right interactions for the right goal occur at the right time, actors in the innovation system may be able to find ways to profit from the seemingly chaotic socio-economic situation.

With increased institutional pluralism in agricultural extension and advisory service delivery, the Agricultural Innovation System (AIS) approach is critical in the current demanding and dynamic nature of agriculture. Collaboration among them that is well-coordinated and mutually beneficial will put together ideas, expertise, and a better organizational culture and resources to work for the benefit of farmers. The AIS pays close attention to systemic change, not in the strict context of organizations, but rather in the sense of the general collection of behaviors and practices that have a significant impact on innovation processes (Amanuel, 2014). AIS actors innovate not in isolation, but in collaboration with other actors such as growers, companies, farmer associations, scholars, financial institutions, and government agencies, as well as the socioeconomic climate. To put it another way, agricultural innovation is a phenomenon driven by individual and collective attitudes, innovation capacities, and enabling conditions (World Bank, 2012).

Table 1.1 Defining features of the three main frameworks used to promote and invest in knowledge in the agriculture sector

Defining feature	National agricultural research systems (NARS)	Agricultural knowledge and information systems (AKIS)	Agricultural innovation systems (AIS)
Actors	Research organizations	Farmer, research, extension, and education	Wide spectrum of actors
Outcomes	Technology invention and transfer	Technology adoption and innovation	Different types of innovation
Organizing Principles	Using science to create new technologies	Accessing agricultural knowledge	New uses of knowledge for social & economic change
Mechanism for innovation	Technology transfer	Knowledge and information exchange	Interaction and innovation among actors
Role of Policy	Resource allocation, priority setting	Linking research, extension, and education	Enabling innovation
Nature of capacity strengthening	Strengthening infrastructure and human resources	Strengthening communication between actors in rural areas	Strengthening interactions between all actors; creating an enabling environment

Source: World Bank (2006)

1.8.4 Adoption: Concepts and theories

Technologies and innovations play an important role in economic development. As a strategy to combat low productivity and food insecurity, increased technology adoption has become a key topic on the development policy agenda for developing countries. Ethiopia's agricultural policy and strategy were primarily focused on increasing agricultural production through the use of improved technologies. Adoption of any technology and innovation is not a one-step process as it takes time for adoption to complete. First-time adopters have the choice of continuing to use the new technology or discontinuing it. The time it takes for a technology to be adopted varies depending on economic units, countries, and the technology's characteristics. As a result, a thorough understanding of the technology adoption and diffusion process is needed for the development of successful agricultural research and extension systems (Hailu, 2008).

Adoption and diffusion of technologies are two terms that are related but not identical. They define the decision to use or not use a given technology, as well as the spread of that technology among economic units over time (Hailu, 2008). Adoption (at the farm level) is differentiated from diffusion (aggregate adoption) by Jack (2011). According to him, adoption is characterized as the extent to which a new technology (innovation) is used in long-run equilibrium when the farmer has complete knowledge of the new technology and its potential. Aggregate adoption (diffusion) was described as the process of a technology's spread across an area (Feder et al., 1985). This means that aggregate adoption is determined by the total number of people who use a particular technology in a given geographic region. The introduction of a new technology consists of two phases. In the first phase, the new technology is introduced to farmers through, for instance, demonstration plots or other means, and the new technology will be adopted when found beneficial (Hailu, 2008). According to Dinar and Yaron (1992), the second phase is distinguished by a gradual decline in the utilization of the new technology until it is abandoned.

Adoption theory looks at the individuals and the choices he or she makes on whether to adopt or reject a particular technology (innovation). Many theories have been suggested to understand why people embrace emerging technology and choose to adopt them. Among those adoption theories include the Theory of Diffusion of Innovations (DIT) (Rogers, 1995), the Theory of Task-Technology Fit (TTF) (Goodhue and Thompson, 1995), the Theory of Reasonable Action (TRA) (Fishbein and Ajzen, 1975), the Theory of Planned Behavior (TPB) (Ajzen, 1991), the Decomposed Theory of Planned Behavior (Taylor and Todd, 1995), the Technology Acceptance Model (TAM). Rogers produced a well-known theory known as "diffusion of innovation" (1995). According to the theory, it explains “the process by which an innovation is disseminated through certain networks throughout time among the members of a social system” (Rogers, 1995). Diffusion is the process by which representatives of a social system express an innovation over time through specific channels. Rogers' (1995) diffusion of innovation theory explained that innovation and adoption occur after a series of phases, including understanding, persuasion, decision, implementation, and confirmation, which resulted in the creation of Rogers' (1995) S-shaped adoption curve of innovators, early adopters, early majority, late majority and laggards.

Many adoption studies have shown that the rate of technology diffusion varies greatly. It has been suggested that prospective adopters' views of the new technology's characteristics influence how quickly it is adopted. Rogers (1983) defined five characteristics of inventions that influence the speed at which they are adopted. Relative advantage, compatibility, ambiguity, divisibility, and observability were among the characteristics of inventions. Supe (1983) introduced two more factors that influence adoption rates: differences in the cost of adoption and the technology's community action criteria. Byerlee and Hesse de Polanco (1986) looked at the relationship between technology adoption rates (speed) and various economic factors. Their research discovered that the rate at which technology is adopted is determined by five factors (profitability, riskiness, divisibility or initial capital requirement, complexity, and availability).

1.8.5 Food Security: Concepts, dimensions and paradigm shifts

Over the last 50 years, the initial concept of food security has changed, implying changes in government policy thought. Food security as a concept emerged in the 1970s as a result of a growing international debate on food issues during a global crisis that saw the proportion of the world's malnourished population rise. It was defined in 1974 at the World Food Summit as the amount of global food supplies. As a result, food security has become a synonym for food self-sufficiency on a global and national level. During this period, food security was primarily concerned with the supply side of the food, whether by local agricultural production or imports from the international market. Nonetheless, food supply at the national or global level does not guarantee population access to food. Food security, according to Sen (1981), should consider not only availability but also access at the household and individual level. Food security had moved away from the food supply and toward food access at the household or person level (Maxwell, 1996). As a result, food security has been described as having enough food for everyone to live a safe and productive life. Since then, the term "food security" has been expanded to include food nutritional value. Finally, the World Food Summit in 1996 defined food security as "*physical*, *social, and economic access to sufficient, clean, and nutritious food that fits their dietary needs and food preferences for an active and healthy life at all times*" (FAO, 1996).

Food security is widely thought to be based on four key dimensions: availability, access, utilization, and stability. These concepts are fundamentally hierarchical, with availability being necessary but not sufficient for access, which is necessary but not sufficient for successful utilization (Webb et al., 2006). The supply side is addressed by the food availability dimension, which refers to the amount of food physically present in the country across all types of domestic production, imports, food stocks, and food help over a given time (WFP, 2009). The access dimension considers demand at the household and individual levels, as well as economic and physical access to food, with a focus on vulnerable people's access. The access aspect has three components: physical (transport), economic (financial), and socio-cultural (religion, gender, or social reasons). The food utilization dimension looks at food that is both healthy and nutritious and meets their dietary requirements. It is insufficient to ensure that food is available and affordable to households for people to eat a healthy and balanced diet. To achieve a state of nutritional well-being in which all physiological requirements are fulfilled, it is directly related to a healthy and sufficient diet, clean water, and sanitation (FAO, 2002). It is insufficient if anyone receives what appears to be an appropriate amount of food if he or she is unable to consume the food because he or she is often sick. All other aspects of food security are influenced by stability. It recognizes the temporal dimension of food protection by including susceptibility to specific types of risks (Pangaribowo et al., 2013). A community, family, or person must have access to sufficient food at all times to be food safe. They should not be at risk of going hungry as a result of the economic or climate crisis, or during a period of seasonal food insecurity.

Since the World Food Conference in 1974, there have been three major and overlapping paradigm shifts in the way people think about food security (Devereux, 2009; Ramos et al., 2008; Devereux and Maxwell, 2001). These three paradigms shifts are:

- A shift from the global and the national to the households and the individuals
- A shift from the food-first perspective to the livelihood perspective
- A shift from objective indicators to subjective perception

Shift from the global and the national to the households and the individuals

Following the First World Food Conference in 1974, the initial focus was on food supply issues and, to a lesser extent, price stability of essential food items at the international and national levels. To close the food gap, the emphasis was on increasing the amount of food available at the national level, either through domestic production or through imports. As a result, the 1974 World Food Summit defined food security as the continuous availability of enough world supplies of basic foodstuffs to enable steady growth in food consumption and to offset fluctuations in production and pricing (UN, 1975). This concept makes it clear that for a country to be food-safe, it must have enough food available for consumption, either from domestic production or from outside imports. During that time, research focused on determining why agricultural productivity is poor and how to boost food production to ensure national food security. As a result of this initiative, the Food Availability Decline (FAD) hypothesis has emerged.

Food Availability Decline (FAD) Theory

Food insecurity and famine, according to the FAD theory, are triggered by declines or failures in overall food availability/agricultural productivity at the local, regional, or national level (Sijm, 1997). The central argument of FAD theory, according to Devereux (1988), is that something that disrupts food production will lead to food insecurity. Food shortages can lead to food crises, and famine can result from a food shortage. The Ethiopian famines of 1973–1974, 1984–1986, and 2002 are all linked to major drops in agricultural output and productivity. Furthermore, people starve because food supply falls below the minimum energy requirements at a local, national, or regional level, according to this theory. Food shortages and famines, according to this theory, are triggered by a sudden decrease in per capita food supply. Natural hazards (drought, floods, insect infestation, etc.), agricultural productivity decline due to low adoption of modern technologies, and resource diversion are three possible causes of the decline in agricultural production that have been largely discussed in the literature (the transfer of labor from agriculture to industry). As a consequence, food prices go up and people, who are not able to bear such an increase, consume fewer calories (Sarracino, 2010).

Besides that, according to the FAD hypothesis, food security is primarily a matter of increasing food availability. As a solution, it proposes increasing food supply and, as a result, availability; improving food imports; and, most recently, promoting sanitary improvements. Unfortunately, Sen (1981) has slammed such a solution, claiming that famines can be caused by a variety of factors and can occur even in areas where food production or availability has not decreased. In this way, the FAD approach fails to recognizee this broader range of triggers and, as a result, to recommend appropriate policies. Sen rejects the necessity of the FAD theory in light of these considerations. He acknowledges, however, that famines can be triggered by a decrease in food availability, and he incorporates this theory into its entitlement system.

Food Entitlement Decline (FED) Theory

Sen (1981) proposed this theory as an alternative approach for analyzing food insecurity, arguing that food availability in the economy does not inherently entitle an individual to eat it. According to this theory, food security at the household or person level cannot be achieved solely by global or national food availability. As a result, FED has made a major contribution to the change of focus to the household and person level of study. In a country where enough food is available, a household or person can face a food shortage. As a result, food scarcity becomes a problem of lack of access, which is described as the inability to produce enough food or the inability to purchase food due to a lack of purchasing power. Insofar as what is produced is not equally distributed and the entitlement mechanism that defines access to food is not modified, an increase in domestic production does not inherently avoid famine or hunger. Overall, researchers focused on one part of the issue and ignored the others based on their area of concern and interest. The proponents of the FAD theory place a premium on food supply, but this does not guarantee accessibility. The proponents of FED theory, on the other hand, overlooked the value of availability by concentrating on entitlement. However, food supply is a requirement and a critical factor in gaining entry.

Response Failure

Devereux (2009) has introduced a new concept to the food security debate. He emphasizes a change in emphasis to focus on "response failure" as an explanation for the persistence of food insecurity and famine, particularly in Sub-Saharan African countries. Response failure refers to national governments and the international community's failure to meet people's basic needs when they are affected by external shocks like drought. Food shortages and famines are the product of a complex system of causes, according to the main point of the response failure. According to Devereux (2009), a single factor explanation of famine and food insecurity is insufficient to explain why famine and food crises persist in the twenty-first century. Both the FAD and FED approaches do not have adequate reasons for why famine occurs in the twenty-first century. Famine and food insecurity continue in some countries due to response failure, which is the failure to provide food to vulnerable people when they are exposed to shocks to cover their food gaps. It is as an explanation for famine prevalence can be a result of different factors which include: lack of accurate and timely information, inadequate humanitarian response, and the political unwillingness of governments to protect vulnerable citizens, and lack of or insufficient response from donors.

Shift from 'food first' to 'livelihood' perspective

In addition to the aforementioned shift in perspective, the analysis and emphasis of attention have shifted from a food-first to a livelihood-first perspective, which focuses not only on food production but also on households' and individuals' ability to obtain the additional food they need for a balanced diet. The empirical findings on food security, which show that the response of food insecure people to the problem of food scarcity focuses on long-term livelihood goals rather than short-term food needs, are the key reason for this change in thought. Food security, according to Devereux and Maxwell (2001), is a fundamental requirement that underpins all human needs and the structure of social life.

Many studies have debated the presumption that people regard food as a primary need, citing the fact that food security is a component of people's larger livelihood systems. Food protection in the long run is dependent on a variety of services to which families, societies, and individuals have access or are entitled (Maxwell, 2001). According to Woller (2011), vulnerable households must align their current food needs with their ability to protect their ongoing livelihood viability and potential food needs through a variety of livelihood strategies. As a result, effective food security initiatives must resolve not only food security concerns but also broader issues such as households' livelihoods and vulnerability contexts. Successful livelihood initiatives, on the other hand, must consider how food security issues affect household livelihood strategies.

Shift from ‘objective indicators’ to ‘subjective perceptions’

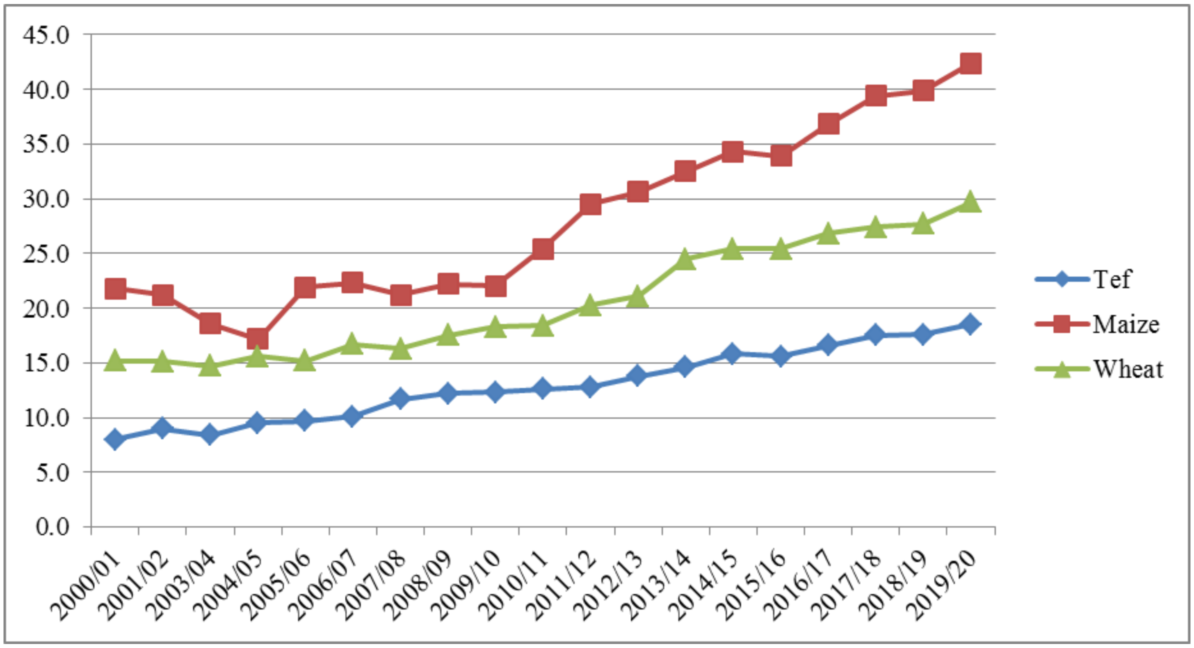
The third paradigm shift involves moving away from an objective measure of food security and toward a subjective assessment of the food security strategy. Before the rise of subjective approaches to food security, traditional approaches relied on quantitative metrics such as consumption levels, average daily calorie intake, or, more broadly, a timely, accurate, and nutritionally adequate supply of food. The key metric that was used the amount of consumption (Monde, 2003). However, according to several academics, these types of food security methods have problems for at least two reasons. The first issue with objectively measuring food security arises from the exclusion of qualitative dimensions of food security from quantitative measurements. Technical food quality, conformity with local food habits, cultural acceptability, and human dignity, and autonomy and self-determination are all-important qualitative issues in food protection (Barraclough, 1991).

The second issue is that most academics believe that the definition of nutritional adequacy is flawed in and of itself. Individual nutritional requirements, according to Devereux and Maxwell (2001), are a feature of the age, health, height, workload, environment, and behavior. Calorie needs estimates for average adults and children with average activity levels in average years are constantly revised. It's difficult to determine specific calorie requirements for various groups of people. As a result of these issues, there has been a change in how people think about food security. It became clear that, while the quantity of food entitlement is significant, the nature of that entitlement is equally important. Subjective data collection methods allow us to understand how individuals and their household members express their attitudes and reactions to food insecurity, as well as how the information provided is related to their cultural and personal values, reflecting their sense of deprivation, which may or may not always coincide with any external or absolute norm (Webb et al., 2006).

1.9 Success stories of *tef* R&D and extension

By linking the supply and demand sides, agricultural productivity can play a critical role in overall economic growth and household food security. It is the indicator of the total of agricultural output produced per unit of input (Mozumdar, 2012). One of the primary avenues for economic growth and agricultural transformation in developing nations is to increase agricultural productivity through the adoption and distribution of improved agricultural technologies (Gollin, 2010; Evenson and Gollin, 2003). Agricultural research and extension systems play an important role in boosting agricultural productivity by developing and disseminating agricultural technologies to farmers. For the past half-century, agricultural research and extension has done a lot to improve smallholders' *tef* production systems.

Since the 1970s, the national *tef* research program has released more than 44 improved varieties as well as production packages (MoA, 2019). The release of the most popular variety, specifically "Quncho," resulted in spectacular success, with *tef* yields reaching as high as 30 qt/ha. As a result, national average of *tef* productivity has improved dramatically from 8 qt/ha in 2000/01 to 18.5 qt/ha in 2019/20 (CSA, 2019). Furthermore, the amount of area covered by the *tef* extension package has grown from 7% in 2002 to 35.5 % in 2017/18 (CSA, 2018). Throughout the previous half-century, efforts have been made to incorporate various techniques and tools in order to improve the *tef* production system and productivity. At both the production and consumption levels, significant changes have happened in the *tef* innovation systems and value chain. Moreover, *tef* consumer demand is increasing, and the *tef* marketing system is becoming more efficient (Minten et al., 2018).



Source: CSA data of various years

Figure 1.2 Trends of national average *tef* productivity in quintal per hectare

1.10 Analytical framework

In this theoretical context, the systemic constraints of agriculture research and innovation systems, as well as the factors impeding the performance of the agricultural extension system, are considered. This comprehensive approach encompasses R&D, as well as extension and innovation systems (Figure 1.3). The approach is used as an analytical framework to investigate the relationship between *tef* research and development and systemic constraints in *tef* innovation systems, as well as the factors that influence the extension system's performance and the related determinants that affect household adoption of multiple *tef* technologies. This was lead to why research, extension, and innovation systems were unable to transform smallholders' *tef* production system.

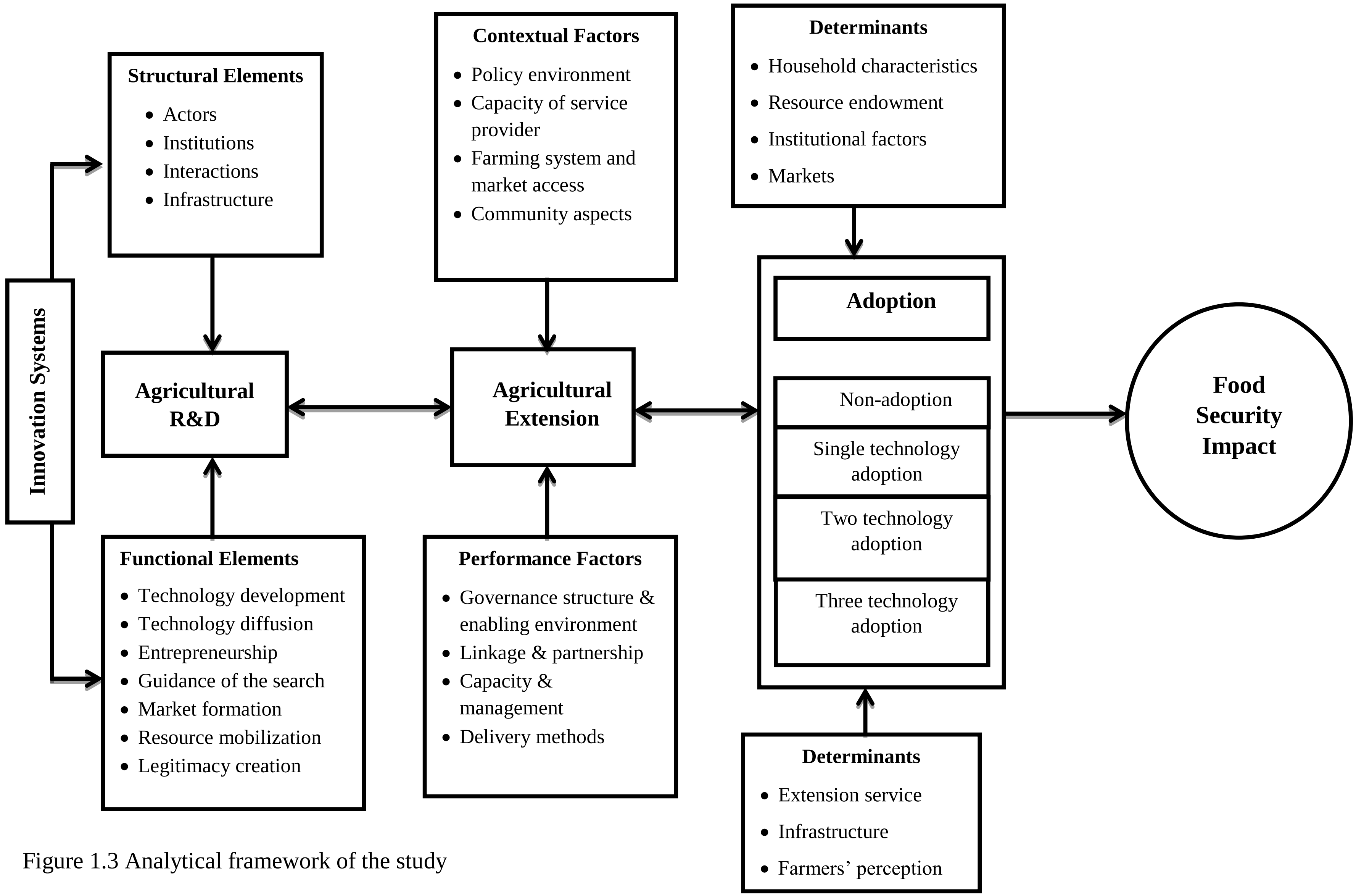


Figure 1.3 Analytical framework of the study

Source: Adopted from Giraldo et al. (2008)

1.11 Organization of the dissertation

The remaining sections are organized as follows in the dissertation. The second section is devoted to analyzing the systemic constraints of the *tef* innovation system which affect the development of the sub-sector. This explores how the innovation system has functioned to support the development of *tef* sub-sector and what systemic constraints have been in the process. This is accompanied by an assessment of performance of extension system (individual DAs and extension organization) and identified the factors explaining it. The next section then analyzes the impacts of various combinations of improved *tef* technologies on smallholders' food security. The analyses include the impact of those technologies on dietary energy supply, the diversity of household diets, and food consumption score. The determinants of the household adoption decision and the number of a combination of *tef* technologies were described in the fifth chapter. All these sections are put together in the final section and the key results are synthesized. It then ends by explaining, in terms of synthesis of main findings, conclusion, development and policy implications, and implications for further researcher for managing the challenges to *tef* innovation system, extension and technology adoption in Central Ethiopia.

1.12 References

Ajzen, I. (1991). The Theory of Planned Behavior. Organization behavior and human decision processes, Academic Press, Inc. 179-211.

Amanuel Assefa (2014). Agricultural innovation in a changing Ethiopian context: The case of dairy farming and business in the Addis Ababa milk shed. A PhD dissertation submitted to College of Agriculture, Engineering and Science, University of KwaZulu-Natal.

Anandajayasekeram, P., Puskur, R., & Elias Zerfu (2009). *Applying innovation system concept in agricultural research for development*. ILRI (aka ILCA and ILRAD).

ATA (2013). Results of 2012 new tef technologies demonstration trials draft report VF. Agricultural Transformation Agency, Addis Ababa, Ethiopia.

ATA, MoA & EIAR (2013). Working Strategy for Strengthening Ethiopia's *tef* Value Chain: *Vision, Systemic Challenges, and Prioritized Interventions, Addis Ababa*.

Avila, A. F., & Evenson, R. E. (2010). Total factor productivity growth in agriculture: the role of technological capital. *Handbook of agricultural economics*, *4*, 3769-3822.

AWAO (2017). Annual report of Ada'a woreda agricultural office. Unpublished document.

Bajpai, N. (2011). Business research methods. Pearson Education India.

Barraclough, S. (1991). An end to hunger: The social origins of food strategies. *Social Policy and Inclusive Development, 195.*

Bekabil Fufa, Befikadu Behute, Simons, R., & Tareke Berhe (2011, November). Strengthening Tef value chain: In: *Tef* Improvement: Achievements and Prospects. In *Proceedings of Second International Workshop* (pp. 7-9).

Belay Kassa (2003). Agricultural extension in Ethiopia: the case of participatory demonstration and training extension system. *Journal of social development in Africa*, *18*(1), 49-84.

Berhanu Gebremedhin & Hoekstra, D. (2007). Cereal marketing and household market participation in Ethiopia: the case of teff, Wheat and rice (No. 307-2016-4963, pp. 5-14).

Birhanu Gedif, Tegegn Molla, Solomon Addisu & Yibeltal Ayenew (2016). Status of Agricultural innovations, innovation platforms and innovation investment. 2015 PARI Federal Democratic Republic of Ethiopia. In *Forum for Agricultural Research in Africa*.

Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., ... & Cohen, M. (2009). From best practice to best fit: a framework for designing and analyzing pluralistic agricultural advisory services worldwide. *Journal of agricultural education and extension, 15*(4), 341-355.

Boettiger, S., Denis, N., & Sanghvi, S. (2019). Successful agricultural transformations: six core elements of planning and delivery. McKinsey & Company.

Burchi, F., Fanzo, J., & Frison, E. (2011). The role of food and nutrition system approaches in tackling hidden hunger. *International Journal of Environmental Research and Public Health, 8*(2), 358–373.

Byerlee, D., & Hesse de Polanco., E. (1986). Farmers' stepwise adoption of technological packages: evidence from the Mexican Altiplano. *American Journal of Agricultural Economics, 68*, 520-527.

Cafer, A., & Rikoon, S. (2017). Coerced agricultural modernization: a political ecology perspective of agricultural input packages in South Wollo, Ethiopia. *Journal of Rural Social Sciences, 32* (1), 6.

Cheng, A., Mayes, S., Gemedo Dalle, Sebsebe Demissew & Massawe, F. (2017). Diversifying crops for food and nutrition security–a case of *tef*. *Biological Reviews*, *92*(1), 188-198.

Cohen, J. M. (1987). *Integrated rural development: the Ethiopian experience and the debate*. Nordic Africa Institute.

Creswell, J. W. (2002). *Educational research: Planning, conducting, and evaluating quantitative* (pp. 146-166). Upper Saddle River, NJ: Prentice Hall.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Crymes, A. (2015). The international footprint of tef: Resurgence of an ancient Ethiopian grain.

CSA (2020). Agricultural sample survey 2019/20 report on area and production of major crops for private peasant holdings, *Meher* season, volume I. Central Statistical Agency *Addis Ababa*.

CSA (2018). Agricultural sample survey 2017/18 report on area and production of major crops for private peasant holdings, *Meher* season, volume I. Central Statistical Agency, *Addis Ababa*.

CSA (2017). Population projection of Ethiopia for all regions at *woreda* level from 2014 – 2017, Central Statistical Agency, Addis Ababa.

CSA & WFP (2019). Comprehensive Food Security and Vulnerability Analysis (CFSVA). Ethiopia, WFP and Headquarters, WFP.

Davis, F., Bogozzi, R., & Warshaw, P. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science*, *35*, 982-1003.

Debelo Duressa (2015). Analysis of factors influencing adoption of Quncho tef: The case of Wayu Tuqa District. *International Journal of African and Asian Studies*, *12*, 20-28.

Degefa Tolossa (2005). Rural livelihoods, poverty and food insecurity in Ethiopia: A case study at Erenssa and Garbi communities in Oromiya Zone, Amhara National Regional State. (Doctoral dissertation, *Norwegian University of Science and Technology*, *NTNU*, *Trondheim*)

Dejene Bayissa & Bekele Tassew (2015). Determinants of farmer's adoption of full extension package on improved tef technology: the case of Dendi district, West Showa, Oromia Regional State, Ethiopia. *International Journal of Current Research, 7*(9), 20816 – 20821.

Demese Chanyalew (2015). Ethiopia's Indigenous policy and growth: agriculture, pastoral and rural development. *Addis Ababa, 867 pages*.

Demese Chanyalew, Berhanu Adenew & Mellor, J. (2010). Ethiopia's agricultural sector policy and investment framework (PIF) (2010 - 2020), draft final report. *Federal Democratic Republic of Ethiopia, Ministry of Agriculture and Rural Development. Addis Ababa*.

Deresse Dalango & Teklu Tadesse (2019). Determinants of smallholder teff farmer's chemical fertilizer technology adoption in Southern Ethiopia, in case of Gena District in Dawro Zone (Heckman Two-Stage Model). *Jurnal Perspektif Pembiayaan dan Pembangunan Daerah, 7* (2), 111-126.

Devereux, S. (2009). Why does famine persist in Africa? *Food Security, 1*(1), 25-35.

Devereux, S. (1988). Entitlements, availability and famine: A revisionist view of Wello, 1972- 74. *Food Policy, Vol.13, No. 3*.

Devereux, S., & Maxwell, S. (2001). Food security in sub-Saharan Africa. Bourton Hall, ITDG Publishing.

Dinar, A. & Yaron, D. (1992). Adoption and abandonment of irrigation technologies. *Agricultural Economics*, *6*, 315 – 332.

Dorfman, J.H. (1996). Modelling multiple adoption decisions in a joint framework. American *Journal of Agricultural Economics*, *78*, 547–557.

Dube, A. K., Fawole, W. O., Govindasamy, R., & Özkan, B. (2019). Agricultural Development Led Industrialization in Ethiopia: Structural Break Analysis. *International Journal of Agriculture Forestry and Life Sciences*, *3*(1), 193-201.

Efa Gobena, Degye Goshu, Tinsae Demisie & Tadesse Kenea (2016). Determinants of market participation and intensity of marketed surplus of tef producers in Bacho and Dawo Districts of Oromia State, Ethiopia. *Journal of Agricultural Economics and Development*, *5*(2), 20–32.

Etsehiwot Semreab (2018). The determinants of agricultural technology adoption and its' impact on teff productivity in the case of Amhara and Oromia national regional state.

Fantu Nisrane, Guush Berhane, Minten, B., & Alemayehu Seyoum (2017). Agricultural transformation in Africa? Assessing the evidence in Ethiopia. *World Development*, *105*, 286-298.

FAO (2015). Analysis of price incentives for Tef in Ethiopia Technical notes series, MAFAP. Food and Agricultural Organization. Rome.

FAO (2002). The state of food insecurity in the World 2001. Rome Retrieved on July 29, 2018 from http://www.fao.org/docrep/005/y4671e/y4671e06.htm#fnB31.

FAO (1996). Rome declaration on world food security and world food summit plan of action. Food and Agriculture Organization.

FAO, IFAD, UNICEF, WFP & WHO (2020). The state of food security and nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO.https://doi.org/10.4060/ca9692en.

Faure, G., Davis, K. E., Ragasa, C., Franzel, S., & Babu, S. C. (2016). Framework to assess performance and impact of pluralistic agricultural extension systems: The best-fit framework revisited (Vol. 1567). Intl Food Policy Res Inst.

Feder, G., Just, R., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic development and cultural change, 33*(2), 255-298.

Fentahun Mengistu (2015). Thoughts on governance and future orientation of Agricultural Research in Ethiopia. *Ethiopian Journal of Agricultural Sciences*, *25*(1), 17-30.

Fentahun Mengistu, Abebe Kirub & Fisseha Zegeye (2017). Retrospect and prospect of Ethiopian agricultural research. Ethiopian Institute of Agricultural Research, EIAR, Addis Ababa.

Fishbein, M., & Ajzen, I. (1975). Belief, attitude, intention, and behavior: An introduction to theory and research. Reading, Mass; Don Mills, Ontario: Addison-Wesley Pub. Co.

Fuglie, K. (2016). The growing role of the private sector in agricultural research and development world-wide. *Global Food Security*, *10*, 29-38.

Gerba Leta, Girma Kelboro, Stellmacher, T., & Hornidge, A. (2017). The agricultural extension system in Ethiopia: operational setup, challenges and opportunities ZEF, Center for Development Research, University of Bonn Working Paper 158.

Getachew Diriba (2018). Overcoming agricultural and food crises in Ethiopia: Institutional evolution and the path to agricultural transformation. Master Printing Press.

GFSI (2020). Performance of countries based on their 2020 food security score. A report from the economist intelligence unit, Global Food Security Index 2020. Retrieved from http://foodsecurityindex.eiu.com/Index on March 1, 2021.

Giraldo, D. P., Betancur, M. J., & Arango, S. (2008). Food security in development countries: A systemic perspective. *Technology*, *1*, 15.

Goodhue, D. L., & Thompson, R. L. (1995). Task technology fit and individual performance. *MIS Quarterly*, *19*, 213-236.

Guush Berhane, Ragasa, C., Gashaw Tadesse & Thomas Woldu (2018). The state of agricultural extension services in Ethiopia and their contribution to agricultural productivity. *ESSP Working Paper-Ethiopia Strategy Support Program, (118).*

Guush Berhane, Hirvonen, K., & Minten, B. (2016). Agricultural mechanization in Ethiopia: Evidence from the 2015 Feed the Future survey. ESSP Research Note 48.

Guush Berhane, Zelekawork Paulos, Kibrom Tafere & Seneshaw Tamru (2011). Food grain consumption and calorie intake patterns in Ethiopia. IFPRI Ethiopia Strategy Support Program II (ESSP II) Working Paper, 23.

Habtemariam Kassa (2008). Agricultural extension in Ethiopia: historical evolution, relevant policies and challenges. *Digest of Ethiopia's National Policies, Strategies and Programs*.

Hailu Beyene (2008). Adoption of improved tef and wheat production technologies in crop-livestock mixed systems in northern and western Shewa zones of Ethiopia (Doctoral dissertation, University of Pretoria).

Hailu Tefera, Getachew Belay, & Sorrells, M. (2001). Narrowing the Rift. *Tef* research and development.

Ifenkwe, G. (2012). Agent-related factors affecting the performance of agricultural extension staff in Abia State, Nigeria. *Journal of Agricultural Science, 3*(1), 45–48.

Ivankova, N. V., Creswell, J. W., & Stick, S. L. (2006). Using mixed-methods sequential explanatory design: From theory to practice. *Field methods*, *18*(1), 3-20.

Jack, B. K. (2011). Constraints on the adoption of agricultural technologies in developing countries. *White paper*, *Agricultural Technology Adoption Initiative*, *Boston: J-PAL (MIT) and Berkeley: CEGA (UC Berkeley)*.

Juma, C. (2009). Growing prosperity: Agriculture, economic renewal and development, draft outcome document from the experts meeting on 'Innovating out of Poverty'.

Kebebew Assefa, Sherif Aliye, Getachew Belay, Gizaw Metaferia, Hailu Tefera and Sorrells, M (2011). Quncho: the first popular *tef* variety in Ethiopia, *International Journal of Agricultural Sustainability, 9*(1), 25-34.

Kebebew Assefa, Solomon Chanyalew & Zerihu Tadele (2013). *Achievements and Prospects of Tef Improvement-Proceedings of the Second International Workshop, November 7-9, 2011, Debre Zeit, Ethiopia*. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia; Institute of Plant Sciences, University of Bern, Switzerland.

Klerkx, L., Aarts, N., & Leeuwis, C. (2010). Adaptive management in agricultural innovation systems: the interactions between innovation networks and their environment. *Agriculture Systems, 103*(6), 390–400.

Lee, H. (2018). Tef, A rising global crop: Current status of tef production and value chain. *The open agriculture journal*, *12*(1), 185-193.

Maiangwa, M. (2010). Importance, problems, and reform of agricultural research in Africa. *Journal of Agriculture, Forestry and the Social Sciences*, *8*(2), 127-138.

Maxwell, D. (1996). Measuring food insecurity: The frequency and severity of coping Strategies, *Food Policy, 21* (3), 291–303.

Maxwell, S. (2001). Agricultural issues in food security. In Stephen D. and Simon M., food security in sub-Saharan Africa. Institute of Development Studies, UK.

Maxwell, S., & Smith, M. (1992). Household food security: A conceptual review. Maxwell, S. & Frankenberger T.R. (eds.) Household Food Security: Concepts, indicators, measurements. A technical review, 1-72. Rome: UNICEF and IFAD.

Melaku Tafese (2020). Evaluation of proximate composition and sensory quality acceptability of Ethiopian flat bread (Injera) prepared from composite flour, blend of maize, tef and sorghum. *International Journal of Food Engineering and Technology, 4*(2), 18-24.

Mengistu Gebre (2015). Tef row planting technology and household food security in Adaa Woreda, Oromiya, Ethiopia. An MSc thesis submitted to College of Development Studies, Addis Ababa University

Minten, B., Seneshaw Tamru, Ermias Engida & Tadesse Kuma (2018). Dynamics in tef value chains. *The economics of teff: Exploring Ethiopia's biggest cash crop*, 327-352.

Minten, B., Seneshaw Tamru, Ermias Engida & Tadesse Kuma (2016). Feeding Africa's cities: The case of the supply chain of teff to Addis Ababa. *Economic Development and Cultural Change, 64*(2), 265-297.

Misigana Merga (2018). Progress, achievements and challenges of Tef breeding in Ethiopia. *Journal of Agricultural Science and Food Research, 9*(1), 1-8.

MoA (2020). Agriculture sector investment prioritization (2019/20-2024/25). Ministry of Agriculture, Addis Ababa.

MoA (2019). Crop variety register issue, no 22 (2019). Ministry of Agriculture. Addis Ababa.

MoANR (2017). Ethiopia's agricultural extension strategy: Vision, systemic bottleneck and priority intervention. Ministry of Agriculture and Natural Resources, Addis Ababa.

Monde, N. (2003). Household food security in rural areas of Central Eastern Cape: The case of Guquka in Victoria East and Koloni in Middle drift districts. A PhD Dissertation, Department of Agricultural Economics, Extension And Rural Development, University Of Fort Hare, South Africa.

Mozumdar, L. (2012). Agricultural productivity and food security in the developing world. *Bangladesh J. Agric. Econs. XXXV, 1&2,* 53-69.

MSWAO (2017). Annual report of Minjar Shenkora woreda agricultural office. Unpublished document.

Mulat Demeke & Di Marcantonio, F. (2013) Analysis of incentives and disincentives for teff in Ethiopia. Technical notes series, MAFAP, FAO, Rome.

Mulubrhan Amare, Cissé, J. D., Jensen, N. D., & Bekele Shiferaw (2017). The Impact of Agricultural Productivity on Welfare Growth of Farm Households in Nigeria: A Panel Data Analysis. *FAO, Rome*.

Musiolik, J. (2012). *Innovation system building: on the role of actors, networks and resources. The case of stationary fuel cells in Germany*. Utrecht University.

NBE (2019/20). Annual report of 2019/20. National Bank of Ethiopia, Addis Ababa, Ethiopia.

Negera Eba & Getachew Bashargo (2014). Factors Affecting Adoption of Chemical Fertilizer by Smallholder Farmers in Guto Gida District, Oromia Regional State, Ethiopia. *Science, Technology and Arts Research Journal*, *3*(2), 237-244.

NPC (2016). Growth and transformation plan II (2015/16–2019/20). FDRE National Plan Commission. Volume I: Main Text. *Addis Ababa*.

Okoboi, G., Kuteesa, A., & Barungi, M. (2013). The impact of the national agricultural advisory services program on household production and welfare in Uganda. *Africa Growth Initiative, Working paper, 7*.

Otchia, C. S. (2014). Agricultural modernization, structural change and pro-poor growth: Policy Options for the Democratic Republic of Congo. *Journal of Economic Structures*, *3*(1), 1-43.

Pangaribowo, E., Gerber, N., & Torero, M. (2013). Food and nutrition security indicators: A review. Working Paper 108. Center for Development Research.

Pardey, P. G., Alston, J. M., & Chan-Kang, C. (2013). Public agricultural R&D over the past half century: an emerging new world order. *Agricultural Economics*, *44*(1), 103-113.

Ragasa, C., Ulimwengu, J., Randriamamonjy, J., & Badibanga, T. (2016). Factors affecting performance of agricultural extension: Evidence from Democratic Republic of Congo. *The Journal of Agricultural Education and Extension*, *22*(2), 113–143.

Rajalahti, R., Janssen, W., & Pehu, E. (2008). *Agricultural innovation systems: From diagnostics toward operational practices*. Agriculture & Rural Development Department, World Bank.

Ramos, C., Sibanda, P., State, H. & Van, D. (2008). Assessing and addressing food security in North Kingston: Challenges and opportunities for the community and beyond. School of urban and regional planning. Queens University, Kingston, Canada.

Rao, N. C., Sutradhar, R., & Reardon, T. (2017). Disruptive innovations in food value chains and small farmers in India. *Indian Journal of Agricultural Economics*, *72*(1), 24-48.

Rapela, M. A. (2019). *Fostering Innovation for Agriculture 4.0*. Springer International Publishing.

Reardon, T., & Timmer, C.P. (2007). Transformation of Markets for Agricultural Output in Developing Countries since 1950: How Has Thinking Changed? *In Handbook of Agricultural Economics, vol. 3, edited by R. E. Evenson and P. Pingali, 2808–2855. Amsterdam: Elsevier Press.*

Reta Hailu, Degefa Tolossa & Genet Alemu (2018). Water security in the Awash Basin of Ethiopia: an institutional analysis. A PhD dissertation submitted to Centre for Rural Development, College of Development Studies, Addis Ababa University.

Rogers, E.M. (1995). Diffusion of Innovations. 4th ed., New York: The Free Press

Rogers, E.M. (1983). Diffusion of innovations. New York: Free Press.

Sarracino, F. (2010). Explaining famines: A critical review of main approaches and further causal factors, NAF: International Working Paper Series 10/02.

Saunders, M., Lewis, P., & Thornhill, A. (2012). Research methods for business students. 6th edition, Pearson Education Limited.

Sen, A. (1981). Poverty and famines, an essay on entitlement and deprivation, Oxford, Oxford University Press.

Seyfu Ketema (1989). Production trends, germplasm resources, breeding and varietal improvements of small millets, with special emphasis on *tef* in Ethiopia. *Small millets in global agriculture. IDRC, Oxford & IBH Co., India*.

Sijm, J. (1997). Food security and policy interventions in Sub-Saharan Africa: Lessons from the past two decades. Amsterdam thesis publishers.

Spaenij-Dekking, L., Kooy-Winkelaar, Y., & Koning, F. (2005). The Ethiopian cereal tef in celiac disease. *New England Journal of Medicine, 353*(16), 1748-1749.

Spielman, D. J. (2005). *Innovation systems perspectives on developing-country agriculture: a critical review* (No. 591-2016-39898).

Supe, S. V. (1983). An introduction to extension education. New Delhi: Oxford & IBH Publishing Co.

Tareku Legese (2021). Market chain analysis of Teff in Tole Woreda, Ethiopia. *J Agric Sc Food Technol 7*(1), 20 – 30. DOI: https://dx.doi.org/10.17352/2455-815X.000083.

Taylor, S., & Todd, P. (1995). Understanding Information Technology Usage: A Test of Competing Models. *Information Systems Research, 6*, 144-176.

Tsedeke Abate, Abera Deressa & Amare Molla (2004, February). The Ethiopian NARS: Evolution, Challenges and Opportunities. In *Meeting of ASARECA/NARS/World Bank Retreat on Reform of Agricultural Research and Technology Dissemination Systems in Eastern Africa* (pp. 26-28).

UN (1975). Report of the World Food Conference. Rome, 5-6 November 1974. New York, United Nations.

Usman, M., Ahmed, U. J., & Javed, M. (2017). Agricultural productivity and food security: Role of public and private sector investment in research and development. *Journal of Environmental and Agricultural Sciences*, *12*, 1-10.

Vandercasteelen, J., Mekdim Dereje, Minten, B., & Alemayehu Seyoum (2016). Row planting teff in Ethiopia: Impact on farm-level profitability and labor allocation. ESSP Working Paper 92.

Vandercasteelen, J., Mekdim Dereje, Minten, B., & Alemayehu Seyoum (2013). Scaling-up adoption of improved technologies: The impact of the promotion of row planting on farmers' tef yields in Ethiopia. *LICOS-Discussion paper series 344/2013*, 1-25.

van Ittersum, M., van Bussel, L., Wolf, J., Grassini, P., van Wart, J., Guilpart, N., & Claessens, L. (2016). Can Sub-Saharan Africa Feed Itself? Proceedings of the National Academy of Sciences of the United States of America, 113 (52), 14964–14969.

Webb, P., Coates, J., Frongillo, E., Rogers, B., Swindale, A., & Bilinsky, P. (2006). Measuring household food insecurity: Why it's so important and yet so difficult to do. Advances in developing country food insecurity measurement.

WFP (2009). Summary of food security and vulnerability in selected urban centers of Ethiopia. World Food Programmme. Retrieved on September 10, 2018 from http://m.wfp.org/cotent/wfp-annual-report-2009-english.

Woller, G. (2011). Livelihood & food security conceptual framework. Washington Lift – Livelihood and Food Security Technical Assistance, Washington DC.

World Bank (2012). *Agricultural innovation systems: An investment sourcebook*. The World Bank Publications.

World Bank (2011). *Agricultural innovation system*: *A Guide to the World Bank*. The World Bank. Washington, DC.

World Bank (2006). Enhancing agricultural innovation: How to go beyond the strengthening of Research Systems. World Bank, Washington, DC.

Yaghoubi-Farani, A., Mohammadi, I.M., & Movahedi, R. (2015). “The Role of Organizational Culture and Management Behavior in Organizational Innovation: A Case Study of the Agricultural Extension Organization (AEO) in Iran.” *Public Administration and Policy in the Middle East, Public Administration, Governance and Globalization 9*, 163–171. doi:10.1007/978-1-4939-1553-8_9.

Yang, J., Huang, Z., Zhang, X., & Reardon, T. (2013). The rapid rise of cross-regional agricultural mechanization services in China. *American Journal of Agricultural Economics, 95* (5), 1245–1251.

Yazachew Genet, Tsion Fikre, Worku Kebede, Solomon Chanyalew, Kidist Tolosa & Kebebew Assefa (2020). Performance of Selected Tef Genotype for High Potential Areas of Ethiopia. *Ecology and Evolutionary Biology*, *5*(3), 35-42.

Yifru Teklu & Hailu Tefera (2005). Genetic improvement in grain yield potential and associated agronomic traits of tef (*Eragrostis tef*). *Euphytica*, *141*, 247-254.

2. EXPLORATION OF SYSTEMIC CONSTRAINTS OF *TEF* SECTOR DEVELOPMENT IN CENTRAL ETHIOPIA: A COUPLED STRUCTURAL–FUNCTIONAL INNOVATION SYSTEMS ANALYSIS

Abstract

This study investigates how the *tef* innovation system has functioned to support the development of *tef* sector and what have been the systemic constraints in the process. A coupled structural-functional analysis is used to explore the systemic constraints of the *tef* innovation systems in Central Ethiopia. The findings show that limited capacity of existing actors, weak interactions and partnerships among actors, weak enforcement of institutions and inadequate and poor infrastructure are the structural elements that have constrained the development of the *tef* innovation systems. Results further reveal that among the seven innovation functions, technology development, technology diffusion, entrepreneurial activities, market development, resource mobilization, and legitimacy creation have been weak in the *tef* innovation functions. A failure in one of the innovation system's functions would have a knock-on effect on other functions, resulting in an overall dysfunctional innovation system. This study concludes that failures of the structural elements together with weaknesses of the innovation system functions have constrained the development of the *tef* innovation systems and the *tef* sector. Therefore, a combination of technological, institutional, and technical intervention would be paramount to tackle the systemic constraints that impeded the *tef* innovation systems.

Keywords: Ethiopia, functional systems, innovation, institutions, *tef*, structural elements

2.1 Introduction

The demand for *tef* has risen and is expected to continue to rise due to population growth, average incomes, and urbanization (Lee, 2018; ATA, 2013; Bekabil et al., 2011). Domestic *tef* production, however, has not kept pace with the population growth as a result the actual supply is well below the actual domestic and foreign market demand (Tareke et al., 2011). Researchers, extensionists, development practitioners, and policy-makers are faced with great challenge of meeting the rising demand for *tef*. Since the late 1950s, efforts have been made to improve the *tef* innovation system and production system (Yazachew, 2020; Kebebew et al., 2011). Despite such efforts, the *tef* innovation system has not been well-developed to support the livelihood of smallholders and the productivity is low and not reached at the desired leve (Tekle, 2020; Yazachew et al., 2020; Misgana, 2018; Tareke et al., 2011). Moreover, the uptake of improved *tef* technologies is low and limited to only a few varieties (Dejene and Bekele, 2015; Debelo, 2015; Negera and Getachew, 2014; Kebebew et al., 2013; Vandercasteelen et al., 2013). This poses the question as to why the tef innovation system is not well-developed and well-functioned. Besides why smallholder farmers are unable to take advantage of new improved technologies and agronomic practices in the *tef* sector. What systemic constraints obstacles the development of the *tef* sector and innovation system and prevents improved *tef* technologies from diffused at the large scale to smallholders?

Given these challenges to the sector, *tef* is Ethiopia's most important staple crop in terms of both production and consumption (Minten et al., 2016; Vandercasteelen et al., 2013; Bekabil et al., 2011). *Tef* ranked first in terms of area coverage, 3.1 million ha (24.1% of the area) and is second to maize in terms of volume of production among cereals, accounting for about 17.1% of the total produce in the category (CSA, 2020). It has high protein, fiber and complex carbohydrates content, relatively low calorie content, and is gluten free (FAO, 2015; ATA, 2013). *Tef* accounts for about 15% of all calories consumed in Ethiopia (Guush et al. 2011) and provides about 66% of daily protein intake (Lee, 2018; Bekabil et al., 2011). The grains of *tef* are also low in the glycemic index, making them suitable for celiac patients and people with type 2 diabetes (Lee, 2018; Spaenij-Dekking et al., 2005). *Tef* also used as a nutritious feed for cattle, the price is higher than other cereals, no disease epidemic has threatened its performance, and grain can be stored for a long time without being attacked by weevils (Melaku, 2020; Seyfu, 1989).

Despite spectacular success has been achieved in *tef* R&D, the *tef* innovation system is not well-developed and well-functioned to transform the *tef* production system and the livelihood of smallholders. Moreover, *tef* productivity is not reached at the desired level. *Tef* has been historically neglected crop compared to other cereals. According to Kebebew et al. (2013) *tef* has been a historically neglected crop compared to other cereals and remained largely excluded from advances in plant science, thus being categorized as "orphan", "neglected" or "underutilized" crop. We can witness that impressive progress made in other major cereal crops such as wheat, maize, and rice due to the prior acquisition and application of basic knowledge to the development of high-yielding varieties (Kebebew et al., 2013). Moreover, the *tef* innovation system and value chain has not reached its full potential because of various systematic constraints along the value chain (Bekabil et al., 2011).

Given the high prevalence of rural poverty and the large productivity gap, improving *tef* productivity and production system is Ethiopia's top priority, the high prevalence of rural poverty, and the large productivity gap. Agricultural development is a fundamental tool to increase agricultural productivity and ultimately food security (Mulubrhan et al., 2017; Usman et al., 2017; Fuglie, 2016; Avila and Evenson, 2010; Habtemariam, 2008). However, it needs and depends on innovation and innovation systems (Juma, 2009). The role of each actor in the generation and dissemination of agricultural technologies has been acknowledged in the agricultural innovation systems (AIS) approach (Kebebe et al., 2015; Amankwah et al., 2012; Klerkx et al., 2010; van Mierlo et al., 2010). The AIS approach recognizes the role of actors, institutions, actors' interactions, infrastructure and the historical dynamics of processes of innovation (Kebebe et al., 2015; Adjei-Nsiah et al., 2008). Thus, this research follows an innovation systems approach to investigate the systemic constraints of the smallholders' *tef* development, as a case study of Minjar Shenkora and Ada'a *woredas* in Central Ethiopia. Therefore, this study investigates how the *tef* innovation system has functioned to support the development of *tef* sector and what have been the constraints in the process. This study adapted the components of the structural-functional analysis framework to analyze the historical development of *tef* sector since the *tef* R&D began in the late 1950s (Wieczorek and Hekkert, 2012) and recommends possible interventions that could address the systemic barriers in the *tef* innovation system *tef* sector development.

The paper contributes to the existing an innovation system analysis literature in the three ways. Firstly, this research will contribute to the literature by investigating the systemic constraints by combining the *tef* R&D, extension, and innovation system together. Hence, this study is important to understand the *tef* sector systemic constraints simultaneously in a single study, thus, it is vital for designing a possible interventions to address the constraints together. Secondly, this paper is different from most of the previous studies, considering both the structural and the functional elements of the *tef* sector development constraints. This study will help to investigate the problems from the perspectives of the structural and functional elements point of view of the innovation system. Thirdly, this study contributes to the scant empirical evidence on the innovation system analysis of *tef* commodity.

2.2 Conceptual framework

Several conceptual frameworks have been developed to analyze agricultural innovation systems since the emergence of the innovation systems approach to study the systemic barriers of innovations (Kebebe et al., 2015; Klerkx et al., 2012). Structural elements analysis has been previously employed to study agricultural innovation systems (AIS) in both developed and developing countries (Amankwah et al., 2012; Turner et al., 2013). Functional elements analysis has been recommended as a promising approach to analyze AIS in developing countries (Rajalahti et al., 2008). Despite various frameworks that have been developed by different scholars separately, they were all intended to study the problems to the innovation system and technological change (Kebebe et al., 2015). To offsetting the limitations of each separate framework, Wiezcorek and Hekkert (2012) proposed a comprehensive framework that combined both structure (the elements that make up the system) and functions (how these elements work in support of the innovation). This enables analysis of the effectiveness of the important functions that support innovation, along with the presence and quality of the structural elements that are required for these functions to be effective (Bergek et al., 2008). Therefore, this study adapted a coupled structural-functional innovation system analysis framework to investigate the systemic constraints and weaknesses to the *tef* innovation system and technological change. A coupled structural-functional analysis framework and their relationship are described in detail below.

2.2.1 Structural analysis

The structural elements of the innovation system focus on the composition of the AIS: the presence of actors, interactions between actors, the institutions (rules of the game) that influence interactions of actors and infrastructure (Turner et al., 2013). The execution of the seven functions (Table 2.2) is dependent on the four structural elements of the innovation system (Table 2.1). The performance of the seven functions of the innovation system is influenced by the presence and quality of the four structural elements of the innovation systems. When the structural elements do not perform well, the outcomes are called 'system failures' or 'systemic problems' (Kebebe, 2015). The analysis links systemic problems with the various innovation system functions to explore the factors that influence specific functions and hinder the development of the innovation system. The four structure elements and the seven functions elements of an innovation system briefly presented in Table 2.1 and Table 2.2.

Table 2.1 Structure elements of agricultural innovation systems

Structure	Description
Actors	• The "players in the game" • Actors are individuals and organizations and tend to be delineated based on their role ✓ State actors ✓ NGO actors ✓ Farmers ✓ Farmers organizations (cooperatives) ✓ Market actors
Interaction	• Interactions are the dynamic linkages and partnership among actors from individual contacts to networks of actors
Institutions	• The "rules of the game" ✓ Formal institutions: rules, laws, regulations and instructions ✓ Informal institutions: customs, norms, common habits, established practices
Infrastructure	• The basic physical and organizational facilities

Source: Adapted from Wieczorek and Hekkert (2012)

2.2.2 Functional analysis

The functional elements of the innovation system have been focusing on the processes that contribute to successful innovation in the AIS (Turner et al., 2013; Rajalahti et al., 2008; Hekkert et al., 2007). The function of an innovation system is the types of activities related to event types that necessary build-up the innovation system (Suurs et al., 2010; Bergek et al., 2008; Hekkert et al., 2007). Therefore, this study adapted Wieczorek and Hekkert (2012) framework that combined both structural and functional elements of the innovation system, but it should be noted that the order is not the same as the authors. The order of the functions as follows: (1) technology development, (2) technology diffusion, (3) entrepreneurial activities, (4) guidance of the search, (5) market formation, (6) resource mobilization, and (7) legitimacy creation. A summary of system functions and diagnostic questions are given in Table 2.2.

Table 2.2 Functions and diagnosis questions for systemic analysis

System functions	Descriptions	Diagnostic Questions
F1: Technology development	Technology development is a source of advancement and change for agriculture and prerequisites for innovation to occur	Do the *tef* research generated sufficient and demand driven improved technologies and knowledge? All key actors involved in technology development?
F2: Technology diffusion	It is through linkages and important to further develop and adapt technologies, knowledge and innovations, and scale up and scale out (increasing number of users)	Are there sufficient interactions and partnership through which technology and knowledge is exchanged and scaling out?
F3: Entrepreneurial activities	Entrepreneurs have role by exploiting the potential of technologies and perform innovative commercial activities into concrete actions	Are there sufficient entrepreneurs to utilized outputs? Adequate support from the *tef* research system for entrepreneurships?
F4: Guidance of the search	It represents policy and strategies which defined a clear vision, mission, and performance targets which is important for *tef* research and development	Does the research system have clearly defined policy and strategy, vision, mission and clear direction for research and technology development?
F5: Market formation	New technologies often cannot outperform and to stimulate innovation system it is necessary to facilitate the creation of demand (niche markets), where new technologies have a possibility to grow.	Size of market sufficient to sustain entrepreneurial activities and innovation?
F6: Resource mobilization	Resource such as human, financial, and physical resources are crucial for research and innovation system development	Is there adequate and competent human resources? Sufficient public and donor funds? Adequate physical resources and facilities?
F7: Creation of legitimacy	Innovation often leads to resistance from established key actors. It reduces uncertainties and counteracts the resistance to change and developments.	Do key actors and institutions sufficiently contribute to creation of legitimacy? How much resistance is exists towards the research and development?

Source: Adapted from Wieczorek and Hekkert (2012); Suurs et al. (2010); Bergek et al. (2008); Hekkert et al. (2007).

2.3 Materials and methods

This research is based on a qualitative methodology. Qualitative research is data-rich, with extensive descriptions, in-depth inquiries, and the capture of people's own viewpoints and experiences (Creswell and Creswell, 2017). Using a qualitative technique, you can have a better understanding of the research problem. It does not begin with the notion that there is a pre-existing world that can be known, unlike the quantitative approach (Ejiga, 2006). Furthermore, it does not rely on tightly standardized data gathering procedures; rather, it relies on approaches that are adaptable to the social context in which the data are generated. In addition, a qualitative approach uses a number of data collection methods, including interviews, discussion, observation, and photography, as well as visual texts and personal interactions and experiences (Ejiga, 2006). As a result, it is multi-method in nature, encouraging the use of various methodologies in a single study. Therefore, a qualitative approach to investigating the systemic limits and weaknesses of innovation systems is more useful.

Data source and collection

The sources of data for this research were key informant interviews, focus group discussions, and document review, as is common in this kind of innovation system diagnostic studies (Lamprinopoulou et al., 2014; Wieczoreck et al., 2013; Negro et al., 2012; Gildemacher et al., 2009). The study was undertaking in two *woredas* of Central Ethiopia: Minjar Shenkora *woreda* from North Shewa Zone of Amhara Regional State and Ada'a *woreda* from East Shewa Zone of Oromia Regional State. The two *woredas* represent potential areas for *tef* production and better experience in using improved *tef* technologies. The data for this study considered both the national level and *woreda* level.

Key informant interviews: Key informants were identified from agricultural research institutions (7), ministry of agriculture (3), bureau of agriculture and *woredas* agriculture offices (2), development agents (8), farmers' organizations (2), traders (3), model farmers (6), and community elders (4). All the key informants were well experienced and knowledgeable in the *tef* research and development.

Focus group discussions: Six separate focus group discussions, each group consisting of 3-5 (for researchers only) and 6-10 participants were held with extensionists, and development agents with a standardized checklist for discussion. Moreover, eight separate focus group discussions, each group comprising 6-10 participants were held with farmers and community elders. All discussants were asked and discussed their free view and opinions about the main issues associated with *tef* research and development and constraints in the *tef* innovation system.

Literature review: To complement the information obtained from key informants and focus group discussants, peer-reviewed articles, books, proceedings, and conference papers were used. Moreover, government policy and strategy documents, published and unpublished reports have used for the development of *tef* innovation system in Ethiopia.

Data analysis

This study used an event history analysis based on the Wieczorek and Hekkert framework over time to explore the systemic constraints of the *tef* innovation system. The analysis focused on the *tef* sector development since 1950s when formal agricultural research and extension system began in Ethiopia. The event history analysis entails tracing the relationships between system functions and structural elements over time in order to better understand technological innovation systems (Kebebe et al., 2015; Hekkert and Negro, 2009; Bergek et al., 2008; Hekkert et al., 2007; Van de Ven et al., 1999). The analysis was built based on the document analysis and literature review and then endorsed and enriched with data collected from key informant interviews and focus group discussions. The qualitative data collected from key informants and focus group discussants were further analyzed to unravel the performance of the seven functions of AIS. Moreover, the event analysis is a narrative on how various structural elements and innovation system functions have interacted and shaped the *tef* innovation system over time.

2.4 Results and discussions

2.4.1 Structural analysis of the *Tef* innovation system

This section presents the performance of the four structural elements of the *tef* innovation system. The analysis includes the presence or capabilities of the existing actors, the presence or quality of their interactions and partnerships, the presence or quality of the institutional setup, and the presence or quality of the infrastructure.

Actors

Our analysis of actors involved in the *tef* sub-sector showed the dominance of public sector actors. The Ministry of Agriculture, regional bureau of agriculture, federal and regional research institutions has the mandate to generate and diffuse impoved technologies and extension and advisory services to smallholders. Although these actors are relevant in the *tef* innovation system, key informants indicated that five key actors in the *tef* innovation system that include state actors, NGOs actors, farmers' organizations, farmers, and market actors. Focus group discussants pointed out that private sector actors in the *tef* innovation system is largely absent.

State actors

Our analysis of state actors identified the following key state actors in the *tef* innovation system along the value chains, which include the Ministry of Agriculture (MoA) and Regional Agriculture Bureaus (BoAs), federal and regional research institutions, universities/Agricultural Technical and Vocational Education and Training (ATVET), public seed enterprises, federal and regional cooperative agencies, Agricultural Transformation Agency (ATA), Ministry of Finance (MoF), Ministry of Trade (MoT), and Ministry of Industry (MoI). These state actors have different institutional affiliations and functional relationships. The state actors engaged in multiple roles and responsibilities that include policy and strategy formulation, implementation, coordination, enforcement, supervision, and evaluation functions. For this study; however, the following key state actors were highlighted and described in Table 2.3, as they are the most relevant in the *tef* innovation processes.

Table 2.3: Some features of key state actors in the innovation system

State Actors	Major Functions and Role	Emphasis on *Tef* Development	Human Resources	Development Approach
MoA/ BoA	Coordinate the regional bureau and *woreda* agriculture offices, and supervises the three extension agents in the each *kebeles*.	*Tef* is one of the top priority crops in the study areas. Attention is given at various level zone, woreda, kebele	3-5 DAs with mainly diploma qualifications are assigned to the FTC to train farmers practically and give extension services	Demonstrate and transfer improved technologies to model farmers using FTCs s entry points
EIAR/ RARIs	Technology generation and adaptation popularize and demonstrate for farmers to create demand to the new technologies. Organize scientific forums.	DZARC is the center of excellence of *tef* and highly engaged in *tef* research and located with a smaller distance from the study areas	Two of the three PhD researchers in the *tef* research system found in DZARC, near to the study areas. But no senior researchers other than breeders in *tef*	Use various methods such as ADPLAC and FRG to aware, train and show demonstrate technologies and technical issues mainly done on station.
HLIs/ ATVETs	Teaching and training of Agricultural professionals	No HLIs and ATVETs closest to the study areas	Professors and PhD holders are available at universities but have very little contact with farmers. No adequate professionals at ATVETs	Conventional teaching Method and supplemented by apprenticeship
ATA	Identify systemic constraints of agricultural development and establish strong interactions among agricultural organizations and projects	*Tef* is a top priority crop for ATA, a number of studies conducted for appropriate development interventions	Adequate professionals available due to better incentives	Address systemic bottlenecks with in agricultural transformation agenda an agricultural commercialization clusters
Others	Policy formulation, finance provision and facilitation	No particular focus and emphasis by others	No adequate human resources at various level	Demand based and customer based approach

Source: Compiled from own analysis

Non-Governmental Organizations (NGOs) actors

Although numerous NGOs and CGIAR Centers are participating in Ethiopian research and development, only a few NGOs and one CGIAR (Bioversity) are interested in *tef* research and development. NGOs involved in *tef* research systems such as the McKnight Foundation, the International Atomic Energy Agency (IAEA), Syngenta Foundation, and the University of Bern. In addition, there are NGOs engaged in agricultural extension and advisory services promotion and dissemination such as SG-2000, Oxfam, World Vision, Self-Help Africa, CRS, SNV, Agri-service Ethiopia, etc. However, according to key informants, no NGOs currently supported the *tef* extension service provision in the study areas. For example, SNV is active in the study areas only to popularize and disseminate improved livestock technologies and advisory services for smallholders.

Farmers' organizations (cooperatives)

We identified a few agricultural cooperatives organised by the *woredas* offices of agriculture. The agricultural cooperatives in the study areas, according to key informants and focus group discussants, are primarily involved in collecting outputs from smallholders and distributing inputs, and they do not supply complementing technologies and services required in tef production. Focus group discussants acknowledge that the numbers of cooperatives in their areas but they are inadequate and limited capacity to serve all smallholder farmers. Moreover, the agricultural cooperatives have different capacities in terms of organizational capacity, finance, and the number of members. Most of the cooperatives serve as a channel for transferring agricultural inputs from MoA/BoA to the farmers.

Farmers

In the study areas, almost all (about 99%) of *tef* growing farmers are smallholder producers. These farmers are the smallest units of an innovation system and an important actor that put innovations and knowledge into practice. The involvement of farmers in knowledge and technology development facilitates the establishment of a knowledge society in which farmers are not just seen as end-users of technology but as an active part of an innovation system. The innovation system should be open to accepting farmers' indigenous knowledge to experiment and innovate, taking advantage of their valuable contribution. Despite such facts, key informants and focus group discussants describe their feelings as there is a gap in terms of integrating farmers' indigenous knowledge with the scientific knowledge to develop new technology and practices. Further, they mentioned that the R&D system gave less attention to local knowledge and considered mostly primitive and do not involved in the technology development process rather the research system looks at farmers to demonstrate their technologies for farmers.

Market actors

Various actors were involved in *tef* sector from the point of production till it reached the final destination (consumption). Only the key ones are discussed and presented in Table 2.4. *Tef* collectors, inputs suppliers, transport service providers, commission agents, equipment suppliers, and private pesticide providers are all part of the complex system of the *tef* value chains, despite they are not discussed in this study. The market participant identified in the transaction process of *tef* in the study area includes farmers/producers, farmer traders/local assemblers, regional wholesalers, cooperatives, retailers, commission agents, and processors (millers). The *tef* market actors involved in different activities such as producing, collecting, assembling, wholesaling, and retailing.

Table 2.4 Key *tef* market actors in the study areas

Market actors	Scale	Channel	Challenges/weaknesses
Producers/farmers	• Large number of *tef* growere in the study areas existed • Dominated by smallholders	• Producers sell to local assemblers known as farmer traders • Selling directly or selling through broker to urban assemblers and regional wholesalers. • They transport to the nearest markets village market or urban markets by themselves	• They mostly sold at harvest when prices are low. • Having less marketing facilities such as road, electricity, potable water etc.
Local assemblers (Farmer traders)	• The number of local traders in the study areas increasing • Rural collectors' sale *tef* to wholesalers.	• They are the only actors who buy *tef* from producers home • They are part-time traders in the assembly markets who used to buy small quantity of *tef* from farmers in village markets during slack period for the purpose of reselling	• They buy small quantity of tef from the producers/farmers
Wholesalers	• Only a few big marketers (wholesalers) dominated the *tef* output markets	• Wholesalers are major market actors of the marketing system usually buy larger volume than any other actors in the marketing system and resell the products to urban retail merchants and processors	• They sometimes purchase through broker which influence the profit margin of producers
Retailers	• Large number of retailers existed	• Retailers are located at the end of the marketing chains which have direct contact with consumers	• High decision making power on direct consumers
Cooperatives	• Only a few existed	• Supply inputs to farmers in time of production and buy farmers' output at harvest.	• Limited capacity to purchase outputs from farmers at the premium price

Source: Compiled from survey results and key informant interviews

Interactions

Although interactions and partnerships among actors are very important for the well-functioning of the *tef* innovation systems, our analysis shows that the interactions and partnerships are fairly limited. This is mostly due to differing perspectives among actors regarding aims, assumptions, and capacities, as well as a lack of trust, according to key informants. Most of the previous studies are in line with arguments such as Kebebe et al. (2015) and Seife et al. (2012). This weaknesses seriously highlighted in agricultural research, extension, and farmers (Gerba, 2018; Belay and Dawit, 2017; MoANR, 2017; Gerba et al., 2017; Belay, 2003). Due to this weakness, the uptake of improved *tef* varieties by farmers is limited to only to a few varieties (Kebebew et al., 2013). This has led to a challenge for a significant productivity improvement for *tef* crop. The required recognition of collaboration and coordination mechanisms, as well as the resource commitment required to make them function, is still generally lacking, according to key informants.

Since 1986, efforts have been made to improve and harmonize the interactions and partnerships among players in order to create functional links. These include the Research Extension Liaison Committee (RELC) (1986–1998), the Research-Extension-Farmer Advisory Council (REFAC) (1998–2008), and the Agriculture Development Partners Linkage Advisory Council (ADPLAC) (2008–present) (Belay and Dawit, 2017; Ludi et al., 2013). The ADPLAC was established as a multi-sectoral platform among actors in agricultural R&D (MoANR, 2017). In addition, in 2016, the Ethiopian Agricultural Research Council Secretariat (EARCS) was established to coordinate and strengthen relationships among national research systems. Despite such efforts, the interaction and collaboration among those actors remained limited and has been far from satisfactory. The presence of the multi-sectoral platform ADPLAC in most regions of the nation, including the study areas, is acknowledged by focus group discussants and key informants; nonetheless, this platform has little decision-making power and lacks sufficient resources to strengthen it. The platform also lacks a long-term vision and strategy for systematically creating alignment across the various development actors for a greater impact and it has not properly institutionalized at all levels. Representative individuals in the organizations lack commitment because it is an additional burden for them. Nonetheless, the MoA recently recruited permanent staff to coordinate and lead the ADPLAC at the national level, thus, it is expected the regions to recruit permanent staff for effective delivery of the responsibilities. Besides, despite the big responsible to coordinate and lead the national research system, the EARCS has not been playing its role as expected and hence it simply plays a facilitation role and has no decision-making power.

Institutions

Institutions can either encourage innovative systems by allowing for change, or they can stifle it by being dogmatic and closed-minded. According to North (2006), the incentive system of a society is formed by institutions and, as a result, political and economic institutions are the underlying factor in economic success. Institutions can be either inclusive or extractive (Kebebe et al., 2015). Inclusive institutions enable and encourage the great majority of individuals to participate in economic activities that best utilize their talents and abilities, while also allowing them to make their own choices (Acemoglu and Robinson, 2010). Extractive institutions have the opposite properties to inclusive institutions in that, for the benefit of a select group of elites, they are designed to gain profits and wealth from the greater community.

The findings of our study show that the political and economic structures in Ethiopia have historically been extractive. During the Imperial regime, the agricultural policy was mainly focused on large-scale commercial farming by ignoring the large majority of smallholders to benefit from R&D. The political system of the imperial era removed most of the fertile land from smallholders and shifted ownership to ruling elites through the *gult* land tenure system (Katkalo et al., 2010). Rather than promoting the widespread use of modern agricultural methods, the political system prioritized collecting taxes from the subject peasantry and extracting natural resources (Katkalo et al., 2010). Thus, farmers had few incentives to adopt improved agricultural technologies as they faced a high risk of landlords expropriating and taxing their output.

After removing from power the imperial regime, the *Derg* announced an agrarian reform program to declare all rural land to be the property of the state and controls all economic spheres including agriculture. The application of ineffective agricultural policies and a lack of investment in the smallholder sector, which dominates the national economy, have severely hampered agricultural development. Hence, the political system discouraged private enterprises and entrepreneurial activities. The *Derg* regime implemented agrarian reform including land tenure reform, nationalization of natural resources, expropriation of farmlands without compensation for the establishment of state farms, forced settlement in villages, promotion of producer and service cooperatives, the imposition of production quotas, and the regulation of agricultural commodity prices and marketing (Hoben, 1995). During the *Derg* regime, *tef* received little attention, and the government planned to substitute *tef* with more productive crops such as triticale due to low yield; but it was survived due to its high preference by the consumers (Hailu et al., 2001). A large percentage of smallholder farmers do not have access to better agricultural technologies or extension services.

Since 1991, the Ethiopian People's Revolutionary Democratic Front (EPRDF) leadership has prioritized smallholder agriculture for growth through the Agricultural Development Led Industrialization (ADLI) plan. By leveraging improved agricultural technologies and diversifying production on smallholder farms, the ADLI strategy encourages the adoption of labor-intensive methods to raise output and productivity. The agricultural sector considers small-scale agriculture to be a cornerstone. Consequently, the major focus of the national agricultural research systems is on small-scale agriculture and fish-folks while due attention is also given to private large-scale farmers (Fentahun et al., 2017). During this time, the research and development policies rely on the adaptation of proven technologies rather than generation. This policy direction set by the government appears a right one in the short term, and most of the released technologies by the research system are adapted ones (Fentahun, 2015). However, according to key informants, this should not be practical for endemic crops like *tef*, coffee, *noug* etc. where the source of origin is Ethiopia. Therefore, domestic research could play a vital role, and adaptation strategy is not being possible. Domestic research has to build adequate capacities to domestically develop improved technologies and ensure technology security and even in the long-term plan technology exports.

Infrastructure

Ethiopia's infrastructure development is weak, despite the importance of infrastructure in promoting and maintaining innovative systems. Although some improvements have been made in recent years, Ethiopia's development has been hampered for a long time by a large infrastructure gap. Infrastructure investment that has been successful has contributed significantly to the production and distribution of improved technologies (Johanson and Saint, 2007). Underdeveloped infrastructure, such as low road access, electricity, telecommunication, railways, etc. has held back Ethiopia's R&D (Foster and Morella, 2011). The lack of infrastructure creates a gap between farmers' output prices and market prices, thus reducing the income associated with the underdevelopment of the *tef* innovation system. Jayne et al. (2010) show that poor infrastructure increase the fixed cost of distribution and lowers the profit margin of farmers and can further reduce the adoption of improved technologies. Furthermore, inadequate infrastructure affects agricultural productivity, lowers earnings, and can further stifle the adoption of new technologies (Jayne et al., 2010). According to key informants and focus group discussants, the lack of roads in rural areas limiting the diffusion of improved technologies and constrained the adoption rate of the country. Moreover, lack of infrastructure particularly in rural areas creates a gap between the output prices and the market price and lowering the farm households' profits.

However, the country has initiated an ambitious investment program aimed at upgrading its infrastructure and setting up a modern road maintenance financing system. These investments in the public sector include the expansion of road networks, electricity, telecommunication, and most recently railways. For instance, Ethiopia has spent 37.3 billion birr in 2018/19 (excluding urban road), which rose by 12.6% from the previous year (NBE, 2018/19). As a result, the total road network has increased from 20,000 km in 1991 to 138,127 km in 2018/19 (NBE, 2018/19). Despite significant efforts to increase electricity development, Ethiopia continues to have one of the most underdeveloped power systems in Sub-Saharan Africa (SSA). Despite the number of customers for mobile telephone services and rural multi-purpose communication centers to benefit the rural communities has been increased, the coverage is still limited to certain areas. However, these services greatly helped rural communities in getting important information they needed for selling their products in the markets (NPC, 2017). Moreover, although in recent years, Ethiopia has made substantial improvements in the development of electric power, the country still has one of the most underdeveloped power systems in the SSA.

Table 2.5 Structural analysis of *tef* technological innovation system in Ethiopia

Time line/Period	Actors	Interactions	Institutions	Infrastructure
1950s – 1974 (Imperial regime)	• *Tef* production dominated by smallholders farmers • Limited key actors in research and knowledge institutes, • Input suppliers, civil society were missing	• No policy framework for linkages between actors	• Extractive institutions (lack of supportive policy to large majority smallholder farmers in *tef* production)	• Lack of *tef* R&D capacity • Underdeveloped *tef* supply chain • Poor infrastructure such as roads, electricity & telecom coverage
1975 – 1991 (*Derg* regime)	• *Tef* production dominated by smallholders • Lack of private input and service providers, • Weak knowledge, research institutes, and civil society	• The first functional linkages called Research Extension Liaison Committee (RELC) in 1986 was established • Weak interaction among various actors	• Partially extractive institutions • Strong campaign and enforcement of smallholders for shifting of *tef* with other high productive staple crops.	• Very limited government resource to *tef* development • Limited *tef* R&D capacity • Limited road, electricity & telecom coverage • Underdeveloped *tef* supply chain
1991 – present (EPDRF/PP)	• *Tef* production dominated by smallholders, currently about 7.1 million smallholders existed • Shortage of input and service providers	• Different platforms have been established including RELC, REFAC, ADPLAC, etc. • Limited commitment among actor to harmonize interrelated roles and establish functional linkages	• Inclusive institution (smallholder is taken as a cornerstone of the *tef* production) • Weak enforcement of existing rules and regulations	• Limited but improving R&D facility and infrastructure such as road, electricity & ICT coverage • Underdeveloped *tef* supply chain

Source: Own analysis

2.4.2 Functional analysis of the *Tef* innovation system

Technology development (F1)

The research system's central mandate is to develop improved technologies and knowledge that are oriented towards the overall growth of the agricultural sector. The *tef* research system, however, is constrained by limited basic and applied *tef* research, which serves as a basis for high-quality technology development. On one hand, a strong knowledge base needs to be developed from which more complicated *tef* research can be pursued. Since it is an endemic and staple food crop in Ethiopia, the development of basic research knowledge on *tef* is relatively little unknown in the international community. The *tef* research system was therefore heavily on the shoulder of domestic research. On the other hand, the focus of domestic research is highly focused on breeding, with limited attention to applied research in many areas, such as socio-economics, agronomy, physiology, food chemistry, crop protection, and mechanization. Despite such facts, key informants claimed that there are improved *tef* technologies that can enhance the crop yield on the shielve of the research system. But, they raised concerns regarding the dissemination of those technologies based on the interest of smallholders.

Although the number of technologies generated cannot ensure impact, the performance of the research system is measured by the achievements made in the generation of new technologies and production systems. For example, among the total improved released crop varieties (1,264), the *tef* research program has released 44 varieties. Despite spectacular success has been achieved in terms of developing improved tef varieties, no breakthrough for generating resistant to lodging, acidity, and waterlogged to address the critical challenges of smallholders. Lodging is one of the major constraints limiting the *tef* productivity especially when it occurs during the grain-filling period (Tareke et al., 2011). Lodging affects both the quality and quantity of the produce (Seyfu, 1993). Furthermore, the lack of pre- and post-harvest technologies has a negative impact on tef growers by increasing output losses. According to focus group discussants and key informants, significant *tef* yield losses are incurred during threshing, because threshing is done on the ground, and the quality of the grain is affected as it can become mixed with the soil, sand and other foreign matter. The typical post-harvest loss is estimated to be 15 to 25 % (Demese, 2015). Moreover, although smallholder farmers demanding some technologies for row planting, no mechanization farming is practiced for solving the problem of row planting for *tef* production. The national *tef* research system has attempted to develop varieties resistant to lodging, and pre-post-harvest technologies; however, no varieties have been developed to date.

Technology diffusion (F2)

The diffusion of improved agricultural technology has mainly been carried out by the public in Ethiopia. The Ministry of Agriculture (MoA) and the Regional Government Office of Agriculture have a core mandate to distribute extension services to end-users. The diffusion of technology involves the active participation of actors. Klerkx et al. (2012) suggested that the research system must be efficiently linked and interacted with other actors in the innovation system in order to promote and disseminate innovations. The presence of various actors in technology diffusion was acknowledged by key informants and focus group discussants. Nevertheless, interaction and partnership among relevant actors in the value chain are limited and weak. In spite of the availability of released technologies, the adoption of improved *tef* technologies is low and limited to just a few varieties due to weak interactions (Kebebew et al., 2013). This is mainly because of different perceptions of objectives, assumptions, capacities, or lack of trust among actors. This indicates the presence of “directionality failure”, which refers to the lack of shared vision and the inability of collective coordination of fragmented change agents (Kebebe et al., 2015; Seife et al., 2012). This resulted in a productivity gap in agriculture and subjected the country to recurrent food shortages and food insecurity (Tsedeke et al., 2011).

In addition, despite the Participatory Extension System (PES) approach since 2010 (ATA, 2014), the technology delivery system still features the classical model of technology transfer (ToT) model (MoA, 2010; Röling, 2009; Belay 2003). The technology diffusion approach in Ethiopia is highly organized in a top-down technology transfer manner, according to Gerba et al. (2017), and DAs may encourage farmers to take up and use technologies, but rarely encourage them to develop and adapt technologies to their circumstances. A successful agricultural extension system, however, accepts and integrates the traditional knowledge of farmers into the processes and sees farmers as partners in decision-making (Gizachew, 2008). Key informants and focus group discussants spoke of the disparity between the expansion of the disseminated technologies and the farmers' demands. This means that the delivery system of the extension service still has a linear route. Although there is an annual demand forecast plan by the MoA through DAs; there is a huge gap in quantity, quality, and form between the *woreda* demanded and the technologies dispatched by the federal governments through cooperatives and other means, according to focus group discussants. Therefore, farmers are forced to use their own varieties, borrow from neighbors, take the available inputs or look at their choices.

Entrepreneurial activities (F3)

This sub-section discusses the entrepreneurial activities of smallholder *tef* producers. The bases for business activities in Ethiopia are agricultural products (Werotaw, 2006). Hence, the entrepreneurship issue is as important for the survival of its population because the large majority of the population engaged in agriculture. Entrepreneurship is a continual process that involves creating a new company to manufacture new goods and services (Werotaw, 2006). Entrepreneurial activities in Ethiopia, however, are poor, underdeveloped, and not modernized, according to key informants and focus group discussants. Most farmers are subsistence and they sell their produces immediately after harvest without any value addition and there are no entrepreneurial activities in their nearest to work together.

According to our analyses, a variety of reasons contribute to Ethiopia's low entrepreneurial activity. Farmers and others interviewed in the tef value chain said there were a small number of enterprises engaged in entrepreneurial activity and value addition. This was primarily due to actor capability limits, as the bulk of agricultural businesses are small to medium-sized organizations. The base of entrepreneur activities and value addition is largely dependent on agricultural outputs, but it is very backward and resource is at a low level. Most of the entrepreneur companies are based in urban areas, particularly in Addis Ababa, which makes *injera* to sell for local and international markets. These include Mama Fresh, Sheba Farm, and Love Grass. According to key informants, there have no large-scale entrepreneur activities and value addition in the *tef* commodities rather than *injera* making. The share of these companies is very minimal and utilized less than 1% of all *tef* consumed in Ethiopia and the rest processed by families in their own homes or informal neighborhood processors (Bekabil et al., 2011).

Moreover, weak entrepreneurship skills and capacity of *tef* producers and limited advisory service on entrepreneurship constrained the development of entrepreneur activities in Ethiopia.

Key informants and focus group discussants affirmed that most farmers lacked the entrepreneur skill to undertake entrepreneurial activities due to the lack of advisory services to the farmers. Furthermore, in Ethiopia, entrepreneurial activities have not been adequately supported by knowledge and training. Besides, cultural barriers and social constraints are also responsible for the poor entrepreneurial capability of smallholders. They argue that most smallholders in Ethiopia often do not make investments, even when returns are high, because they have low aspirations. Additionally, a public-private partnership to support entrepreneurial activities is weak and limited. Limited interaction and collaboration among actors in the *tef* value chain to support smallholders to engage in entrepreneur activities and value addition. Focus group discussants and key informants mentioned that lack of sufficient financial resources and advisory services required undertaking entrepreneurial activities. However, secure adequate finance, advisory services, or inputs for technological inputs is difficult for smallholders to participate in entrepreneur activities and value addition.

Guidance of the search (F4)

Several policies and strategies have been designed and implemented in Ethiopia since the 1950s. These policies and strategies have been oriented towards the development and promotion of agricultural growth and food security. Agricultural policy and strategy have been following and shaped up by the successive regimes that ruled the country. The imperial regime was the first government in Africa to exercise different development policies and economic development planning. The policies were adopted over the course of three consecutive five-year agriculture development programs during this time (Demese, 2015). Large-scale commercial farms were significantly supported in the first two five-year plans (1957-1962 and 1962-1967), at the expense of the majority of smallholders. An increase in production was expected to be achieved through accelerated investment in large-scale farms under the dominant line of thinking of the imperial government (EEA, 2005). The military regime came to power in 1974 with new policies in Ethiopian agriculture and land use policy. The *Derg* ended the previous system and transferred private ownership to public ownership so that it distributed land to rural farm households. The *Derg* established different associations and cooperatives in the countryside (Dessalegn, 1984). Therefore, the agricultural policy was implemented through the alliance of cooperatives and state farms.

Through the Agricultural Development Led Industrialization (ADLI) policy, the present government has made smallholder agriculture a development priority (Dorosh and Mellor, 2013). Consequently, the main focus of the strategy aimed to generate surplus agricultural output by using technological inputs on smallholder farms. According to this direction, the government implemented the Sustainable Development and Poverty Reduction Program (SDRP, 2002/03-2004/05) and the Plan for Accelerated and Sustainable Development to End Poverty (PASDEP, 2005/06-2009/10) in attempts to realize the vision of ADLI. PASDEP's success and the lessons learned from its execution served as the foundation for the growth and transformation plans I (GTP I) and II (GTP II) for 2010/11-2014/15 and 2015/16-2019/20, respectively. During these successive implementation plans, the level of productivity has been increased but it does not reach the expected level to ensure national self-sufficiency.

Ethiopia does not have a national agricultural extension strategy or long-term strategic vision for a long time until 2017. Hence, the extension system has been used in different approaches or methods to deliver services. The first national agricultural extension strategy was developed in Ethiopia in 2017. However, the government of Ethiopia has been developed various policies and strategies for a longer time, but the implementation approach has been repeatedly changing. Despite this, Ethiopia has been developed the National *tef* strategy and value chain since 2013 to align all stakeholders on a unified and comprehensive approach to improve the production and profitability of *tef* producers, while also improving opportunity for consumers (ATA, MoA and EIAR, 2013). Moreover, the second phase national *tef* research strategy (2016-2030) has been developed and brought into practice through engaging various relevant actors in the *tef* value chain to transform agricultural production and productivity.

However, the process of implementing agricultural development policies and strategies has been the major challenge in Ethiopia. The policy and implementation strategies have been repeatedly changing and inconsistent, according to key informants. This repeated and sudden changing of policies and implementation strategies contributes to increasing the number of farmers who do not trust the state extension and planning system (Gerba et al., 2017). Habtemariam (2008) described it as “rapidly changing policy signals” in which case the state frequently sends signals that induce swift changes. Accordingly, the extension system has been promptly changing, from national-scale activities.

Market formation (F5)

Tef is mainly grown as a cash crop in most of the country, particularly in the study areas. It is the second most important cash crop after coffee (Efa et al., 2016). Tef's market surplus is equivalent to the total market surplus of the country's three major cereal crops (sorghum, maize, and wheat) (CSA, 2013). Focus group discussants in the study areas reveal that most of their produces are supplied to the market. Access to accurate and timely market information enables appropriate decision-making by farmers and traders in terms of what to produce and trade, where and when to buy or sell (Demese, 2015).

Our document analysis indicated that demand for tef products is increasing in Ethiopia due to rapid population growth, rising income, and urbanization. *Tef* production, on the other hand, is mostly based on traditional methods, and the output market lacks large-scale processing and purchasing in order to benefit from economies of scale (Lee, 2018). Ethiopia, while having the biggest output volume, is not profiting from its crop on the international market (FAO, 2015). Other countries, on the other hand, are actively participating in tef marketing in order to grab the growing market. The export volume has been declined since 2006 when the government imposed an export ban on unprocessed *tef* grain and flour to protect local consumers; however, the domestic price of *tef* remains high, widening the price gap between *tef* and other cereals such as wheat and maize (FAO, 2015). Despite such facts, *tef* producers may not be benefited as expected, according to key informants and focus group discussants. This is due to the inefficiency of tef markets as well as the ineffectiveness of input and output markets. During the field visits in the study areas, we identified various smallholder traders, but only a few big marketeers dominated the *tef* output markets. According to his analysis, the four largest *tef* traders controlled 65% of the total market volume. Market supply chains are considered to be long and complex, characterized by many transactions, with heavy involvement of middlemen and brokers. Hence, the market transaction costs are artificially inflated due to this complex supply chain.

Focus group discussants in the study areas identified inadequate supply, untimely availability, and poor quality of agricultural inputs as a major constraint to *tef* development. Moreover, discussants identified the absence of adequate private enterprise to sell improved technologies as major constraints, because the supply and distribution of agricultural inputs have been for the most part owned and run by the government (Bekabil et al., 2011). They further mentioned that important inputs for *tef* production such as planting, post-harvest technologies have not been availed in the input markets as a major constraint influencing *tef* production. We identified different cooperatives and farmers' unions in the study areas, however, according to focus group discussants, the cooperatives are mainly involved in supplying some agricultural inputs such as chemical fertilizer and collecting agricultural produces, but the majority of them do not provide the complementary inputs and services needed in *tef* production.

Efforts have been made by the government to enhance the efficiency of the output market by taking various measures. Connect *tef* producers directly to the markets through cooperatives and farmers' unions. Cooperatives are organized to increase the value of members' output by reducing the number of middlemen. It can improve farmers' marketing by providing storage facilities. During field visits, we identified various warehouses in the study areas established by cooperatives. Focus group discussants acknowledge the presence of warehouses for serving as storage for smallholders to store theirs produces to get the premium prices. Moreover, the MoA and different actors have developed the working strategy to strengthen *tef* value chain to minimize the intermediaries that influenced the output marketing.

Resource mobilization (F6)

Resources in terms of human, financial, and physical resources are very important for facilitating and sustaining innovation systems. Successful investment in those resources has made a significant contribution to the generation and dissemination of improved technologies (Johanson and Saint, 2007). The competence of human resources in R&D is highly important for an effective innovation system. Innovation systems need to attract, improve, reward, and retain competent staff. According to key informants, the tef innovation system, particularly tef research, has a severe deficit of human resources in terms of both quality and quantity. This limits the scope of breeding, agronomy, and crop protection research, among other areas. These resource shortages are compounded by the fact that *tef* is an “orphan crop” and has not supported by the international scientific community. Our analysis show that large majorities of researchers are the youngest, junior, and qualified to the BSc degree level, despite the number of researchers continued to increase in the research system. In addition, *tef* is endemic to Ethiopia as a staple food; there is a lack of international experience in advanced modern sciences. There is a lack of emphasis by the CGIAR Centers for *tef* research, as there exists for other crops. Therefore, the *tef* research staffs have been working in isolation from other similar scientists in the world, except a few like the Bern University and Bioversity institute. There has been little if any capacity improvement since the late 1950s, which is detrimental to the *tef* research progress. This indicates that the human resource capacities in the *tef* research are lack experience from the international community. Therefore, those young researchers lack international experience and exposure to the implementation of quality research.

Ethiopia has proved its commitment to agricultural and rural development by dedicating 10% of the national budget to the sector in the last decade, based on the Maputo Declaration (MoANR, 2017; ATA, MoA and EIAR, 2015). Signatory countries, including Ethiopia, have allocated 10% of their expenditure to agriculture and rural development. Although several countries were unable to achieve this target, Ethiopia was among the top 10 countries between 2003 and 2011. However, since 2012, agricultural expenditure has dropped well below 10%, with an average spending share of around 5.2% (MoA, 2020). The proportion allocated to agriculture is even smaller when agricultural development expenditure and food security expenditure are further disaggregated (Birhanu et al., 2016; MoA, 2020).

Agricultural research expenditures generated far less than the 1% benchmark specified by the Comprehensive Africa Agriculture Development Program (CAADP) as of AgGDP (AU, 2006). The amount of research expenditure in the country remains well below the sub-Saharan African average and is one of the lowest in Africa (FAOSTAT, 2019; Beintema and Tesfaye, 2018; EARCS, 2016). Likewise, the *tef* R&D has not been obtained adequate funding to undertake advanced research. The financial resource deficiency of *tef*, however, is compounded by the fact that *tef* is an "orphan crop" and the receipt of donor funds is very small. This is primarily because *tef* is endemic as a food crop to Ethiopia and, compared to other cereal crops, it is less likely to obtain external funding and adapting basic research knowledge from the international scientific community. Therefore, adequate public budgets are required, at least on an equal footing with other cereals. However, our analysis indicates that the crop has earned insufficient domestic public funding and is second to last in terms of cereal funding. Attempts have been made since the 1990s to raise funds from foreign donors such as the McKnight Foundation and the International Atomic Energy Agency (IAEA), but they have not been sustainable. Currently, through the Syngenta Foundation, the University of Bern is funding the research to increase productivity. Nevertheless, it is inadequate and very limited to advance the *tef* R&D.

Other factors that constrained the development of the *tef* innovation system in Ethiopia are the physical resources and research facilities limitations. In order to meet their duties, there has been a major gap in physical infrastructure and research facilities that needs to be filled. For example, many of the research facilities, labs, and research centers have been established through various projects such as ARTP, RCBP, and EAAPP; and, of course, the AGP project is currently underway. Due to long service, the majority of such research facilities and laboratories are old and obsolete. In addition, precision equipment, advanced analytical facilities, farm machinery, irrigation facilities, and ICT infrastructure are seriously lacking. The research system is thus forced to follow traditional methods of research that do not predict outcomes in the process and require a longer time to develop improved technologies. The Advanced Tef Research Laboratory, on the other hand, was established in 2020 with financial support from the Syngenta Foundation and with the help of the University of Bern and ATA.

In addition, to promote best practices, FTCs serve as hubs for knowledge and information sharing centers. In recognizing this fact, the government established more than 12,500 FTCs located across the country's national regional states (MoANR, 2017; Lefort, 2012). However, they are at varying levels of functionality, and a large number of them are unable to provide farmers with the expected services, including study areas. This is partly due to the lack of physical infrastructure and equipment, the lack of farmers' ownership, and the minimal involvement of farmers in the management of the FTC. Due to these limitations, a considerable number of FTCs were unable to function as intended, and several were closed. During our field observations, for instance, Golo Dertu kebele FTC was closed due to a lack of physical resources, facilities, and lack of support from farmers and FTC management members.

Creation of legitimacy (F7)

Tef agricultural development policy and implementing procedures employed since the 1950s influenced by the policy direction of successive regimes. During the Imperial period (1950s–1974), Tef research and development focused on increasing the production and productivity of large-scale commercial farming. However, the large majority of smallholder *tef* producers were restricted to benefit from using improved agricultural technologies. Similarly, the *tef* research program has passed through different phases since the 1950s at Jimma College of Agriculture focused on breeding to enhance productivity (Cheng et al., 2017; Minten et al., 2016; Kebebew et al., 2011; Berhanu and Hoekstra, 2007). During 1956–1974, the research focused largely on germplasm enhancement, genetic improvement relying entirely on pure-line selection, and initiation of induced mutation techniques. The *Derg* administration launched an agrarian reform program in which all rural land would be declared state property, and the regime would have control over all economic domains, including agriculture. The government regulated the grain trade through the Agricultural Marketing Corporation, a government-owned corporation (AMC). During this period, the government attempted to discourage *tef* production because of its low yield but its high demand and adaptation to various environmental conditions of the country have sustained it (FAO, 2015). While the government declared land tenure, there was no access to research, extension and agrometeorological services for large numbers of smallholders. The *tef* research breeding program between 1975 and 1995 discovered the crossing techniques.

The EPRDF government implemented major policy reforms after overthrowing the preceding military government in 1991. The Agricultural Development Led Industrialization (ADLI) plan prioritizes smallholder agriculture for development. Since then *tef* is considered one of the major commodities to ensure food security. During this period, research and development policy documents reveal that agricultural technology development should be focused on the adaptation of proven technologies. This policy document will be possible and practical to find suitable technologies from elsewhere in the globe and adapt them for immediate use. However, this strategy cannot be practical for crops like *tef* where the source of origin is Ethiopia. Therefore, *tef* technology development depends largely on domestic research; adaptation strategy is not being possible. The government looks right in the short term, and most of the released technologies by the research system are adapted ones (Fentahun, 2015). Generally, available evidence shows that policies and implementing procedures and associated with the dynamic of government interest, influence legitimacy creation to the *tef* innovation systems in the country.

2.4.3 Structural-functional analysis of the *Tef* innovation system

This section presents a coupled weakness of the functional elements with the failure in the structural elements, based on the results provided in previous sections (Table 2.6). The systemic failures and weaknesses in the *tef* innovation system have affected the development of innovation functions such as technology development, technology diffusion, entrepreneurial activity, market formation, resource mobilization, and creation of legitimacy. This indicates that the failures and weaknesses in structural elements of the innovation system underpin the slow development of *tef* innovation functions. This result is in line with the findings of prior studies by Kebebe (2015) and Negro et al (2012). Absence or weakness in one of the innovation functions, in turn, would have a significant impact on the other system functions which ultimately cripple the whole *tef* value chain. The systemic imperfections and malfunctioning in innovation functions, in turn, constrained farm households from taking advantage of improved technologies and economic benefits. The result of a coupled structural-functional analysis implies that the underdevelopment of the *tef* research and development in Ethiopia could be described by the weaknesses in innovation functions and systemic imperfections or failures such as limited actors and competence of actors, institutional and interaction, and partnership failures.

Table 2.6 Systemic problems causing weaknesses or absence of the functions in the *tef* innovation systems

System function	Weakness in innovation functions	Systemic failure (missing or weak)	Type of structural weakness
F1: Technology development	• Inadequate technology and knowledge for farmers alternative choices and for all agro ecologies • Insufficient knowledge on institutional arrangements for coordinating harmonizing sources of knowledge among the NARS • Limited *tef* research outside breeding such as mechanization, irrigation, threshing, processing, storage	• No private actors in the research system, dominated by public research • Weak interactions and partnership among actor in developing demand driven technologies • Limited research capacity to developing breakthrough technologies • Lack of basic knowledge • Lack of advanced molecular sciences	• Missing relevant actors • Capability failure • Hard and soft institution failures • Interaction, cooperation, and partnership failure
F2: Technology diffusion	• Limited public actors engaged in technology and knowledge diffusion • Extension mainly focus on dissemination of improved technology and knowledge • Lack of adequate and quality inputs for technology diffusion based on farmers' choice	• Main actors in technology diffusion engaged in multiple tasks (overloaded) • Poor infrastructure for technology diffusion • Development agents lack clear guidelines to manage innovation system • Weak or limited cooperation and interactions among key actor i.e. research-extension-farmers	• Missing relevant actors • Interaction failure • Infrastructure failure
F3: Entrepreneurial activities	• Limited number of firms undertaking entrepreneurial activity and value addition. • Most farmers are smallholder and subsistence farming • The existed private entrepreneurs small and medium size • Low aspiration, social constraints and	• Weak entrepreneurship skill and capacity • Limited advisory service on entrepreneurship • Poor infrastructure for entrepreneurial activities • Weak public-private partnership to support entrepreneurship	• Limited actors, • Demand articulation failure • Interaction and partnership failure • Physical infrastructure failure • Capability failure

System function	Weakness in innovation functions	Systemic failure (missing or weak)	Type of structural weakness
	cultural barriers		
F4: Guidance of the search	• No national extension strategy till 2017 • Policy and implementation strategies inconsistent and repeatedly changing • Limited duty-free privileges for innovations for long time	• Limited actors to increased protection of property rights • Weak enforcement of laws and property rights • Limited organizational capacity and human competence to protect property right of *tef* germplasm	• Hard and soft institution failures • Capability failure
F5: Market formation	• The supply of agricultural inputs dominated by public sector • Limited scope and coverage of cooperatives to address all farmers • Markets are inefficient and poorly functioning	• Lack of coordination and partnership hindering delivery of inputs • Poor infrastructure for the output markets such as road networks and ICT • Limited private market actors for agricultural inputs	• Missing actors • Infrastructure failure • Interaction failure • Market failure
F6: Resource mobilization	• Most *tef* research and development programs and projects financed by public • Limited private/donors funding for *tef* research and development • Dire shortage of physical resources, facilities, modern laboratory equipment	• Inadequate funding • Lack of adequate physical facilities and competent human resources	• Physical infrastructure failure • Insufficient financial resources • Limited research and development capability
F7: Creation of legitimacy	• Interaction, partnership and advocacy among professional association, policy makers, farmers' organizations is weak • Lack of clear policies for endemic crops to set clear vision, objectives and targets	• No strong legal framework for interactions and limited enforcement among relevant actors • Weak interaction and collaborations among relevant actors	• Missing actors • Interaction and partnership failure • Capability failure

Source: Own analysis based on the framework

2.5 Conclusions and policy implications

This study tried to investigate the systemic constraints of the *tef* sector development through the innovation system approach in Central Ethiopia. It was driven by one fundamental research question: how the *tef* innovation system has functioned to support the development of *tef* and what have been the systemic constraints in the process. A coupled structural-functional analysis of innovation system framework was used to analyze the failure of the structural elements and the weaknesses of the functional elements in smallholder *tef* production systems. The limited capacity of existing actors, weak interaction among actors, weak enforcement of institutions, and poor and inadequate infrastructure are the structural elements that all associated with the underdevelopment of the *tef* innovation systems. These structural weaknesses have also influenced the development of innovation system functions such as technology development, technology diffusion, entrepreneurship, market formation, resource mobilization, and legitimacy creation. This means that a weakness in one of the innovation system's functions will have a ripple effect on other functions, resulting in a dysfunctional innovation system as a whole. Hence, there is no a single, all-encompassing intervention that addresses the problems in the *tef* innovation systems. Thus, the *tef* sector development could benefit from current efforts aimed at enhancing systemic interaction in the AIS.

Three important conclusions are drawn from this study. Firstly, synergetic efforts, diverse kinds of knowledge, and understanding are very helpful to unpack the constraints of the *tef* innovation system and sector development. The study revealed that there is no single or all-encompassing intervention that tackles the *tef* sector constraints. Therefore, the *tef* sector development could benefit from current efforts targeted to strengthen interactions in the innovation system. Secondly, a range of organizational interventions includes a combination of technological, institutional, and technical intervention would be of paramount importance to tackle the structural and functional constraints that impeded the development of *tef* sector. Thirdly, the underdevelopment of the *tef* sector could be explained by the weaknesses in the innovation system functions as well as systemic failures in the structural innovation systems. As a result, the smallholder *tef* producers are unable to establishing and operating well-functioning entrepreneurial activities and market formation.

The results of this study point to the following important implications. First, this study revealed that how a coupled structural and functional innovation system analysis and their synergy played a key role in identifying constraints in smallholders' *tef* development, rather than applied separately. Because both of them are insufficient by themselves to investigate the constraints in an agricultural innovation system approach. As a result, not only is it vital to link both roles to the structure of innovation systems for analytical purposes, but it is also necessary for practical reasons. Second, our result revealed that a coupled structural and functional innovation system analysis is a promising analytical tool to investigate the systemic constraints of *tef* sector development in Central Ethiopia. The study shows the relationship between the two in that the functional analysis complements the structural one by showing how an agricultural innovation system is organized. We can witness, the coupled functional-structural framework appears to be a promising framework in exploring the systemic constraints of the smallholders' *tef* sector development and other smallholder agriculture sector development in Ethiopia and elsewhere. Therefore, further research is required on how a coupled functional-structural framework appears to be a promising framework in identifying the bottlenecks in the smallholder innovation system in developing countries.

2.6 References

Adjei-Nsiah, S., Leeuwis, C., Giller, K., & Kuyper, T. (2008). Action research on alternative land tenure arrangements in Wenchi, Ghana: learning from ambiguous social dynamics and self-organized institutional innovation. *Agriculture and Human Values*, *25*(3), 389-403.

Acemoglu, D., & Robinson, J.A. (2010). Why is Africa poor? *Econ. Hist. Dev. Reg. 25*, 21–50.

Amankwah, K., Klerkx, L., Oosting, S., Sakyi-Dawson, O., van der Zijpp, A., Millar, D. (2012). Diagnosing constraints to market participation of small ruminant producers in northern Ghana: An innovation systems analysis. *NJAS-Wageningen Journal of Life Sciences 60*, 37-47.

ATA (2014). Transforming Agriculture in Ethiopia. Annual report 2013/2014. Agricultural Transformation Agency, Addis Ababa.

ATA (2013). Results of 2012 new *tef* technologies demonstration trials draft report VF. Agricultural Transformation Agency, Addis Ababa, Ethiopia.

ATA, MoA & EIAR (2015). Strategy to improve Ethiopia's National Agricultural Research System (NARS): Vision, *systemic bottlenecks, strategic interventions and implementation framework, Addis Ababa.*

ATA, MoA & EIAR (2013). Working Strategy for Strengthening Ethiopia's *tef* Value Chain: *Vision, Systemic Challenges, and Prioritized Interventions, Addis Ababa*.

AU (2006). Status of food security and prospects for agricultural development in Africa. *African Union (AU), Addis Ababa*.

Bekabil Fufa, Befikadu Behute, Simons, R., and Tareke Berhe (2011, November). Strengthening Tef value chain: In: Tef Improvement: Achievements and Prospects. In *Proceedings of Second International Workshop* (pp. 7-9).

Belay Kassa (2003). Agricultural extension in Ethiopia: the case of participatory demonstration and training extension system. *Journal of social development in Africa*, *18*(1), 49-84.

Belay Kassa & Dawit Alemu (2017). Agricultural research and extension linkages: Challenges and intervention options. *Ethiopian Journal of Agricultural Sciences*, *27*(1), 55-76.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research policy, 37*(3), 407-429.

Berhanu Gebremedhin & Hoekstra, D. (2007). *Cereal marketing and household market participation in Ethiopia: the case of teff, Wheat and rice* (No. 307-2016-4963, pp. 5-14).

Beintema, N., & Tesfaye Haregewoin (2018). *Ethiopia: Agricultural R&D indicators factsheet update*. Intl Food Policy Res Inst.

Birhanu Gedif, Tegegn Molla, Solomon Addisu & Yibeltal Ayenew (2016). Status of agricultural innovations, innovation platforms, and innovations investment. 2015 PARI project country report: Federal Democratic Republic of Ethiopia. In *Forum for Agricultural Research in Africa*.

Cheng, A., Mayes, S., Gemedo Dalle, Sebsebe Demissew, & Massawe, F. (2017). Diversifying crops for food and nutrition security–a case of *tef*. *Biological Reviews, 92*(1), 188-198.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

CSA (2020). Agricultural sample survey 2019/20 report on area and production of major crops for private peasant holdings, *Meher* season, volume I. Central Statistical Agency, *Addis Ababa*.

CSA (2013). Agricultural sample survey 2012/13 report on area and production of major crops for private peasant holdings, *Meher* season, volume I. Central Statistical Agency, *Addis Ababa.*

Debelo Duressa (2015). Analysis of factors influencing adoption of Quncho tef: The case of Wayu Tuqa District. *International Journal of African and Asian Studies, 12,* 20-28.

Dejene Bayissa & Bekele Tassew (2015). Determinants of farmer's adoption of full extension package on improved tef technology: the case of Dendi district, West Showa, Oromia Regional State, Ethiopia. *International Journal of Current Research, 7*(9), 20816 – 20821.

Demese Chanyalew (2015). Ethiopia‘s Indigenous policy and growth: agriculture, pastoral and rural development. *Addis Ababa, 867pages*.

Dessalegn Rahmato (1984). *Agrarian reform in Ethiopia*. Nordic Africa Institute.

Dorosh, P. A., & Mellor, J. W. (2013). Why Agriculture Remains a Viable Means of Poverty Reduction in Sub-Saharan Africa: The Case of Ethiopia. *Development Policy Review*, *31*(4), 419-441.

EARCS (2016). Ethiopian agricultural research council roadmap (Amharic version). Ethiopian Agricultural Research Council, Addis Ababa.

EEA (2005). *Report on the Ethiopian Economy* (Vol. 5). Ethiopian Economic Association, Addis Ababa.

Efa Gobena, Degye Goshu, Tinsae Demisie & Tadesse Kenea (2016). Determinants of market participation and intensity of marketed surplus of *tef* producers in Bacho and Dawo Districts of Oromia State, Ethiopia. *Journal of Agricultural Economics and Development*, *5*(2), 20–32.

Ejiga Jemberu (2006). The persistent food crisis in Ethiopia: causes, government responses and household strategies; the case of Enebse Sar Midir district. *Trondheim, Norway: Norwegian University of Science and Technology*.

FAOSTAT (2019). Food and Agriculture Organization of the United Nations. Retrieved from FAOSTAT agricultural database http://www.faostat.fao.org/ on September 12, 2019.

FAO (2015). Analysis of price incentives for *tef* in Ethiopia Technical notes series, MAFAP, by Assefa B. Demeke M., Lanos B, Food and Agriculture Organization of the United Nations, Rome.

Fentahun Mengistu (2015). Thoughts on governance and future orientation of Agricultural Research in Ethiopia. *Ethiopian Journal of Agricultural Sciences*, *25*(1), 17-30.

Fentahun Mengistu, Abebe Kirub & Fisseha Zegeye (2017). Retrospect and prospect of Ethiopian agricultural research. Ethiopian Institute of Agricultural Research, Addis Ababa.

Foster, V., & Morella, E. (2011). Ethiopia's infrastructure: a continental perspective. *World Bank Policy Research Working Paper Series 2011*.

Gerba Leta (2018). *The Ethiopian Agricultural Extension System and Its Role as Development Actor: Cases from Southwestern Ethiopia* (Doctoral dissertation, Universitäts-und Landesbibliothek Bonn).

Gerba Leta, Girma Kelboro, Stellmacher, T., & Hornidge, A. (2017). The agricultural extension system in Ethiopia: operational setup, challenges and opportunities ZEF, Center for Development Research, University of Bonn Working Paper 158.

Gildemacher, P. R., Kaguongo, W., Ortiz, O., Tesfaye, A., Woldegiorgis, G., Wagoire, W., & Leeuwis, C. (2009). Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. *Potato research*, *52*(2), 173-205.

Gizachew Kebede (2008). Agricultural extension and its impact on food crop diversity and the livelihood of farmers in Guduru, Eastern Wollega, Ethiopia. An MSc thesis submitted to Norwegian University of Life Sciences (UMB), Trondheim.

Guush Berhane, Zelekawork Paulos, Kibrom Tafere & Seneshaw Tamru (2011). Food grain consumption and calorie intake patterns in Ethiopia. *IFPRI Ethiopia Strategy Support Program II (ESSP II) Working Paper*, *23*.

Hailu Tefera, Getachew Belay, Sorrels, M., & Abebe Kirub. (2001). Narrowing the rift: *Tef* research and development. Proceedings of the "International workshop on *tef* Genetics and Improvement", 16-19 October 2000, Debre Zeit.

Hekkert, M., and Negro, S. (2009). Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. *Technological Forecasting and Social Change*, *76* (4), 584–594.

Hekkert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological forecasting and social change*, *74*(4), 413-432.

Hoben, A. (1995). Paradigms and politics: the cultural construction of environmental policy in Ethiopia. *World Development*, *23*(6), 1007-1021.

Jayne, T. S., Mather, D., & Mghenyi, E. (2010). Principal challenges confronting smallholder agriculture in sub-Saharan Africa. *World development*, *38*(10), 1384-1398.

Johanson, R. K., & Saint, W. (2007). *Cultivating knowledge and skills to grow African agriculture: A synthesis of an institutional, regional, and international review* (No. 40997, pp. 1-117). The World Bank.

Juma, C. (2009). Growing prosperity: Agriculture, economic renewal and development, draft outcome document from the experts meeting on 'Innovating Out of Poverty'.

Katkalo, V. S., Pitelis, C. N., & Teece, D. J. (2010). Introduction: On the nature and scope of dynamic capabilities. *Industrial and corporate change*, *19*(4), 1175-1186.

Kebebe Ergano (2015). Understanding factors affecting technology adoption in smallholder livestock production systems in Ethiopia: the role of farm resources and the enabling environment (Doctoral dissertation, Wageningen University).

Kebebe Ergano, Duncan, A.J., Klerkx, L., De Boer, I.J., & Oosting, S.J. (2015). Understanding socio-economic and policy constraints to dairy development in Ethiopia: A coupled functional-structural innovation systems analysis. *Agricultural Systems*, *141*, 69-78.

Kebebew Assefa, Sherif Aliye, Getachew Belay, Gizaw Metaferia, Hailu Tefera and Sorrells, M (2011). Quncho: the first popular *tef* variety in Ethiopia, *International Journal of Agricultural Sustainability*, *9*(1), 25-34.

Kebebew Assefa, Solomon Chanyalew & Zerihu Tadele (2013). *Achievements and Prospects of Tef Improvement-Proceedings of the Second International Workshop, November 7-9, 2011, Debre Zeit, Ethiopia*. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia; Institute of Plant Sciences, University of Bern, Switzerland.

Klerkx, L., Van Mierlo, B., & Leeuwis, C. (2012). Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. In *Farming Systems Research into the 21st century: The new dynamic* (pp. 457-483). Springer, Dordrecht.

Klerkx, L., Aarts, N., & Leeuwis, C. (2010). Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment. *Agricultural systems*, *103*(6), 390-400.

Lamprinopoulou, C., Renwick, A., Klerkx, L., Hermans, F., & Roep, D. (2014). Application of an integrated systemic framework for analysing agricultural innovation systems and informing innovation policies: Comparing the Dutch and Scottish agrifood sectors. *Agricultural Systems*, *129*, 40-54.

Lee, H. (2018). *Tef*, A rising global crop: Current status of *tef* production and value chain. *The open agriculture journal*, *12*(1), 185-193.

Lefort, R. (2012). Free market economy, developmental state and party-state hegemony in Ethiopia: the case of model farmers. *The Journal of Modern African Studies*, *50,* 681-706.

Ludi, E., Alemayehu Belay, Duncan, A., Snyder, K., Tucker, J., Cullen, B., Mthewos Belissa, Temesgen Oljira, Asefa Teferi, Zerihun Nigussie (2013). Rhetoric versus realities: A diagnosis of rainwater management development processes in the Blue

Nile Basin of Ethiopia, CPWF Working Paper. CGIAR Challenge Program on Water and Food (CPWF).

Melaku Tafese (2020). Evaluation of proximate composition and sensory quality acceptability of Ethiopian flat bread (Injera) prepared from composite flour, blend of maize, tef and sorghum. *International Journal of Food Engineering and Technology*, *4*(2), 18-24.

Minten, B., Seneshaw Tamru, Ermias Engida & Tadesse Kuma (2016). Feeding Africa's cities: The case of the supply chain of teff to Addis Ababa. *Economic Development and Cultural Change*, *64*(2), 265-297.

Misgana Merga (2018). Progress, achievements and challenges of Tef breeding in Ethiopia. *Journal of Agricultural Science and Food Research*, *9*(1), 1-8.

MoA (2020). Agriculture sector investment prioritization (2019/20-2024/25). Ministry of Agriculture, Addis Ababa.

MoA (2019). Crop variety register issue, no 22 (2019). Ministry of Agriculture. Addis Ababa.

MoA (2010). Participatory Extension System (Amharic version). Ministry of Agriculture, Addis Ababa.

MoANR (2017). Ethiopia's agricultural extension strategy: Vision, systemic bottleneck and priority intervention. Ministry of Agriculture and Natural Resources and Agriculture Transformation Agency, Addis Ababa.

NBE (2018/19). Annual report of 2018/19. National Bank of Ethiopia, Addis Ababa, Ethiopia.

Negera Eba & Getachew Bashargo (2014). Factors Affecting Adoption of Chemical Fertilizer by Smallholder Farmers in Guto Gida District, Oromia Regional State, Ethiopia. *Science, Technology and Arts Research Journal*, *3*(2), 237-244.

Negro, S. O., Alkemade, F., & Hekkert, M. P. (2012). Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable and Sustainable Energy Reviews*, *16*(6), 3836-3846.

North, D. C. (2006). *Understanding the process of economic change*. Academic foundation.

NPC (2017). The 2017 voluntary national reviews on SDGs of Ethiopia: Government commitments, national ownership and performance trends. National Plan Commission, *Addis Ababa*.

Rajalahti, R., Janssen, W., & Pehu, E. (2008). *Agricultural innovation systems: From diagnostics toward operational practices*. Agriculture & Rural Development Department, World Bank.

Röling, N. (2009). Pathways for impact: scientists' different perspectives on agricultural innovation. *International journal of agricultural sustainability*, *7*(2), 83-94.

Seife Ayele, Duncan, A., Larbi, A., & Khanh, T. T. (2012). Enhancing innovation in livestock value chains through networks: Lessons from fodder innovation case studies in developing countries. *Science and public policy*, *39*(3), 333-346.

Seyfu Ketema (1993). *Tef* (Eragrostis *tef*): Breeding, agronomy, genetic resources, utilization and role in Ethiopian agriculture. IAR, Addis Ababa.

Seyfu Ketema (1989). Production trends, germplasm resources, breeding and varietal improvements of small millets, with special emphasis on *tef* in Ethiopia. *Small millets in global agriculture. IDRC, Oxford & IBH Co., India*, 167-172.

Spaenij-Dekking, L., Kooy-Winkelaar, Y., & Koning, F. (2005). The Ethiopian cereal *tef* in celiac disease. *New England Journal of Medicine*, *353*(16), 1748-1749.

Suurs, R. A., Hekkert, M. P., Kieboom, S., & Smits, R. E. (2010). Understanding the formative stage of technological innovation system development: The case of natural gas as an automotive fuel. *Energy Policy*, *38*(1), 419-431.

Tareke Berhe, Zewdie Gebretsadik, Edwards, S., & Hailu Araya (2011, November). Boosting tef productivity using improved agronomic practices and appropriate fertilizer. In *Achievements and prospects of Tef improvement. Proceedings of the second International Workshop* (pp. 133-140).

Tekle Lombamo (2020). Review paper on: Potential and constraints of teff row planting for enhancing productivity. Journal of Biology, Agriculture and Healthcare, 10(3), 52-63.

Tsedeke Abate, Bekele Shiferaw, Setegn Gebeyehu, Berhanu Amsalu, Kassaye Negash, Kebebew Assefa, Million Eshete, Sherif Aliye & Jürgen Hagmann, J. (2011). A systems and partnership approach to agricultural research for development: Lessons from Ethiopia, *Outlook on Agriculture, 40* (3), 213–220.

Turner, J. A., Rijswijk, K., Williams, T., Barnard, T., & Klerkx, L. (2013). Challenges to effective interaction in the New Zealand agricultural research and extension system: an innovation systems analysis. *Extension Farming Systems Journal*, *9*(1), 89-98.

Van de Ven, A. H., Polley, D. E., Garud, R., & Venkataraman, S. (1999). The innovation journey Oxford University Press. *New York*.

Van Mierlo, B., Leeuwis, C., Smits, R., & Woolthuis, R.K. (2010). Learning towards system innovation: Evaluating a systemic instrument. *Technological Forecasting and Social Change 77*, 318-334.

Vandercasteelen, J., Mekdim Dereje, Minten, B., & Alemayehu Seyoum (2013). Scaling-up adoption of improved technologies: The impact of the promotion of row planting on farmers' tef yields in Ethiopia. *LICOS-Discussion paper series 344/2013*, 1-25.

Werotaw Bezabih (2006). Entrepreneurship and development in Ethiopia. Economic Focus, Vol 8 No. 4.

Wieczorek, A. J., & Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Science and public policy*, *39*(1), 74-87.

Wieczorek, A. J., Negro, S. O., Harmsen, R., Heimeriks, G. J., Luo, L., & Hekkert, M. P. (2013). A review of the European offshore wind innovation system. *Renewable and Sustainable Energy Reviews*, *26*, 294-306.

Yazachew Genet, Tsion Fikre, Worku Kebede, Solomon Chanyalew, Kidist Tolosa & Kebebew Assefa (2020). Performance of Selected Tef Genotype for High Potential Areas of Ethiopia. Ecology and Evolutionary Biology, 5(3), 35-42.

3. UNDERSTANDING FACTORS AFFECTING PERFORMANCE OF AGRICULTURAL EXTENSION SYSTEM IN CENTRAL ETHIOPIA

Abstract

This study was aimed to assess performance of the agricultural extension system and the factors explaining it. The study involves a survey questionnaire of 143 development agents (DAs) and supervisors, key informants, and focus group discussants. The data were analyzed using descriptive statistics and a binary logistic regression model for quantitative data. Transcription, categorization, narration, and interpretation were used to analyzing the qualitative data. Results show that despite government commitments and having one of the highest DA-to-farmers ratios, Ethiopia's extension system has not been able to achieve the desired goals of agricultural transformation. This is due to weak linkages, lack of enabling environment and governance structure, limited organizational capacity and weak management system, limited ways of extension and advisory services provision. This study supplements the findings by other studies that the number of DAs is not a sufficient condition of performance, but an effective and efficient extension system needs to focus on the enabling environment, organization capacity, and management system for DAs to be motivated to work as mandated. The econometric model shows that the organization rewards and sanction system, enforcement of performance targets, interactions among various actors, supervisions, donor funding, number of motorbikes for DAs' mobility and skill development training for DAs are found to be statistically significant for better performance of the extension system. Therefore, the study suggested policy-makers, development practitioners, and other key actors should devise appropriate interventions for those factors that impede the performance of agricultural extension systems.

Keywords: Agricultural extension, development agents, Ethiopia, motivation, performance

3.1 Introduction

Effective and demand-driven agricultural extension and advisory services have significant importance for agricultural development and rural transformation (Gerba, 2018; Pye-Smith, 2012). Agriculture extension has a tremendous potential to improve agricultural productivity and household food security through the transfer of technologies and knowledge (Feder et al., 2010). Despite such facts, available literatures indicate mixed results in terms of the performance and impact of agricultural extension systems (Ragasa et al., 2016). In some countries, agricultural extension services provide a high rate of return and make a significant economic and social benefit (Davis et al., 2012; Benin et al., 2011; Van den Berg and Jiggins, 2007). Other studies, such as those conducted by Birner et al. (2009) and Rivera et al. (2001), found it inefficient and unproductive in addressing the technological demands and agricultural-related constraints of rural poor farmers. This indicated that there is critical knowledge gap in assessing the performance of extension systems and understanding the factors explaining it (Ragasa et al., 2016).

Agricultural extension must focus both on technological innovations (increase productivity and technical efficiency), and on institutional aspects (organizational and leadership development) for better livelihoods of rural farming households (Habtemariam, 2008). Agricultural extension in Ethiopia helped in increasing agricultural productivity in order to meet the growing demand for food, industrial raw materials, and foreign currency earnings (MoANR, 2017; Gerba et al., 2017). It is considered as a policy instrument and appropriate tool for the government to bring about anticipated changes in socio-economic, political, cultural, and environmental aspects (Habtemariam, 2008). Cognizant of this fact, efforts have been made by the government of Ethiopia to improve the performance of agricultural extension and advisory services. Ethiopia also has one of the largest frontline DA-to-farmer ratios in the world (Fantu et al., 2015; ATA, MoA and EIAR, 2015; Davis et al., 2010). Moreover, establishing more than 12,500 farmers training centers (FTCs) located across national regional states of the country (MoANR, 2017; Lefort, 2012). Despite a recent decline since 2012, Ethiopia declared its commitment by allocated 10% of their expenditures to agriculture and rural development in the last decade (MoA, 2020; MoANR, 2017; Demese et al., 2010).

Despite such huge investment and commitments, significant change in the delivery of extension services has not been achieved (ATA, 2014; Spielman et al., 2012). Agricultural extension stimulated demand for technology adoption among farm households but failed to link this to critical agricultural inputs such as improved seed variety, fertilizer, irrigation, and crop pest and disease management strategies (Gerba et al., 2017). The extension system has not been successful in promoting widespread adoption of improved technologies and knowledge (Belay and Dawit, 2017). Low agricultural productivity remains a major challenge for Ethiopia's agriculture sector (Menale et al., 2018; Asfaw et al., 2012). As a result, poverty and household food insecurity still a challenge to the country (Stellmacher, 2015; Oxfam, 2016).

Therefore, improving the performance of the agriculture extension systems has paramount importance to improve productivity and food security. Since it is regarded as a policy instrument and appropriate system to bring the anticipated changes, it is important to assess the key factors that hinder the performance of the extension system. According to Nagel (1997), boosting the performance and impact of the agricultural extension system has resulted in remarkable improvements in the livelihoods of many rural poor. Although agricultural extension is widely studied in Ethiopia, the majority of these studies explicitly or implicitly examine agricultural extension's contribution and impacts on agricultural productivity and food security. There have been few studies in Ethiopia that assess the performance of agricultural extension systems and understand the factors that contribute to it. Thus, this research attempts to assess the performance and analyze the factors that explain the low performance of the agricultural extension system in Ethiopia by answering the research question “What factors explain the low performance of Ethiopia’s agricultural extension system?” Therefore, the research result of this paper contributes knowledge to the empirical literature on the agricultural extension by assessing the current performance of the extension system and identify factors that explain variations in performance; providing insights on how to improve the country agricultural extension system; and illustrating how a well-cited conceptual framework by Birner et al. (2009) can be implemented empirically to provide policy options for a country like Ethiopia.

3.2 Conceptual framework and estimation strategy

Agricultural extension has changed in recent times from only providing improved technologies and knowledge to more of a facilitation role. These changes pose key challenges for performance assessment and impact evaluation. Despite many empirical studies on agricultural extension, a huge knowledge gap in measuring the performance of the system and the factors explaining it. Therefore, this study focused on measuring the performance of the extension system and the factors affecting it by adapting the best-fit conceptual framework.

3.2.1 Measures of performance

Birner et al. (2009) present a conceptual framework that can be used as a best-fit solution to design agricultural extension services. This framework can be used to assess the performance of agricultural extension services, depending on the local context. To assess the performance of the agricultural extension system, this paper adapted Birner et al.'s (2009) framework to the Ethiopian context. The final goal of improving the agricultural extension systems is to enhance the performance to enable them to facilitate technology adoption, improve productivity, incomes, and food security in a sustainable way (Ragasa et al., 2016). Therefore, this research mainly focused on the performance of agricultural extension organizations (AEOs) and individual DAs and associated factors explaining it.

Various indicators were collected based on the framework to measure the performance of AEO and individual DAs. This includes the number of technologies disseminated, the number of farm demonstrations organized, monitor farmers' adoption, monitor the impact of technology adoption on farmers' livelihoods, and a number of training materials produced and promoted. There is a clear dichotomy between those who performed these activities and those who did not for all of these variables, prompting us to estimate binary response models rather than continuous variable regression models. Hence, the performance of individual DA is represented as dummy variables and is measured in terms of (a) whether DA has taught at least one new technology; (b) whether DA monitored the farmers' adoption; and (c) whether DAs monitored the impact of technologies on farmers' livelihoods in the last two years. Similarly, the performance of extension organization is represented as dummy variables and is measured in terms of (a) whether the extension organization has disseminated at least one technology (technology in this study referees as a package of new improved variety, knowledge, improved practice, fertilizer or combination of inputs); (b) whether the organization has conducted farm demonstrations; and (c) whether the organization has produced and promoted training materials in the last two years.

3.2.2 Factors affecting the extension system performance

In Figure 3.1, the framework indicates that how different factors act together to influence the organization and an individual DA's performance. Moreover, we describe these factors more in detail below. Table 3.1 depicts the synthesis of these common themes and specific hypotheses developed based on previous studies, as well as how they are used to develop specific indicators for the qualitative and quantitative analysis in this study, as well as a summary of results using data from the study woredas in Minjar Shenkora and Ada'a. These are grouped into (a) enabling environment and governance structure; (b) linkages and partnerships consistent with the AIS perspective; (c) organizational capacity, management, and learning; and (d) extension and advisory services delivery methods

Table 3.1 Major themes, hypotheses based on literature and indicators used in this study

Themes	Descriptions	Hypotheses/Assumptions	Measurement indicators
Enabling environment and Governance	• Successful AEOs have clearly-defined and commonly shared policy or strategy • Presence of performance targets • Decentralization is a process of bringing extension services closer to the farmers	• Extension policy and strategy, as well as performance targets, are embodiment of vision, thinking, and commitment is a key determinant	• Clearly defined and commonly shared policy or strategy. • Performance targets • Enforcement of these targets • Level of decentralization
Interactions and partnerships	• An integrated approach required linkages and partnership among actors • Strong interactions among actors are very crucial for AEOs and DAs performance	• DAs and AEOs are increasingly expected to create and nurture interactions and partnerships with knowledge sources and users.	• Existence of interaction, partnership and communication among actors • Factors influencing the linkages and partnership
Capacity, management, and learning	• Test which measures of organizational capacity, management, and learning are significant factors in explaining the performance of individual DAs and AEOs in Ethiopia • Capacity in terms of staff numbers, staff qualification, gender composition and motivation is an important dimension	• Adequate and sustainable resources are important for organizations to perform well • Capacity includes not only physical and financial capacity but also effective management system to run the operations	• Number of staffs and qualification • Average ratio of DA to farmers • External/donor funds received • Availability of motorbikes and vehicles • Enforcement of penalty and rewards • Quality of the supervisors • Leadership style • Strategies to promote leadership
Extension and advisory services delivery methods	• The methods used in the provision of agricultural extension services	• Mixed extension delivery methods works better than single approach	• Types of training or technology transfer • Participatory approach • Types of media used

Source: Birner et al. (2009); Birner et al. (2006); Faure et al. (2012),

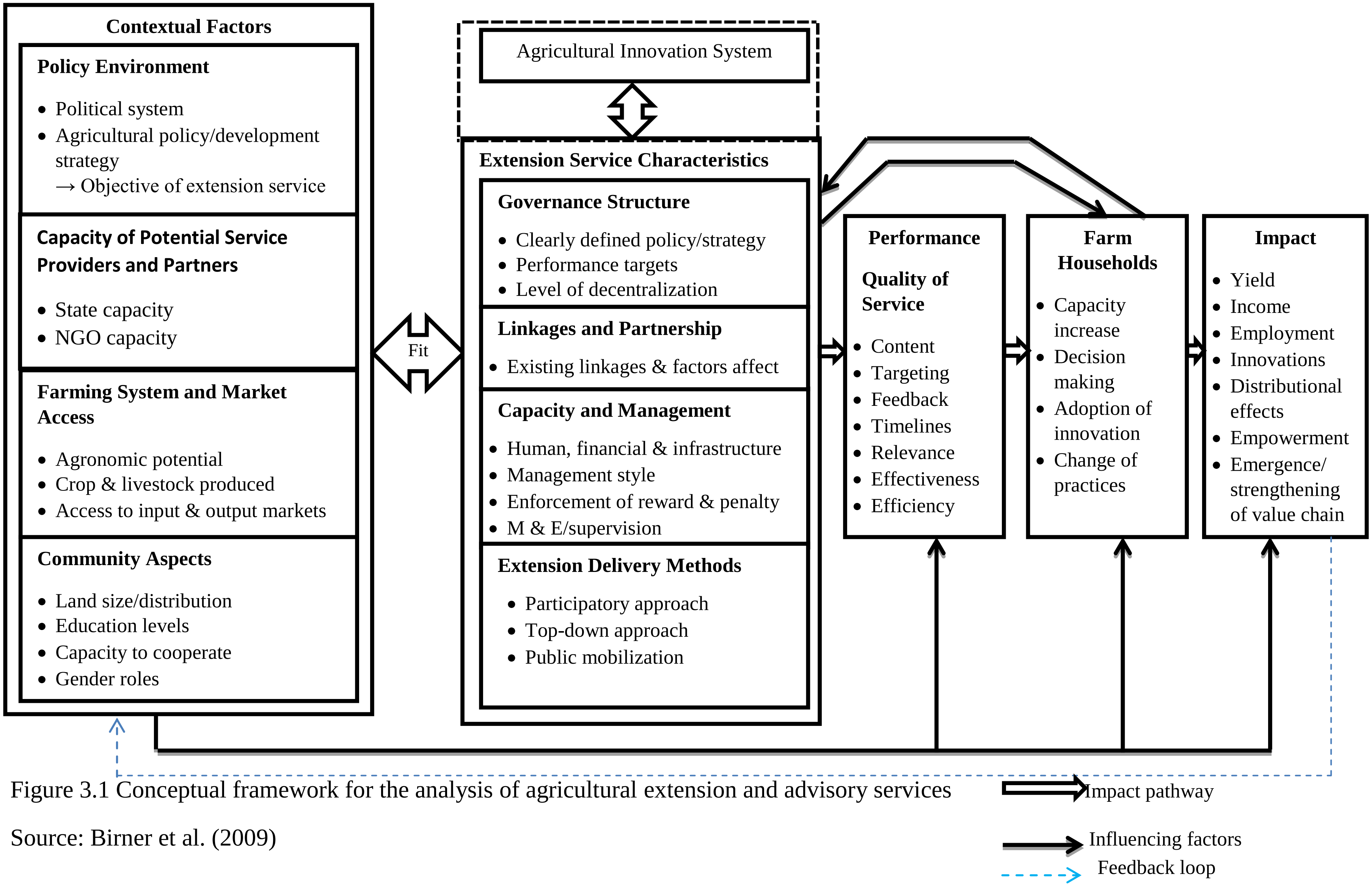


Figure 3.1 Conceptual framework for the analysis of agricultural extension and advisory services

Source: Birner et al. (2009)

3.3 Materials and methods

The study employed a mixed-methods approach, including quantitative and qualitative data gathering and analysis. A structured questionnaire was used to obtain quantitative data from 143 respondents (127 DAs and 16 supervisors) (Table 3.2). All DAs (except few for long time absent from his/her work station) from Minjar Shenkora *woreda* of Amhara Regional State and Ada'a *woreda* of Oromia Regional State participated for the survey. Key informant interviews and focus group discussions were performed to generate qualitative data to supplement the quantitative data. Key informants were identified from agricultural extensionists, heads of agriculture offices, DAs, agriculture cooperatives, model farmers, and community elders. All of the key informants had extensive experience with and knowledge of the extension system at the national and local levels. Eight separate focus group discussions, each group comprised of 6-10 participants were held with farmers, community elders, and DAs. Moreover, secondary data sources were used from peer-reviewed articles, books, and annual reports, and published and unpublished documents from relevant sources.

Two types of structured questionnaires were prepared for this study (1) organization-level performance, with heads of agriculture offices, supervisors, experts, and individual DAs as respondents; and (2) individual-level performance, with individual DAs as respondents. The questionnaires were designed to capture indicators that allow assessment of the performance of the system as well as factors explaining it. Face-to-face interviews were conducted with the use of Computer Assisted Personal Interview (CAPI) to improve the quality of data collection and reduce error during the data entry process. Five enumerators were selected based on their experience in using the CAPI and the local languages. Field-based training was given to all enumerators on how to administer and complete the questionnaire. After training, the questionnaires were pretested in one village outside the sampled kebeles. The objective of the pilot survey was to enable enumerators to practice the interview in the field and to get constructive feedback on the contents of the questionnaire.

Table 3.2 Distribution of individual DAs and their supervisors in the study *woredas*

Woredas	Individual DAs	Supervisors	Total
Minjar Shenkora	65	9	74
Ada'a	62	7	69
Total	127	16	143

Source: Minjar Shenkora and Ada'a *woredas* BoA, 2019

Econometric estimation: Binary logistic regression model

We analyze the observed differences across the extension organizations and agents to explore what factors are explaining strong or weak performance within the extension system using an econometric model. Various options of econometric models are available for analyzing the factors influencing the categorical dependent variables. A linear regression model is a popular method in many studies; however, it is only utilized when the dependent variable is assessed on a continuous scale. Discriminant analysis and logistic regression methods are commonly employed for dichotomous variables, although both have drawbacks. If all predictors are continuous and normally distributed, discriminant analysis is utilized. Logistic regression is frequently used when predictors are heterogeneous and/or not evenly distributed. Because either the probit or logistic models can be employed for a categorical dependent variable, the probit model is an alternative to the logistic model. But, probit is based on a standard normal distribution, and the logit is based on standard logistic distribution. These two models are often lead to the same conclusion and most difficult to choose between the two on a theoretical basis (Greene, 2012). Given the binary nature of the outcome variables, this paper follows the widely used logistical regression model to estimate the marginal effects and statistical significance of the factors described on the probability of good performance among extension organizations and agents. Moreover, given the hierarchical nature of the data, the multilevel model was also employed to estimate the factors explaining the performance, but results were similar to those of the simple logit regression.

The functional form of the logit model can be specified as follows where P_i denotes the probability of respondents who performed those activities that is $Y_i = 1$ and $\exp^{(Zi)}$ stands for the irrational number to the power of Z_i (Gujarati, 2009). The model can be written as:

$$P_i = E\left(Y = \frac{1}{X_i}\right) = \frac{1}{1+e^{-(\beta_0+\beta_1 X_1)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

For the case of explanation, equation (1) is written as;

$$P_i = \frac{1}{1+e^{-Z_i}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The probability that a given respondents is decided to perform those activities properly is expressed as by equation (2), while the probability of those that did not perform the activities is expressed by equation (3).

$$P_i = \frac{1}{1+e^{Z_i}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Therefore, equation (3) can be expressed as follow

$$\frac{1}{1-P_i} = \frac{1+e^{Z_i}}{1+e^{-Z_i}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Finally, taking the natural logarithm of equation (4) we obtain:

$$L_i = \ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where P_i= is a probability of respondent's performed those activities ranges from 1 to 0,

Z_i = is a function of i explanatory variables (X),

β_o is an intercept,

$\beta_1, \beta_2, \beta_i$ are slopes of the equation in the model,

L_i= is log of the odds ratio, which is linear in the parameters,

X_i= is vector of relevant respondents' characteristics.

If the disturbance term (ε_i) is introduced, the logit model becomes

$$L_i = \ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i + \varepsilon_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Explanation of variables

Dependent variables for an extension organization

As shown in Table 3.3 the dependent variables we considered in the binary regression model for agricultural extension system are : the number of technology that FTCs are disseminated at least one technology (TECHNOLOGY), FTCs conducted farm demonstrations (DEMO), and the number of training materials produced or promoted in the last two years (TRAINING).

Table 3.3 Descriptive statistics of variables explaining on organizational performance

Variables	Description	Mean	SD
Dependent Variables			
TECHNOLOGY	1= if the AEO disseminated at least 1 technology	0.46	0.50
DEMO	1= if the AEO conducted farm demonstration	0.38	0.48
TRAINING	1= if the AEO produced and promoted training materials	0.50	0.50
Explanatory Variable			
DAs (+)	Number of DAs in each *kebeles* (count)	3.17	0.59
FEMALE_DAs (+)	Number of female DAs in each *kebeles* (count)	0.19	0.39
OPER_PLANNING (+)	1= if organization has annual planning	0.85	0.36
PERF_TARGET (+)	1= if organization has performance targets	0.34	0.48
SUPERVISION (+)	1= if the organization has strong regular supervision	0.43	0.50
DONOR_FUND (+)	1= if the organization received donor funding	0.27	0.44
SANCTION (+)	1= if the organization enforces punishment	0.16	0.37
REWARD (+)	1= if the organization has reward system	0.52	0.50
MOTORBIKES (+)	Number of motorbikes per staff (ratio)	0.28	0.45
TIMESPENT (+)	Proportion of DAs' time spent on getting to the field (%)	32.66	11.13
INT_OTHER_EXT (+)	Interactions with other extension organizations (1-5 scale)	2.66	0.86
INT_INPUT (+)	Interactions with input suppliers (1-5 scale)	2.58	0.78
INT_TRADERS (+)	Interactions with buyers/traders (1-5 scale)	2.13	0.72
INT_RESEARCH (+)	Interactions with research organization (1-5 scale)	1.92	0.75
INT_FO (+)	Interactions with farmers organization (1-5 scale)	2.58	0.89
INT_AUTHOR (+)	Interactions with local political authority (1-5 scale)	3.99	0.75

Source: Own calculation based on survey data

Dependent variables for an extension organization (FTCs)

The dependent variables we considered in the binary regression model for an individual DAs: the number of technology that DAs understand (TECHNOLOGY), assess the status of technology adoption (MONITORED), and assess the impact of technology on farmer's food security status (IMPACT) (Table 3.4).

Table 3.4 Descriptive statistics of variables explaining individual DA performance

Variables	Description	Mean	SD
Dependent Variables			
TECHNOLOGY	1= if DA taught at least 1 new technology	0.38	0.49
MONITORED	1= if DA monitored farmers' adoption	0.33	0.47
IMPACT	1= if DA assess impact on farmers	0.18	0.39
Explanatory Variable			
SEX (+/-)	1= if sex of the respondent is male	0.70	0.46
AGE (+)	Age of the respondent in years	26.70	3.35
EDU_CER (+)	1= if education level of DA is certificate holder	0.07	0.24
EDU_DIP (+)	1= if education level of DA is diploma holder	0.62	0.49
EDU_BSC (+)	1=if education level of DA is first degree	0.31	0.47
EXPERIENCE (+)	Working experience of DAs in years	4.50	2.91
DIS_WORK (-)	Distance to the working area in km	13.23	8.65
CONTACTS (+)	The frequency of DAs contact to farmers	3.30	6.74
PERF_TARGET (+)	1= if organization has performance targets	0.34	0.48
TRAINING (+)	1= if DA received training	0.72	0.45
MOTORBIKE (+)	Number of motorbike per staff	0.11	0.32
INT_OTHER_DAs (+)	1= if DA has interactions with other DAs	0.38	0.49
INT_RESEARCHERS (+)	1= if DA has interactions with researchers	0.29	0.44
ACHIEVEMENT (+)	Level of DA achievements (1-5 scale)	3.66	0.63
REWARDING (+)	Rewarding system (1-5 scale)	2.42	1.01
FACILITIES (+)	Working facilities (1-5 scale)	2.45	0.95
COM_SALARY (+)	Competitive salary of the organization (1-5 scale)	2.11	0.99
SUPERVISION (+)	Level of supervision (1-5 scale)	2.88	1.09
JOB_SATISFACTION (+)	Level of job satisfaction of DA (1-5 scale)	2.69	1.08
WORKLOAD (+)	The work load level of DA (1-5 scale)	2.29	0.92
INVOLVEMENT (+)	Involvement of DA in decision making (1-5 scale)	2.24	0.91

Source: Own calculation based on survey data

3.4 Results and discussions

3.4.1 Assessing the agricultural extension system in Ethiopia

3.4.1.1 Enabling environment and governance

Successful extension systems have a clearly defined and commonly shared mission, vision, and measurable performance targets, based on their agricultural policy or strategy (Ragasa et al., 2016). Because these targets are very helpful for the system to closely monitor and evaluate the progress and interventions. However, Ethiopia has not clearly defined and commonly shared agricultural extension strategy till 2017; rather it used different approaches or methods to deliver extension services. This lack of a clearly defined and commonly shared national extension strategy on the system is mirrored in the absence of measurable performance targets and in the extension system for a long time. The survey result shows that, of the total interviewed, only about 34% reported any performance target set by the extension system (supervisors and heads) (Table 3.3).

Agricultural extension services can be improved when the extension system relies on a decentralized supply of extension services and private providers (Anderson and Feder, 2004). Since 1991 Ethiopia has been introduced a decentralized political system of the federal and national regional governments (Belay, 2003; Kassahun and Poulton, 2014). Nevertheless, the extension service still largely followed a linear path approach of supply-driven. The balance between top-down and bottom-up planning is greatly limited (Gerba et al., 2017). Decentralization and power-sharing aim to empower the national regional governments to develop their approaches to implement their agriculture programs based on the country's policy and strategy. But, the power-sharing of the administration with the agricultural sector tends to create uniform political opinion between the agriculture sector and the administration. Every regional state agricultural office is structured in similar patterns to that of the federal MoA, though, decentralized governance system, regional states can reform the structure to suit their context up to *kebele* level (Birhanu et al., 2016).

3.4.1.2 Linkages and partnerships

Given the knowledge brokering and facilitation role of extension, linkages and partnerships with relevant actors are vital. They are very important for transferring not only shelved technologies in the research system but also extension and advisory services to the end-users. It is collaborative relationships among actors in a decentralized manner and highly important to create knowledge, innovation, and learning relevant to farmers. However, the findings indicated linkages and partnerships among actors are limited. Limited interactions were reported by AEOs, individual DAs, supervisors, and heads of agriculture offices. Only 38% of DAs reported that they have interacted with other DAs in other areas; however, the large majorities (77%) have never interacted with the researchers in the last two years. About 55%, 72%, and 78% of surveyed respondents reported that the extension organization has weak linkages with other organizations working for farmers, NGOs, traders or buyers, and research centers, respectively. Contrary to this, 85% of respondents reported that the extension organization has strong interactions with local political authorities. This indicates that either the local authorities have close support to the extension service delivery or they may use the extension service for political motives. According to key informants, the political authorities urge DAs to advocate the interest of the ruling party program and organized farmers for political purposes. Dessalegn (2009) argues that the Ethiopia extension system operates in not politically neutral. Moreover, experts are assigned based on political loyalty to the ruling party rather than their relevant professional qualifications (Kassahun and Poulton, 2014). Therefore, all these constraints impede the efficiency of the extension system, thereby reducing its performance.

The majority of DAs (83.6%) reported that existing linkages in the study areas were field days (Figure 3.2). This is followed by an on-farm demonstration (48.4%), training workshops (36.9%), informal personal contacts (34.4%), and planning meetings (5.7%). Key informants and focus group discussants acknowledge field days are the most common means of creating linkages and partnerships among actors. However, studies conducted by Chiligati (2010); CSIR and MOFA (2013) show that planning meetings with different actors was very important to establish linkages and partnerships among actors. Informal personal contacts with relevant actors are given much emphasis by scholars to create linkages among actors because it has the potential to improve interactions as they are less costly and arise based on felt needs. About 34.4% of

DAs reported that informal personal contacts are one of the existing interactions in the study areas.

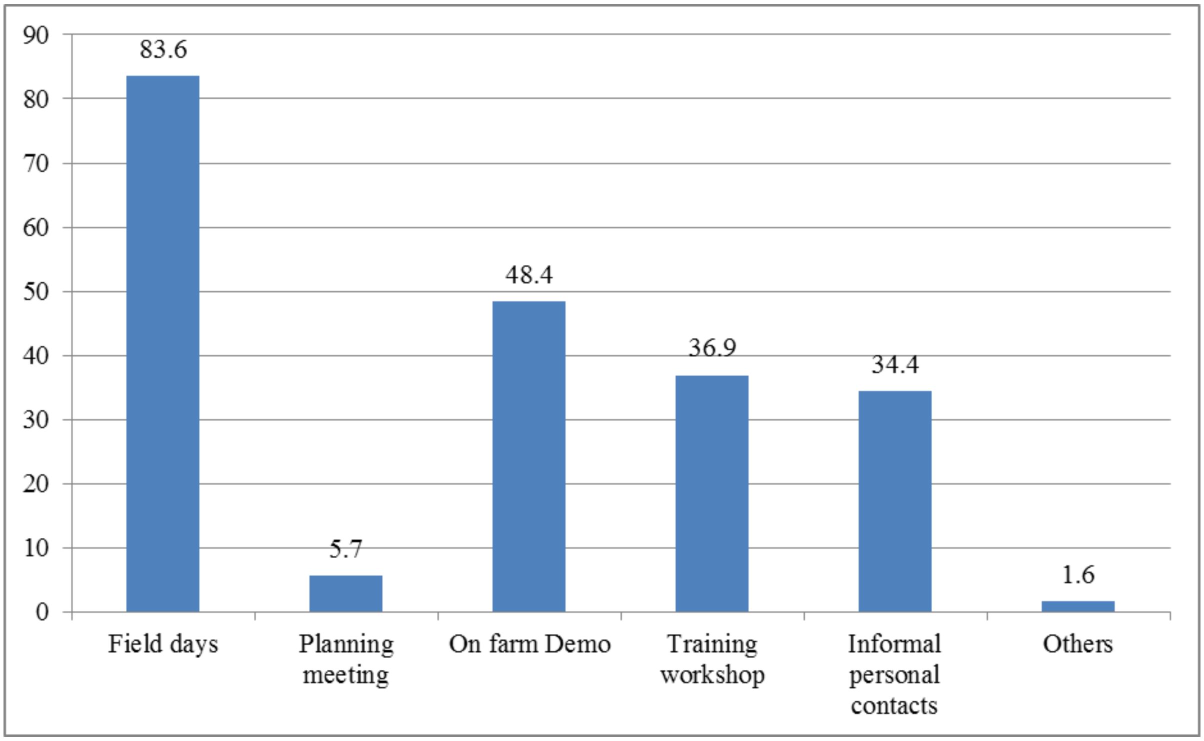


Figure 3.2 Existing linkages and partnerships among actors in the study areas

Source: Own calculation based on the survey

Factors inhibited linkages and partnerships among actors

As reported by respondents, the most pressing factors of linkages and partnerships are poor coordination, limited involvement of actors in technology dissemination, weak M & E system, and inadequate funds for linkages. Results in Table 3.5 show that about 93% of DAs reported that poor coordination and collaboration among actors was the major limiting factor of the linkages and partnerships among actors. This is followed by untimely availability of agricultural inputs (91.3%), limited involvement of actors in technology development and dissemination (84.3%), inadequate funds for linkages (78.7%), weak M & E system (77.2%), low knowledge in a participatory approach (63.8%), and weak farmers' organizations (51.2%). Key informants and focus group discussants complemented the limiting factors of linkages and partnerships include remoteness, lack of commitments among actors, lack of adequate personnel at all levels to facilitate the linkages and lack of transportation are the most pressing factors that affected the linkages and partnership with actors in the study areas.

Table 3.5 Factors identified by development agents to inhibit interactions among actors

Inhibiting factors	**Score**	**Score %**
Poor coordination among actors	118	92.9
Low involvement of key actors in technology dissemination	107	84.3
Weak M & E system	98	77.2
No/inadequate funds	100	78.7
Low education of farmers	64	50.4
Low income of farmers	24	18.9
Weak farmers' organizations	65	51.2
Low knowledge in participatory approaches	81	63.8
Low wages /lack of incentives	24	18.9
Weak extension services	65	51.2
Improper diagnosis of farmers' problems	45	35.4
Untimely availability of input	116	91.3

Note: Score % = $\frac{\text{No (yes)}}{\text{No (yes)} + \text{No (no)}} * 100$

Source: Own calculation based on field survey

3.4.1.3 Organizational capacity, management, and learning

Human resources and learning

Ethiopia has one of the largest frontline DA-to-farmer ratios in the world (Davis et al., 2010; Fantu et al., 2015; ATA, MoA and EIAR, 2015). The ratio of DAs-to-farmers is 30% higher than the world standard (World Bank, 2016). In our study areas, the ratio ranges from 1:209 in Golo-Dertu to 1:312 in Dhenkaka *kebele*, Ada'a *woreda* of Oromia Regional State, and 1:234 in Agerate to 1:239 of Adama *kebele*, Minjar Shenkora *woreda* of Amhara Regional State. In both *woredas*, the ratio was higher than the national average of 1:476 (MoANR, 2017). Three DAs specialized in the crop, livestock, and natural resource management and one animal health assistant, and one cooperative expert to serve the surrounding three to five *kebeles*. This denotes that the number of DAs may not be a problem in Ethiopia but managing and guiding these available human resources for better achievement and performance.

Beyond the number of human resources, there is strong evidence of the lack of the quality of the staff. There is a gap between the relatively large number of DAs and their relatively low technical competence in the extension service (MoANR, 2017; Gerba et al., 2017; Belay et al., 2012). Results in Table 3.4 show that a large majority of DAs (69%) have a three-year ATVETs diploma or certificates, and only 31% have university degrees. Among the BSc holders, the majority of DAs received their degrees from the non-agriculture professions. The profile of staff shows a lack of diversity in the skill of DAs. Most DAs are specialized in specific commodities rather than comprehensive and applied skills and knowledge required combining crop, livestock, and natural resource management. There was no mention of a DA specializing or training in pre- and post-harvest or marketing extensions. According to key informants and focus group discussants most DAs lack both hard skills (marketing, post-harvest, value chain analysis, and agricultural intensification and diversification), and soft skills (process facilitation, communication, and organization of farmer-producer groups) which are important for farmers and it is consistent with the previous studies of McGuire (2012).

In addition to the number and competence of DAs, work motivation and job performance are very important in the extension of service delivery. Motivated DAs enjoy their work, committed more to not only their extension organizations but also the clients' farmers, less insubordination and grievance, and contributing to the long-term success of the extension system. However, the survey result indicates that 68.9% and 21.3% of DAs had medium and low levels of work motivation, respectively. This result is in line with most of the previous studies conducted by Dessalegn and Nuri (2018); Belay et al. (2012); Ifenkwe (2012); Khalil et al. (2009). Farmers' focus group discussants affirmed that most DAs in their study areas had average work motivation due to poor working facilities, lack of recognition, lower salary, far working locations, limited opportunities for further education, working for longer hours a day, and poor infrastructure.

Financial resources

Investment in the provision of extension services has been important for agricultural development and rural transformation. By allocating more than 10% of the national budget to the agriculture sector, Ethiopia has demonstrated its commitment to agriculture and rural development, based on the Maputo Declaration (MoANR, 2017; ATA, MoA and EIAR, 2015). Although several countries were unable to achieve this target, Ethiopia was among the top 10 countries between 2003 and 2011. However, since 2012, agricultural expenditure has dropped well below 10%, with an average spending share of around 5.2% (MoA, 2020). The proportion allocated to agriculture is even smaller when agricultural development expenditure and food security expenditure are further disaggregated (Birhanu et al., 2016; MoA, 2020). Moreover, the nominal figure allocated for agriculture in Ethiopia is much lower as compared to other developing countries.

Physical resources

Lack of adequate infrastructure in Ethiopia has been hindering the performance of the extension system. DAs reported that mobility to their operational area is difficult because of a lack of motorbikes, or vehicles for their extension activities. DAs reported that the average distance to their operational areas is 13.23 km (Table 3.4). This is mainly because most DAs lived in cities and travel daily to their working stations, except Adama *kebeles* of Minjar Shenkora *woreda* where all DAs lived in the dormitory given by the government. However, 89% of DAs reported no motorbike for their operational activities. According to their estimation on average 33% of their time is spent getting to the work station and operational areas (fields) per month due to poor infrastructures and lack of motorbikes.

FTCs in Ethiopia serve as an entry point to bring about behavioral changes among farmers, however, most of them are found at varying levels of functionality, and some of them are not functioning. During our field observations, FTC in Golo-Dertu *kebele* was closed and not serving the farming community due to lack of the required physical facilities and farming material for demonstrations. According to DAs, most FTCs are poorly equipped and lack sufficient facilities for providing the required services to the farmers, which is the most pressing constraint of FTCs

(Figure 3.3). This is followed by a lack of long-term vision and plan of FTCs (95.9%), and no policy support to re-use the internal revenues (94.3%). Each *kebeles* are expected to establish their Management Committees (MCs) for the continuous follow-up and support of FTCs. Farmers, however, perceive FTCs as government institutes rather than their own and lack clarity on the basic advantages of FTCs. Therefore, farmers do not adequately support FTCs for better functionality, and they always expected governments to furnish FTCs. Well-functioning FTCs have their capacity to generate internal revenues, however, key informants and focus group discussants reveal that FTCs do not have the legal right to re-use the generated internal revenues. Therefore, it is one possible alternative for the government to consider FTCs as a business entity to run by themselves from their internal revenues for the better functionality of service delivery.

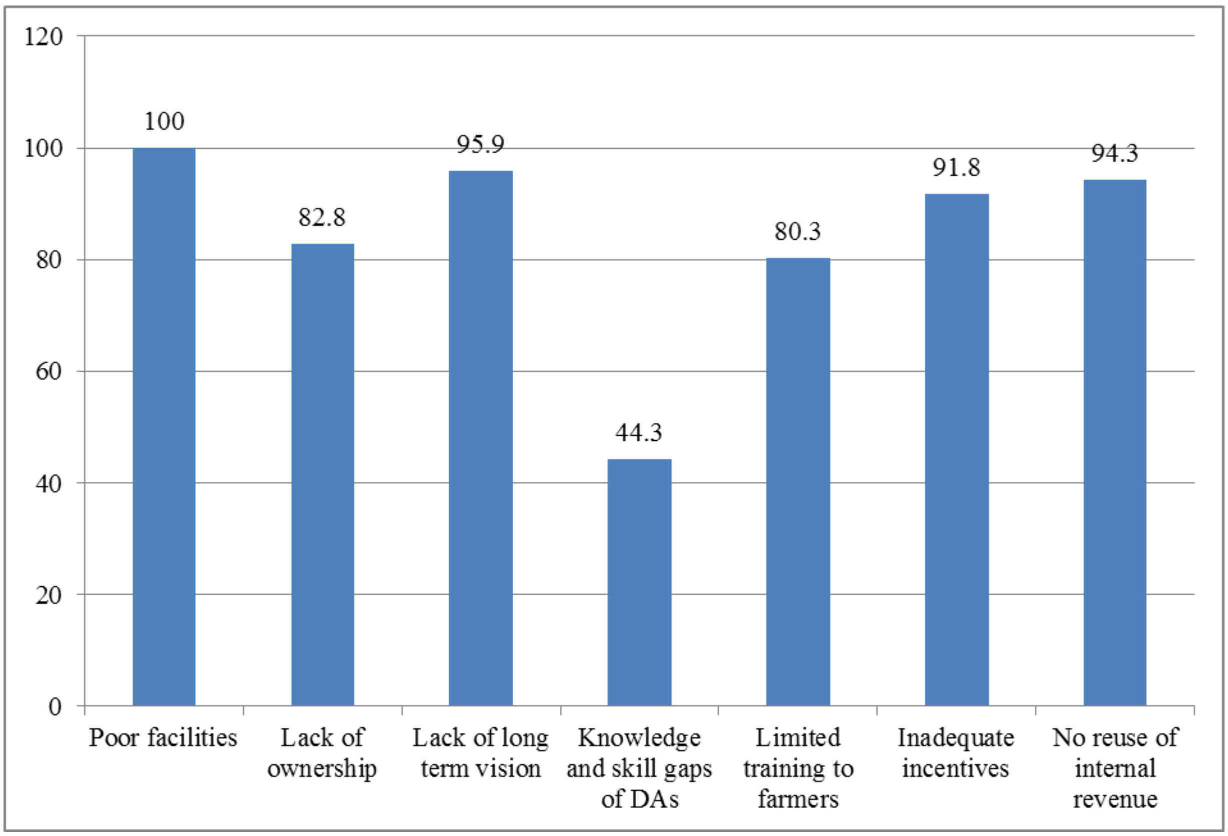


Figure 3.3 Percentage shares of constraints of FTCs rated by respondents

Source: Own calculation based on survey data

Organizational management

Organizational management is measured in terms of planning extension activities and procedures in place for monitoring and coordination. Respondents reported that having a planning process for their extension activities and operations. The analysis indicates that how the extension system is managed has been received little attention in Ethiopia as compared to governance structures and service delivery methods. Although it seems that there are positive responses from DAs on the time spent with their supervisors and the support from them, 43% of DAs were not satisfied with the supervision received from their supervisors.

Results further showed that there are lack of a performance-based management system and reward and sanction system based on performance within the AEO system. The lack of a performance-based management system and targets is a reflection of a lack of clear national policy and weak commitment to the higher decision-making bodies. Only 16% of respondents reported having a system of sanction or disciplinary actions for poor performance. About 52% reported having a rewarding system for the good performance of staff within AEO. Organizations who using rewards and sanctions in their management system believed to be improved their performances (Sefton et al., 2007). By employing the rewards and sanctions system in their organizations, the system can improve the organization's performance by more than 60% (NAO, 2008).

3.4.1.4 Extension and advisory services delivery methods

Despite several extension and advisory service delivery methods, visit farms are still the most dominant ones. The large majority of respondents (94.3%) reported that farm visit or farmers' house visit is the most common approach used in the study areas. This is followed by an on-farm demonstration (66.4%), a combination of different methods (40.2%), meeting with farmers grouping (37.7%), and invite farmers to the office (21.3%). But, there is limited use of ICT-based extension and advisory service delivery methods such as internet, mobile, radio, or television. Only 8.2% of DAs reported mobile-based extension service provision.

The result further shows that the average number of DA contacts with an individual farmer to provide the extension service is 3.3, with a minimum of 0 and a maximum of 75. More than half of DAs reported that having 1–5 numbers of contacts (visits) to farm households in last year. Only 11% have had more than five contacts while 32% not having a single contact with an individual farmer. According to key informants, farmers' house-to-house contact was difficult to DAs because the infrastructure and transportation problems made the problem serious. This indicates the main challenges of the current extension system to promote and provide extension services to rural communities.

3.4.2 Factors affecting performance of extension organization and development agent

A critical part of any regression analysis involves the diagnostics checking before fitting the model. As such, the likely existence of multicollinearity among the explanatory variables was checked by computing the Variance Inflating Factor (VIF) and Contingency Coefficients (C). The regression diagnostics result of VIF for each of the explanatory variables was found to be significantly less than the standard cut-off value of 10 and revealed the non-existence of serious multicollinearity problems among the explanatory variables included in the model. The 1/VIF is the tolerance and it ranges from 0 to 1, with 1 being the absence of multicollinearity. In our case, all of the VIFs are below 4 and all of the tolerances are close to one indicating that there is no problem of multicollinearity in the data. Similarly, from the Eigenvalues and condition indexes, no severe problems of multicollinearity were noted except for the last two variables. As a rule of thumb, a condition index below 15 is indicative of the absence of a multicollinearity problem (Gujarati, 2009). The diagnostics check results of C also shown very lower values than the standard value and hence confirmed that there was no serious problem of multicollinearity among independent variables included in the model.

The study found that differences among individual DAs and FTCs-based extension organizations performance at different levels to explore what factors matter in explaining the performance within a given extension system. About 38% of individual DAs reported having well understood and disseminated at least one new improved technology in the last two years. 33% of DAs reported that having monitored the adoption status of farmers of those technologies (Table 3.4). Only 18% of them reported that having monitored the impact of the adopted technologies on farmers' livelihoods. While 46% of AEOs reported having taught and disseminated at least one technology or improved management practice in the last two years. And 38% of the respondent reported that the extension organization was organized FTC-based demonstrations in the last two years. More than half of the respondents reported that AEO developed and promoted training materials for the farmers (Table 3.3).

We analyze what factors matter in explaining good or weak performance within a given extension system using econometric models across the extension organization and individual DAs. Given the binary nature of the outcome variables (dummy variables), this study adopted the widely used logistic regression model to estimate the marginal effects and statistical significance of the factors described above on the probability of good performance among extension organizations and individual DAs. The econometric model results of the logistic regression analyses are presented in Tables 3.6 and 3.7. Our model indicates various explanatory variables to be highly significant in explaining the probability of good performance among extension organizations and individual DAs. The pseudo-R^2 is quite high for the AEO model (from 28% to 48%) although low for the individual DAs model (from 18% to 23%). It is a rough indicator for comparing log-likelihoods between similar models though cannot be interpreted as the strength of the predictors in explaining the variance in the outcome variable the same as the ordinary least square regression R^2. Another measure of goodness-of-fit for logit models is the percent correctly predicted by the selected model. Our findings indicate that a good fit as around 63–78% is correctly predicted by the selected AEO and individual DAs models.

Enabling environment and Governance

Results show that AEOs with performance targets are more likely to perform well in terms of extension provision and monitoring technology adoption and impacts on farmers. AEOs with performance targets have 50% more likely to disseminate improved technologies and practices, 19% to promote training materials, and 42% to organize farm demonstrations compared to those without performance targets (Table 3.6). Individual DAs in AEOs with performance targets have 18% higher probability of being active and responsive to monitor farmers' adoption status than those agents in AEOs without performance targets (Table 3.7). This indicates that clear direction and vision, coupled with measurable performance targets, are extremely important. With clearly defined and commonly shared vision and clear definition and communication of roles and responsibilities with the corresponding performance-based management system, the weak extension system can be transformed into an efficient system that supports knowledge dissemination and technology transfer. This result is in line with Ragasa et al. (2016) as a weak extension systems can be changed into an efficient system through measurable performance targets for DAs and AEOs.

Linkages and partnerships

The findings indicate strong confirmation on the significance of linkages and partnerships in extension organization and DA's performance. AEOs that have linkages and partnerships with input suppliers are 24% more likely to perform well in organizing farm demonstrations compared to those who did not have any interactions. Similarly, AEOs who have linkages with traders/ buyers are 22% more likely to perform well to disseminate improved technologies and practices, 14% to develop and promote training materials, and 30% to organize farm demonstration than those who did not have any linkages and partnerships (Table 3.6). Individual DAs that have linkages and partnerships with other DAs are 31% more likely to perform well to understand and disseminate improved technology and practices than those who did not have any interactions. And, agents with good interaction with agricultural researchers are 14% more likely to be active and perform well to evaluate the impact of agricultural technology adoption than those who did not have interactions and partnerships (Table 3.7). This implies that good interactions among actors are very important for AEOs and individual DAs' performance. However, linkages and partnerships among relevant stakeholders are seriously limited. To be effective in their role of brokers of information, organizations, and DAs should be able to connect different stakeholders together. Various literature supported this result as the importance of linkages and partnerships within different stakeholders include Ragasa et al. (2016); Davis and Heemskerk (2012); Hall et al. (2001).

Organizational capacity, management, and learning

No decisive evidence that the number of DAs in the AEOs is a significant factor in explaining the good performance of extension service provision. The model result shows that the number of DAs in the study areas is a statistically insignificant factor in explaining the performance of extension service provision. Nevertheless, the gender balance in staffing and training received by DAs are influenced the performance. AEOs with female DAs are 2% more likely to be active and perform well in disseminating agricultural technology and 3% more likely to perform well in organizing farm demonstration than AEOs without female DAs (Table 3.6). The analysis suggests a strong association between having female DAs in AEOs and performance in service provision which confirms the results of previous studies. In places where female DAs are a few, focusing on girls' education and recruiting more women on agriculture and on the extension will be an important strategy (Ragasa et al., 2016). Moreover, individual DAs' performance could be influenced by the quality of training they received. DAs who received modular and refreshing training are 40% more likely to be effective and perform well in taught and disseminate improved technologies, 22% to monitor farmers' adoption, and 18% to assess the impact of improved technologies on farmers livelihood than those who did not receive one (Table 3.7). Studies conducted by Thach (2008) and Khalil et al. (2008) shows individual competence and skills are positively related to extension agents' performance.

Enforcement of sanction/penalty and rewarding system are significant factors in explaining the performance of extension service provision. The entire success of an organization is based on how an organization keeps its employees motivated and in what way they evaluate the performance for rewards or sanctions. An organization with a strong reward and sanction system and regular performance reviews can maintain and improve service delivery (NAO, 2008). However, the lack of immediate rewards or sanctions impacts negatively on employees' performance. The survey shows that AEO with a rewarding system is 28% more likely to perform well in technology dissemination, and 37% in organizing farm demonstration than those without enforcing the rewarding system. Moreover, DAs who were rewarded for good performance are 21% more likely to perform well to monitor farmers' adoption and 1.3% to assess the impact of technology adoption likely than those who did not rewarding.

Supervision is one of the most important factors influencing the performance of AEO and the work motivation of DAs (Belay et al., 2012). As indicated in Table 3.4, 43% of respondents reported that there is regular and adequate supervision in AEO. The result shows AEOs with regular and adequate supervision are 37% more likely to perform well to disseminate improved technology, 24% to develop and promote training materials, and 54% to conduct farm demonstrations than those without regular and adequate supervision (Table 3.6). Likewise, DAs with regular and adequate supervision are 8% more likely to be active and perform well to monitor the impact of technology adoption on farmers' livelihoods (Table 3.7). This result is in line with the previous studies conducted by Debebe et al. (2016); Belay et al. (2012); Tesfaye (2012); Zelalem (2011). According to key informants, some supervisors lacked how big supervisions benefit and motivated DAs, they considered supervision as a mechanism of finding faults. Moreover, they spent a significant amount of time in political engagements and they did not have adequate time to support DAs. During their supervision also did not want to go down to the grass-roots level for solving our challenges that arose from the farming community.

Receiving donor funding is a statistically significant factor in explaining the performance of AEOs. Table 3.6 shows that AEOs who received donor funding are more likely to perform well in extension service provision compared to those without donor funding. A 1% increase in the proportion of donor funding for AEOs is associated with a 34% increase in the probability of good performance to produce and promote training materials compared to those without donor funds. Among the surveyed DAs, 90.2% used their means of transportation for delivering the extension services (walking or private transport). Results show that the motorbike-to-staff ratio is statistically significant in explaining the performance of AEOs. AEOs that adequate accesses to motorbikes are 36% more likely to perform well for disseminating agricultural technology and 54% to organize farm demonstrations than those without access to motorbikes. DAs that have a closer distance to the work location are 1% more likely to perform well for taught and understand the technologies and disseminate to the farmers than those who far from the working location.

Another significant factor explaining the performance of individual DAs is the degree of involvement in the planning, implementation, and evaluation process in AEOs. Hence, a better participatory planning and evaluation process would help the DAs to own the AEOs with a higher sense of involvement, with more commitment and satisfaction (Belay et al., 2012). Results in Table 3.7 indicate that the degree of involvement of DAs in the planning, implementation, and evaluation process is on average level. DAs being involved in the planning, implementing and evaluation process are 5% more likely to be active and perform well to understand and disseminate improved technologies than those who do not involve in the decision-making process. This result is in line with the previous studies conducted by Belay et al. (2012); Tesfaye (2012); Yohannes (2009), individual DAs with higher involvement and participation in the organization's decision-making process have great performance. Focus group discussants and key informants, DAs are mostly considered as implementers, and a channel of technology transfer, then most of the time they ignored in the decision making process.

Extension and advisory services delivery methods

Farm visit or farmers' house visit is the most common approach used to deliver agricultural extension services. Hence, the number of contacts to farmers is one of the fundamental variables that affect the provision of extension services, thereby the performance of individual DAs. The model shows that the frequency of DAs' contact with farmers is a statistically significant factor in explaining the performance of individual DAs. Individual DAs who have higher contacts with farming households are 0.4% more likely to be good and perform well in monitor the adoption status of the farmers and 3% more likely to be active and perform better in assessing the impact of improved agricultural technologies on farmers' food security (Table 3.7).

Table 3.6 Factors affecting performance of extension organization- binary logistic regression model results

	Disseminated at least One Technology		Produced & Promoted Training Materials		Conducted Farm Demo	
Explanatory Variable	Marginal effect	Std. Err	Marginal effect	Std. Err	Marginal effect	Std. Err
NUMBER_DAs	-0.0125	0.0175	-0.0161	0.0143	-0.0332	0.0218
FEMALE_DAs	0.0202	0.0106*	0.0130	0.0097	0.0266	0.0136*
OPER_PLANNING	-0.2431	0.0858***	-0.1793	0.0757**	-0.3272	0.1087***
PERF_TARGET	0.4990	0.1064***	0.1870	0.1065*	0.4213	0.1286***
SUPERVISION	0.3717	0.1185***	0.2363	0.1017**	0.5430	0.1287***
SANCTION/PENALTY	0.0287	0.2085***	0.0578	0.1641	0.2561	0.1788
REWARDING	0.2750	0.1124**	0.0276	0.0920	0.3659	0.1338***
MOTORBIKES	0.3646	0.1188***	0.0503	0.0774	0.5425	0.1529***
TIMESPENT	0.0045	0.0052	0.0017	0.0042	0.0071	0.0064
DONOR_FUND	-0.2048	0.1770	0.3375	0.0770***	-0.1646	0.2057
INT_OTHER_ORG	-0.0936	0.1204	0.1007	0.0921	0.0388	0.1349
INT_INPUT	-0.0724	0.0758	-0.0241	0.0615	0.2362	0.1170**
INT_TRADERS	0.2165	0.0787***	0.1403	0.0610**	0.3008	0.1125***
INT_RESEARCH	0.0893	0.0856*	-0.0196	0.0695	-0.1585	0.1032
INT_FBO	0.0851	0.1125	0.0011	0.0828	0.0399	0.1246
INT_AUTHORITY	0.0263	0.0710	-0.0181	0.0657	0.0771	0.0900
% correctly predicted the model	71		75		63	
Pseudo R^2	0.39		0.28		0.48	
Number of observations	143		143		143	

Source: Own calculation based on field survey
Note: *, **, *** denotes significance level at 10%, 5%, and 1%.

Table 3.7 Factors affecting performance of development agents- binary logistic regression model results

Explanatory Variable	Taught at least one New Technology		Monitored Farmers' Adoption		Monitored Impact on Farmers	
	Marginal effect	Std. Err	Marginal effect	Std. Err	Marginal effect	Std. Err
SEX	0.1797	0.1228	0.1905	0.0903**	0.0563	0.0711
AGE	0.0006	0.0308	-0.0082	0.0292	0.0002	0.0170
EDUCATION	0.0340	0.1166	0.0160	0.1004	-0.0091	0.0778
EXPERIENCE	0.0135	0.0318	-0.0334	0.0328	0.0180	0.0209
DIS_WORK	0.0093	0.0069**	0.0058	0.0060	0.0027	0.0052
ACHIEVEMENT	-0.1492	0.0964	-0.1075	0.0810	-0.0581	0.0604
REWARDING	0.0614	0.0941	0.2070	0.0856***	0.0128	0.0626**
PERF_TARGET	0.0215	0.1188	0.1822	0.1070**	0.0403	0.0825
TRAINING	0.3978	0.1048***	0.2155	0.0842***	0.1755	0.0982*
MOTORBIKE	-0.1476	0.1466	-0.0102	0.1281	0.0957	0.1381
FACILITY	-0.1301	0.0911	-0.0591	0.0843	-0.0480	0.0628
JOB_SATISFACTION	-0.0571	0.0597	-0.0095	0.0484	-0.0165	0.0367
COM_SALARY	0.0358	0.0636**	-0.0157	0.0596	0.0054	0.0472
SUPERVISION	0.0978	0.0643	-0.0619	0.0560	0.0752	0.0383**
CONTACTS	0.0016	0.0062	0.0039	0.0115*	0.0281	0.0138**
WORKLOAD	-0.0044	0.1022	0.0494	0.0919	0.0139	0.0650
BEING_INVOLVED	0.0505	0.0874**	-0.0956	0.0742	-0.0049	0.0533
INT_OTHERS_DAs	0.3144	0.1086***	-0.0791	0.1032	-0.0762	0.0822
INT_RESEARCHERS	0.0222	0.1196	-0.0472	0.1007	0.1692	0.0723***
% correctly predicted the model	76		65		78	
Pseudo R^2	0.19		0.18		0.23	
Number of observations	127		127		127	

Source: Own calculation based on field survey

Note: *, **, *** denotes significance level at 10%, 5%, and 1%.

3.5 Conclusions

The most explicit goal of the Ethiopian agricultural extension system is to increase food security and to improve farmers' livelihoods through the adoption of improved technologies (Gerba et al., 2017). Based on the national goal, the regional, zonal, and *woreda* level extension systems are responsible to increase the adoption rate of improved technologies through training and awareness creation. The agricultural extension service provision is predominantly operated by the public sector, with limited support from NGOs, small and scattered donor-supported as well as farmers' organizations, and emerging commercial seed farmers. Despite strong government commitments and investment in the agriculture sector, the extension system has not been able to achieve the desired goals of agricultural advancement. Therefore, we assess the performance of the agricultural extension system and factors explain it by using Birner et al. (2009) framework. The following five lessons have emerged from this paper for the wider extension service provision and enhance the performance of the extension system. Some of these are not new but our results re-emphasize and give more sounds to their importance in developing countries like Ethiopia.

Despite the extension service provision is predominantly operated by the public sector, the involvement of relevant actors is very crucial. However, their interactions and collaboration for the provision of extension services are very limited and weak. Public extension services are remaining very important in countries like Ethiopia even in areas with very weak government institutions. Hence, improve the performance of the extension system through strengthening the interaction and partnership among actors is vital by offsetting the limiting factors. Important attention should be given to strengthening the existing ADPLAC platform for better functioning of the extension service provision. This could be also very helpful to avoid a mismatch between the demand for extension services by the end users and the delivery of extension services by the extension system.

The technical competence of DAs is very important besides the number of staff for an effective extension service provision. Moreover, gender balancing in extension staffing also required attention in the extension system. Therefore, not only the quantity and quality of DAs but also the number of female DAs is very crucial through capacity building and creating an enabling environment for motivation and commitment for their work. Enabling conditions such as rewarding and sanction systems, enforcement of performance targets, gender balancing, and skills development and training is found to be statistically significant. Therefore, the agricultural extension system should not only focus on the number of DAs and getting a good ratio of DAs-to-farmers but more significantly, it will be central to look at the quality and competence of DAs.

DAs are the key source of appropriate information to farmers since they are working closely with farmers besides their profession than other stakeholders in agriculture. For smooth extension service delivery DAs need means of transportation for reducing the time and transaction costs for field and farm visits. However, most DAs working under difficult conditions–lack of vehicles, lack of incentives, basic facilities in FTCs to provide training, minimum budget to conduct training, demonstrations, and exhibitions. Hence, appropriate measures should be taken to tackle all those problems to enhance the performance of the extension services. These include furnishing adequately the FTCs to give services at full capacities. We suggest reuse of their internal revenue is one of the mechanisms to strengthen the capacity of FTCs rather than fully depend on government budget allocation. And encourage and support FTCs to generate their income from demonstrations and crops in the land allocated for FTCs. In addition to this, motivate FTCs to search for their donor funding to strengthen their capacities. There are some FTCs supported by projects such as AGPs in the study areas (Denkaka) which could show higher performances.

Improving the efficiency and effectiveness of the extension service provision through the rewarding and sanctions mechanisms at the grassroots level and familiarize themselves with different actors can improve awareness about the change and enable farmers' access to its benefits. Strengthening the existing ADPLAC platform is very important to enhance interaction and cooperation among actors for a large coverage of the extension services. Hence, all relevant actors in the agriculture value chains should work collaboratively to improve the performance of AEOs and individual DAs that they can transfer technologies and knowledge appropriate to the end-users. Further, streamlining the roles of DAs and model farmers, involve or collaborating with other actors can improve the reach, quality, and sustainability of the extension services.

3.6 References

Anderson, J. R., & Feder, G. (2004). Agricultural extension: Good intentions and hard realities. *The World Bank Research Observer*, *19*(1), 41-60.

Asfaw Solomon, Bekele Shiferaw, Simtowe, F., & Lipper, L. (2012). Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food Policy, 37*(3): 283–295.

ATA (2014). Transforming agriculture in Ethiopia. Annual report 2013/2014. Agricultural Transformation Agency, Addis Ababa.

ATA, MoA & EIAR (2015). Strategy to improve Ethiopia's National Agricultural Research System (NARS): Vision, systemic bottlenecks, strategic interventions and implementation framework, Addis Ababa.

Belay Kassa (2003). Agricultural extension in Ethiopia: the case of participatory demonstration and training extension system. *Journal of social development in Africa, 18*(1): 49–83.

Belay Kassa & Dawit Alemu (2017). Agricultural research and extension linkages: Challenges and intervention options. *Ethiopian Journal of Agricultural Sciences*, *27*(1), 55-76.

Belay Kassa, Ranjan, S., Dawit Alemu, Abera Deresa & Jemal Yousuf (2012). Work motivation and job performance of development agents in Ethiopia. Rural Capacity Building Project Ministry of Agriculture Addis Ababa, Ethiopia.

Benin, S., Nkonya, E., Okecho, G., Randriamamonjy, J., Kato, E., Lubade, G., & Kyotalimye, M. (2011). Returns to spending on agricultural extension: the case of the National Agricultural Advisory Services (NAADS) program of Uganda. *Agricultural Economics*, *42*(2), 249-267.

Birhanu Gedif, Tegegn Molla, Solomon Addisu & Yibeltal Ayenew (2016). Status of agricultural innovations, innovation platforms, and innovations investment. 2015 PARI project country report: Federal Democratic Republic of Ethiopia. In *Forum for Agricultural Research in Africa*.

Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., ... & Cohen, M. (2009). From best practice to best fit: a framework for designing and analyzing pluralistic agricultural advisory services worldwide. *Journal of agricultural education and extension*, *15*(4), 341-355.

Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J. M., ... & Kisamba-Mugerwa, W. (2006). *From" best practice" to" best fit": a framework for designing and analyzing pluralistic agricultural advisory services* (No. 4). International Food Policy Research Institute (IFPRI).

Chiligati, J. E. (2010). Factors influencing research-extension-farmer linkages in Tanzania: a case of the Western agricultural research zone. A PhD dissertation submitted to Sokoine University of Agriculture.

CSIR & MOFA (2013). Research-extension-farmer linkages committee manual: Ghana national agricultural research and extension system. The Council for Scientific and Industrial Research and the Ministry of Food and Agriculture, Ghana.

Davis, K., & Heemskerk, W. (2012). *Module 3: Investments in extension and advisory services as part of Agricultural Innovation Systems, in World Bank (2012) Agricultural Innovation Systems: An Investment Sourcebook*. Washington, DC: World Bank.

Davis, K., Nkonya, E., Kato, D., Mekonnen, Alemu, Odendo, M., Miro, R., & Nkuba, J. (2012). Impact of farmer field schools on agricultural productivity and poverty in East Africa. *World Development 40* (2), 402–413.

Davis, K., Swanson, B., Amudavi, D., Mekonnen, D. A., Flohrs, A., Riese, J., ... & Elias Zerfu (2010). In-depth assessment of the public agricultural extension system of Ethiopia and recommendations for improvement. *International Food Policy Research Institute (IFPRI) Discussion Paper, 1041*.

Debebe Cheber, Okoyo, E.O., & Jemal Yousuf (2016). Factors influencing work motivation of development agents: The case of Agarfa and Sinana Districts, Bale Zone, Oromia Regional State, Ethiopia. *International Journal of Agricultural Science Research*, *5*(1), 1-18.

Demese Chanyalew, Berhanu Adenew, & Mellor, J. (2010). Ethiopia's agricultural sector policy and investment framework (PIF)(2010–2020), Draft final report. *Federal Democratic Republic of Ethiopia, Ministry of Agriculture and Rural Development. Addis Ababa*.

Desalegn Abo & Nuri Lefebo (2018). Factors influencing job performance of development agents: The case of Soro Woreda of Hadiya Zone, Southern Ethiopia. *European Journal of Business and Management*, *10*(1), 15-30.

Dessalegn Rahmato (2009). The peasant and the State: Studies in agrarian change 1950s-2000s. Addis Ababa University Press.

Fantu Nisrane, Guush Berhane, Minten, B., & Alemayehu Seyoum (2015). *Agricultural growth in Ethiopia (2004-2014): In Working paper 81. Addis Ababa: IFPRI–ESSP*.

Faure, G., Desjeux, Y., & Gasselin, P. (2012). New challenges in agricultural advisory services from a research perspective: A literature review, synthesis and research agenda. *Journal of Agricultural Education and Extension, 18* (5), 461–492.

Feder, G., Anderson, J., Birner, R., & Deininger, K. (2010). Promises and realities of community based agricultural extension. IFPRI Discussion Paper 00959. Washington, DC: IFPRI.

Gerba Leta (2018). *The Ethiopian Agricultural Extension System and Its Role as Development Actor: Cases from Southwestern Ethiopia* (Doctoral dissertation, Universitäts-und Landesbibliothek Bonn).

Gerba Leta, Girma Kelboro, Stellmacher, T., & Hornidge, A. (2017). The agricultural extension system in Ethiopia: operational setup, challenges and opportunities ZEF, Center for Development Research, University of Bonn Working Paper 158.

Greene, W.A. (2012). *Econometric Analysis, 7th Edn., Harlow*. Pearson.

Gujarati, D. N. (2009). *Basic econometrics*. Tata McGraw-Hill Education.

Habtemariam Kassa (2008). Agricultural extension in Ethiopia: historical evolution, relevant policies and challenges. *Digest of Ethiopia's National Policies, Strategies and Programs*, 469.

Hall, A., Bockett, G., Taylor, S., & Sivamohan, M. (2001). Why research partnership really matter: Innovation theory, institutional arrangements and implications for developing new technology for the Poor. *World Development, 29* (5), 783–797.

Ifenkwe, G. (2012). Agent-related factors affecting the performance of agricultural extension staff in Abia State, Nigeria. *Journal of Agricultural Science, 3*(1), 45–48.

Kassahun Berhanu & Poulton, C. (2014). The political economy of agricultural extension policy in Ethiopia: Economic growth and political control. *Development Policy Review, 32* (2), 197-213.

Khalil, A., Ismail, O., Suandi, T., & Silong, A. (2009). Human resource development competencies as predictors of agricultural extension agents' performance in Yemen. *Human Resource Development International, 12*(4), 429–447.

Khalil, A., Ismail, O., Suandi, T., & Silong, A. (2008). Extension worker as a leader to farmers: Influence of extension leadership competencies and organizational commitment on extension workers' performance in Yemen. *Journal of International Social Research, 1* (4), 368–387.

Lefort, R. (2012). Free market economy,' developmental state' and party-state hegemony in Ethiopia: the case of the 'model farmers'. *The Journal of Modern African Studies, 50*, 681-706.

McGuire, C. J. (2012). Education and training for technical development. *Agricultural Innovation Systems. An investment source book. The World Bank, Washington DC.*

Menale Kassie, Marenya, P., Yohannis Tessema, Moti Jaleta, Zeng, D., Erenstein, O., & Rahut, D. (2018). Measuring farm and market level economic impacts of improved maize production technologies in Ethiopia: Evidence from panel data. *Journal of Agricultural Economics*, *69*(1), 76-95.

MoA (2020). Agriculture sector investment prioritization (2019/20-2024/25). Ministry of Agriculture, Addis Ababa.

MoANR (2017). Ethiopia's agricultural extension strategy: Vision, systemic bottleneck and priority intervention. Ministry of Agriculture and Natural Resources, Addis Ababa.

Nagel, U. (1997). Improving agricultural extension: FAO reference manual. Food and Agriculture Organization, Rome.

NAO (2008). The use of sanctions and rewards in the public sector: Performance measurement practices. National Audit Office, London.

OXFAM (2016). El Niño in Ethiopia: Program observations on the impact of the Ethiopian drought and recommendation for action. OXFAM El Niño Briefings. Accessed on https://www.oxfam.org/sites/www.oxfam.org/files/file_attachments/bn-el-nino-ethiopia.

Pye-Smith, C. (2012). Agricultural extension*: A time for change: Linking knowledge to policy and action for food and livelihoods*. CTA.

Ragasa, C., Ulimwengu, J., Randriamamonjy, J., & Badibanga, T. (2016). Factors affecting performance of agricultural extension: Evidence from Democratic Republic of Congo. *The Journal of Agricultural Education and Extension*, *22*(2), 113–143.

Rivera, W. M., Quamar, M. K., & Crowder, L. V. (2001). Agricultural and rural extension worldwide: options for institutional reform in the developing countries. Extension, Education and Communication Service, Research, Extension and Training Division. *Sustainable Development Department, FAO, Rome*.

Sefton, M., Shupp, R., & Walker, J. M. (2007). The effect of rewards and sanctions in provision of public goods. *Economic inquiry*, *45*(4), 671-690.

Spielman, D., Dawit Kelemework, & Dawit Alemu (2012). Seed, fertilizer, and agricultural extension in Ethiopia. *Food and agriculture in Ethiopia: Progress and policy challenges*, 84-122.

Stellmacher, T. (2015). Socio-ecological Change in Rural Ethiopia*: Understanding Local Dynamics in Environmental Planning and Natural Resource Management*. Peter Lang GmbH, Internationaler Verlag der Wissenschaften.

Tesfaye Getaneh (2012). Work motivation and job performance of development agents in agro-pastoral areas: The case of Bule Hora district, Borana Zone, Ethiopia. An MSc thesis presented to School of Graduate Studies, Haramaya University.

Thach, L. N. (2008). Individual factors as predictors of extension agents' performance in Mekong Delta. A PhD thesis, University Putra Malaysia.

Van den Berg, H., & Jiggins, J. (2007). Investing in farmers—the impacts of farmer field schools in relation to integrated pest management. *World development*, *35*(4), 663-686.

World Bank (2016). World Development Indicators. Accessed March 2016. http://data. worldbank.org/data-catalog/world-development-indicators.

Yohannes Muluneh (2009). Factors influencing work motivation of development agents in Burji and Konso special woredas. An MSc thesis Presented to the School of Graduate Studies of Haramaya University.

Zelalem Bekele (2011). Factors influencing work motivation of development agents, Assosa zone, Benishangul Gumuz Regional State, Ethiopia. An MSc thesis presented to School of Graduate Studies of Haramaya University.

4. THE IMPACT OF MULTIPLE AGRICULTURAL TECHNOLOGIES ADOPTION ON HOUSEHOLD FOOD SECURITY OF SMALLHOLDERS IN CENTRAL ETHIOPIA: AN ENDOGENOUS SWITCHING ESTIMATION

Abstract

The adoption of agricultural technologies has a significant effect on productivity and household food security. Their synergies also increase soil fertility while suppressing weeds, pests, and diseases. Many studies looked at the impact of adopting agricultural technologies in isolation rather than in combination. As a result, the purpose of this study is to examine the impact of a combination of improved tef technologies on yield, household dietary energy supply (DES), dietary diversity (HDDS), and food consumption score (FCS) in Central Ethiopia. The study was based on a household survey questionnaire of 240 sample households, focus group discussants, and key informants in Minjar Shenkora and Ada'a *woredas*. An endogenous switching regression model is used to examine the impact of new agricultural technologies utilized in various combinations. The results suggest that using improved *tef* technologies considerably increases yield and improves DES, HDDS, and FCS in households. The greater food security impact is obtained when these improved technologies adopted in combinations rather than in isolation (individually). However, the greatest adoption effect is achieved when farming households adopted all three improved *tef* technologies. As a result, all R&D actors, including agricultural researchers, development agents, development practitioners, and policymakers, should support a combination of improved *tef* technologies that can improve household food security by boosting productivity and farm income.

Keywords: Adoption effects, combination adoption, Ethiopia, food security, individual adoption

4.1 Introduction

Agriculture in Ethiopia is in a great challenge as a result of the country's growing demand for agricultural food production. Ensuring food security for today's population and generations to come is one of Ethiopia's greatest challenges. Agriculture is considered to play a significant role in ensuring food security and economic growth generally (Tsega et al., 2019). It contributes 32.7% of GDP, 72.7% to employment opportunities, 90% to export earnings, and 90% of raw materials for industries (NBE, 2019/20; CSA and WFP, 2019). Furthermore, despite agriculture's declining share of total GDP, its GDP contribution has risen from 19.6 billion USD to 27.5 billion USD over the last six years (MoA, 2020). The sound performance of agriculture does not only signify the adequate acquisition of food crops to attain food security but also heralds a positive impact on the economy (CSA, 2020). Recognizing the sector's importance, Ethiopia's government has given it its attention and stated its commitment to invest 10% of its budget to agriculture since 2003, yet spending has fallen considerably below 10% since 2012 (MoA, 2020; MoANR, 2017; Demese et al., 2010).

Furthermore, Ethiopia's government has implemented the Agricultural Development Led Industrialization (ADLI) strategy, which aims to enhance the link between agriculture and industry by increasing smallholder productivity (MoFED, 2003). Agricultural research and extension play a vital role in increasing productivity by developing and disseminating innovative technology (NPC, 2016; Maiangwa, 2010). As a result, the national research system has released over 3000 improved technologies, agronomic practices, and recommendations during the last five decades. Smallholder farmers have been able to adopt improved technologies as a result of this action. The agricultural sector's growth is highly dependent on successful innovation and its widespread adoption (Ellis, 1993). Adoption of new technologies is a promising strategy in many developing countries, including Ethiopia, to attain smallholder food security. It contributes significantly to food security by increasing productivity and farm income (Menale et al., 2015; Asfaw et al., 2012). Improving rural people' livelihoods through agricultural productivity would remain a pipe dream unless the level of technological adoption is increased (Gemeda et al., 2007, Ajayi et al., 2003). The success of yield-enhancing technologies and techniques such as improved seed, chemical fertilizer, herbicides, and row planting relies on the type of technology used by farmers.

Numerous studies clearly show that improved agricultural technology have a considerable positive impact on smallholders' household food security (Wubneshe et al., 2019; Hailemariam et al., 2019; Menale et al., 2018; Marenya et al., 2018; Magrini and Vigani, 2016; Bekele et al., 2014; Sosina et al., 2014; Asfaw et al., 2012; Minten and Barrett, 2008). Adopting improved seed varieties, chemical fertilizers, pesticides, and conservation practices, for example, significantly increases household food consumption expenditure, according to Wubneshe et al. (2019). A study by Marenya et al. (2018) showed that the adoption of a combination of improved maize variety and maize-legume diversification increases per capita calorie consumption and dietary diversity consumption in Ethiopia. Asfaw et al. (2012) found that using improved pigeon pea varieties increased household per capita calorie consumption in Tanzania. The adoption of improved agricultural technologies affects poverty and vulnerability to poverty directly or indirectly. The immediate effect is achieved by increasing productivity, which leads to an increase in home-consumed food and marketable surplus, which reduces adopters' poverty and food insecurity. An indirect effect may be achieved through a decrease in food prices for non-adopters and buyers of food (Minten and Barrett, 2008). Menale et al. (2015) the adoption of technologies is associated with significant maize yield improvements and the highest yield effect is obtained from the joint adoption of technologies in Malawi.

In this study, we analyze the impact of the adoption of improved technologies, including improved *tef* variety, chemical fertilizer, and row planting practices. These technologies and practices are widely used and practiced in the study areas. Several studies have estimated the impact of adopting a single or a combination of two technologies on household food security (Regasa et al., 2018; Menale et al., 2018; Yitbarek, 2017; Debelo, 2015; Chima, 2015; Solomon et al., 2015; Negera and Getachew, 2014; Asfaw et al., 2012). Actually, improved agricultural technologies are often recommended to be used in multiple combinations and the maximum potential can only be realized when these technologies are adopted with other complementary inputs. Few studies assessed the impact of adopting multiple improved agricultural technologies and practices in combination on household food security (Wubneshe et al., 2019; Hailemariam et al., 2019; Marenya et al., 2018; Magrini and Vigani, 2016; Menale et al., 2015; Sosina et al., 2014; Spielman et al., 2010). Among those few studies, only a few analyzed the impact of multiple *tef* technologies on household food security by disaggregating dietary energy supply

(DES), dietary diversity (HDDS), and food consumption score (FCS). Most of the multiple technology adoption studies were considered commodities like maize and wheat, only a few considered *tef.* As a result, the aim of this study is to examine the impact of a combination of various improved technologies adoption on household food security in the *woredas* of Minjar Shenkora and Ada'a in Central Ethiopia.

The findings of this study add to the existing literature in three respects. First, this study will add to the literature by analyzing the impact of multiple improved technologies adoption on disaggregated household DES, HDDS, and FCS in a smallholder farming system in Ethiopia. It also informs farmers about which agricultural technology combinations offer the highest DES, HDDS, and FCS. Second, our findings take into account policy-relevant variables that were not assessed in most previous studies, allowing policymakers and development practitioners to devise policy options to resolve the constrained factors. Finally, this study adds to the limited empirical evidence at the local level on the impacts of adopting multiple improved *tef* technology adoptions on DES, HDDS, and FCS of smallholders.

4.2 Materials and methods

4.2.1 Data source and sampling procedures

The data used for this study is based on a cross-sectional household survey conducted in Minjar Shenkora *woreda* of Amhara Regional State and Ada’a *woreda* of Oromia Regional State of Central Ethiopia. Both qualitative and quantitative data collection techniques were used for this study. Quantitative data were collected through a household survey based on structured questionnaires to capture key indicators of food security status and the impact of various combinations of improved technologies adoption. The interviews were conducted with a Computer Assisted Personal Interview (CAPI) to improve the quality of data and remove errors during data entry. Enumerators were selected based on their experience in using the CAPI. As a part of the preparation, field-based training was given to all enumerators on how to administer and complete the questionnaire. After training, the questionnaires were pretested in one village outside the sampled *kebeles*. The objective of the pilot survey was to enable enumerators to practice the interview in the field and to get constructive feedback on the contents of the questionnaire. Qualitative data were collected through key informants, focus group discussants, and personal observations to substantiate the quantitative data. Key informant interviews with model farmers, development agents, and elderly in each sample *kebeles* (peasant association), and also focus group discussions were all conducted by the researcher himself. Moreover, secondary data were used to compile the background information of the study, establish the conceptual framework, and select methods of estimations. Secondary data from published and unpublished documents from BoA, peer-reviewed articles, books, and annual reports, and other relevant sources were also used.

A multi-stage sampling procedure was employed to select *kebeles* from each *woreda* and randomly select households from each *kebeles*. In the first stage, based on their *tef* production potential, two *woredas* from the two regions were selected. Thus, Minjar Shenkora *woreda* from the North Shewa Zone of Amhara Regional State and Ada'a *woreda* from the East Shewa Zone of Oromia Regional State were purposely selected. In the second stage, four *kebeles* (two from each *woreda*) were randomly selected for this study. Hence, Agirate and Adama *kebeles* from Minjar Shenkora *woreda* and Denkaka and Golo-Dertu *kebeles* from Ada'a were randomly selected. In the third stage, the proportional random sampling method was applied to determine the sample size in each *kebele*. Yamane's (1967) suggested formula was used to determine representative households from each sample *kebele*. This simplified formula requires a sample size of 95% confidence, a degree of variability of 0.5, and a level of precision of 5%. Finally, 240 farmers were chosen at random for face-to-face interviews using a simple random method.

4.2.2 Data description

Choice of agricultural technologies variables

We consider improved technologies as a complement to *tef* production systems. Among the technologies are improved *tef* variety, chemical fertilizer, and row planting practices. In the study areas, they can be used in a variety of combinations. In terms of both production and consumption, *tef* is one of Ethiopia's most important crops (Minten et al., 2016; Vandercasteelen et al., 2013; Bekabil et al., 2011). It is the cereal with the highest area coverage and the second highest volume of output, after only maize (CSA, 2020). It is also consumed on a daily basis by almost two-thirds of the population, accounting for 15% of all calories consumed (Yazachew, 2020; Bekabil et al., 2011). Thus, improved *tef* variety is an important technology to be considered in this study. The second variable is chemical fertilizer, which is quite beneficial in increasing soil fertility. Since improved *tef* variety and chemical fertilizer are considered by the government as a package in *tef* production systems, the usage of chemical fertilizer has increased over time. The traditional *tef* sowing method is regarded as one of the primary reasons for low *tef* yields in Ethiopia (Vandercasteelen et al., 2016). In research sites, row planting has been shown to increase *tef* productivity up to three times average productivity and lowers seed costs, making it seem a good value proposition for *tef* producers (Tareke et al., 2011). Moreover, row planting is believed to make weeding easier, requiring less labor.

Table 4.1 presents the combinations of improved agricultural technologies. The farmer could choose from eight combinations of the three technologies. For example, adoption of improved *tef* variety (V), Chemical fertilizer (F), and row planting practice (R) is denoted as $V_1F_1R_1$; adoption of none of the practices is $V_oF_oR_{o,}$ and so on. About 9% of households did not adopt any of the technology packages ($V_oF_oR_o$), 35.4% of households adopted individual technologies, and 33.8% have adopted combinations of technologies. While all three improved technologies were jointly adopted by 22.1% of the households ($V_1F_1R_1$).

Outcome variables

Three sets of household food security indicators (outcome variables) are employed: dietary energy supply, dietary diversity score, and food consumption score. Dietary energy analysis is an important indicator of food adequacy level and food security status of the household. It provides the average daily food available for each person in a country or region and is used to comprehend the minimum average daily dietary calorie of 2100 kcal/ADE/day. Dietary variety was originally intended to be a measure of both the quantity and quality of food access, and the 12 food groups included in the HHDS reflect a combination of both. In circumstances where resource constraints prevent the use of thorough nutritional assessment methodologies, simple scores have been established to measure food diversity in the household. Dietary diversity scores are calculated by taking a basic count of the items or food groups ingested over a given time period, which is commonly 24 hours. Household food consumption score is based on a recall of food groups eaten in the seven days preceding the moment of the interview. The food intake score is computed by looking at how many times certain food groups were consumed in the seven days leading up to the survey and then weighting them based on nutrient density values.

Table 4.1 Proportion of adoption of various combinations of improved technology packages

Technology Packages	Category	Improved *Tef* Variety (V)		Chemical Fertilizer (F)		Row Planting (R)		%
		V_o	V_1	F_o	F_1	R_o	R_1	
V_o F_o R_o	Non-adopters	√		√		√		8.8
V_1 F_o R_o	Individual technology adopters		√	√		√		10.0
V_o F_1 R_o		√			√	√		17.1
V_o F_o R_1		√		√			√	8.3
V_1 F_1 R_o	Combination technology adopters		√		√	√		13.8
V_1 F_o R_1			√	√			√	7.5
V_o F_1 R_1		√			√		√	12.5
V_1 F_1 R_1	All three technologies adopters		√		√		√	22.1
Total								**100.0**

Note: V, F and R refer to technology set for improved *tef* variety, chemical fertilizer and row planting practice, respectively; subscript ‘0’ denotes non-adoption, while ‘1’ denotes adoption of technologies

Control variables

In the econometric analysis, we sorted through with a large body of literature on technology adoption to identify a detailed collection of factors that affect farming households' adoption decisions (Wubneshe et al., 2019; Regasa et al., 2018; Menale et al., 2018; Vandercasteelen et al., 2016; Dejene and Bekele, 2015; Debelo, 2015; Chilot et al., 2015; Menale et al., 2015; Bekele et al., 2014; Menale et al., 2010). Table 4.2 lists the control variables used in the empirical study, their descriptions, and summary statistics for the survey respondents all based on the literature. These studies show that a variety of factors influence the adoption of new technologies and, as a result, our outcome variables. Hence, based on the literature we used the following factors as explanatory variables. Explanatory factors include household characteristics, resource endowments, and membership in cooperatives, extension-related variables, market access, and farmers’ perception.

Table 4.2 Definition and summary statistics of the explanatory variables used in the analysis

Variables	Variable Description	Mean of Alternative Technology Adoption								Overall	
		$V_0F_0R_0$	$V_1F_0R_0$	$V_0F_1R_0$	$V_0F_0R_1$	$V_1F_1R_0$	$V_1F_0R_1$	$V_0F_1R_1$	$V_1F_1R_1$	Mean	SD
HOUSEHOLD CHARACTERISTICS											
SEX (+/-)	1= if the household head is male	0.87***	1.00*	0.93	0.95	0.91	0.83	0.87	0.94	0.90***	-
AGE (+)	Age of the head in years	48.24	43.33	47.34	45.75	47.73	43.50	40.97**	45.51	45.45	12.54
EDUC_0 (+)	1= if the head has no formal school	0.57	0.63	0.49	0.60	0.54	0.45	0.50	0.45	0.52	-
EDUC_1 (+)	1= if the head between 1 and 8 grade	0.43	0.33	0.46	0.40	0.42	0.50	0.43	0.53	0.45	-
EDUC_2 (+)	1= if the head greater than 8 grade	0.00	0.04	0.05	0.00	0.03	0.05	0.06	0.02	0.03	-
HH_SIZE (-)	Household size in ADE	4.62	4.54	4.73**	4.45	4.64	5.22	4.97	4.81	4.75	2.16
RESOURCE ENDOWMENT											
FM_SIZE (+)	Farm size in ha	1.47**	2.31	2.55	2.37	3.07**	3.02	2.72	3.16*	2.58**	1.89
LIVESTOCK (+)	Livestock herd in TLU	3.13	5.16	5.97	3.41***	5.91	6.57**	5.00	7.03***	5.75	4.15
OFF_FARM (+)	1= if HH engaged in off farm activities	0.19	0.17	0.22	0.20	0.21	0.06	0.17	0.09*	0.16	-
INSTITUTIONAL FACTORS											
CREDIT (+)	1= if the HH access credit	0.19***	0.50	0.61	0.65	0.48	0.61	0.73**	0.60	0.56***	-
COOP (+)	1= if HH member of cooperatives.	0.29***	0.58	0.51***	0.60	0.82*	0.78	0.80	0.96***	0.70***	-
EXTENSION SERVICE											
CONTACTS (+)	Frequency of DA contact per year	1.71	2.71	2.22***	2.30	3.18	2.22	2.33	6.42***	3.30	6.74
CONFIDENT (+)	1 = if HH confident to the skills of DA	0.52	0.71*	0.56	0.65	0.64	0.61	0.63	0.66***	0.54	-
TRAINING (+)	1= if the head access to training	0.48**	0.75	0.66	0.70	0.67	0.61	0.70	0.85***	0.70***	-
DIS_EXT (-)	Distance to nearest extension off. (km)	5.81***	4.24	4.50	4.94	4.46	4.00***	3.33	3.14**	4.14***	3.58
MARKET ACCESS											
DIS_INPUT (-)	Distance to nearest input market (km)	6.07	4.99	4.60	5.09	5.46	5.00	4.52**	3.66**	4.74*	4.36
DIS_OUTP (-)	Distance to nearest output market (km)	11.19	8.08**	10.11	8.91	9.79***	7.86	11.68	11.43	10.18**	6.94
HOUSEHOLD PERCEPTION											
ECO_RETUR (+)	Perception on economic return (1-5)	2.80***	3.92	3.27***	3.40	3.58	3.39	3.67	4.51***	3.78***	0.94
PACKAGE (+)	Ext. packages appropriateness (1-5)	3.09	2.67	3.12	3.00	2.85	2.94	3.30*	2.38***	2.85	1.35
PARTICIP (+)	Participatory extension services(1-5)	2.09	2.25	2.34	2.20	2.33	2.06	2.60***	1.94***	2.24	0.83

Note: *, ** and *** denote failure to accept the null hypothesis of equal means or proportional between each package and $V_0F_0R_0$ at 10%, 5% and 1%, respectively
Source: Own calculation based on field survey

4.2.3 Econometric estimation: Endogenous switching regression model

Farmers may endogenously self-select into utilizing or not employing a combination of technologies, rather than adopting them at random. As a result, unobservable characteristics relating to the outcomes of interest are likely to influence decisions. When the three agricultural technologies and practices (improved tef variety, chemical fertilizer, and row planting practice) are combined, there are eight possible combinations. Farming households may adopt various combinations of agricultural technologies based on their choice in a given cropping season. Using an ESR estimate technique, the choice of various technology combinations and the effects of adopting the various technology combinations on crop yield and household food security outcomes are investigated (Bourguignon et al., 2007).

Following random utility formulation, the observed outcome of a combination of agricultural technology adoption can be modeled. The utility obtained by the household is not directly observed; rather, it is observed through the choice of the household. Suppose farm households adopt a combination of technologies, by comparing the utility U_i provided by m alternative packages. The requirement for household i to choose any combination, j, over any alternative package, m, is that $U_{ij} > U_{im}$ $m \neq j$, or equivalently $\Delta U_{im} = U_{ij} - U_{im} > 0$ $m \neq j$. The expected profit U^*_{ij}, that the household derives from the adoption of full package "j" is a latent variable determined by observed household, plot, and location characteristics (X_i) and unobserved characteristics (ε_{ij}) (Hailemariam et al., 2019, 2013).

$$U^*_{ij} = X_i\beta_j + \varepsilon_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, X_i is observed exogenous variables and ε_{ij} is unobserved characteristics.

Combination of technology packages j is chosen if U^*_{ij} is the highest for farming household j. Hence, the household will select an alternative combination of technology package j in preference to adopting any other combination of packages m if

$$U = \begin{cases} 1 \text{ if } U^*_{i1} > \max\limits_{m \neq j} (U^*_{im}) \text{ or } \eta_{i1} < 0 \\ . \\ . \\ . \\ j \text{ if } U^*_{ij} > \max\limits_{m \neq j}(U^*_{im}) \text{ or } \eta_{ij} < 0 \end{cases} \quad \text{for all } m \neq j \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where $\eta_{ij} \neq \max m{\neq}j\ (U^*_{im} - U^*_{ij}) < 0$. It implies that the i[th] farmer will adopt technology package j to maximize his/her expected utility if package j provides greater expected utility than any other package $m \neq j$.

The utility of technology package adoption as a function of exogenous variables at household level as well as regional and time dummies was specified. The probability that farmer i with characteristics X will choose combination technology package j can be specified by a multinomial logit model (Menale et al., 2015; McFadden, 1973).

$$P_{ij} = pr\,(\eta_{ij} < 0 \mid X_i) = \frac{exp\,(X_i B_i)}{\sum_{m=1}^{j} \exp(X_i B_i)} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The endogenous switching regression was modeled in two stages (Gorst et al., 2018). The first is the selection model for adoption of various combinations of technologies denoted with the binary variable. Let M* be the latent variable that captures the expected benefits from the adoption of alternative choice with respect to not adopting (U_{ij} - U_{im}). Hence, the latent variable is specified as follows:

$$M^* = Z_i\alpha + \varepsilon_i \text{ with } M_i = \begin{cases} 1 \ \ if\ Mi > 0 \\ 0\ Otherwise \end{cases} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where M is a binary indicator variable that equals 1 if a household adopt alternative combinations of technologies and zero otherwise; Z is a vector of factors influencing the decision to adopt a combination; α is a vector of parameters to be estimated; and ε is the error term.

The second stage is the outcome equation that split the endogenous model and running a separate regime for the decision of adopt a combination of various technologies and not to adopt. Therefore, the seven alternative combinations of adoption equations are specified as follows:

$$\begin{cases} Regime\ 1: Q_{i1} = Z_i\alpha_1 + U_{i1} if\ I = 1 \\ \vdots \\ Regime\ j: Q_{ij} = Z_i\alpha_j + U_{ij}\ if\ I = j \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

Where Q'_{i1}s are the outcome variables of the ith farmers in regime j, and the error (u's) are distributed with E(Uij $|$X, Z) = 0 and var (Uij $|$X, Z) = δ_j^2. Qij is observed if and only if technology package j is adopted, which occurs when $U_{ij}^* > \max_{m \neq j}(U_{im}^*)$. Using this assumption, the equation of the multinomial ESR in equ (5) is specified as:

$$\begin{cases} \text{Regime 1: } Q_{i1} = Z_i\alpha_1 + \delta_1\lambda_1 + w_{i1}\ if\ I = 1 \\ \vdots \\ \text{Regime j: } Q_{i1} = Z_i\alpha_1 + \delta_1\lambda_1 + w_{i1}\ if\ I = j \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Where δ_j is the covariance between ε's and u's, and λ_j is the inverse Mills ratio (Dubin and Mcfadden, 1984).

4.2.4 Average adoption effects estimation

This sub-section presents how to estimate the average treatment effect of a combination of agricultural technologies from the econometric approach delineated above. The impact of various combinations of improved technology adoption on yield and household food security is estimated using the endogenous regression model where the alternative adopters are considered as the treatment group with the estimation of their counterfactual. The estimated treatment effects are of particular interest in this context, specifically the average treatment effect (ATE) and the average treatment effect for the treated (ATT). The ATE answers the question of how the average outcome would change if everyone in the population of interest had been treated with a particular combination of technology packages relative to non-adopters. Similarly, the ATT and ATU answer the question of how the average outcome would change if everyone who received one particular treatment had instead received another particular treatment.

$E(Q_{ij} \mid I = j) = Z_{ij}\alpha_j + \sigma_j\lambda_{ij}$ → Adopters with adoption (actual) ……………………………(7)

$E(Q_{i1} \mid I =1) = Z_{ij}\alpha_1 + \sigma_1\lambda_{i1}$ → Non-adopters without adoption (actual)…………………....(8)

$E(Qi1 \mid I = j) = Z_{ij}\alpha_1 + \sigma_1\lambda_{ij}$ → Adopters had they decided not to adopt (counterfactual)….(9)

$E(Qij \mid I =1) = Z_{ij}\alpha_j + \sigma_j\lambda_{i1}$ → Non-adopters had they decided to adopt (counterfactual) …(10)

Equations (7) and (8) represent the expected outcomes of adopters and non-adopters that were actually observed in the sample, whereas Equations (9) and (10) denote the counterfactual expected outcomes of adopters and non-adopters, respectively. Expected values are used to calculate unbiased estimates of the effects of adoption on adopters and on non-adopters. The average combination of technology package adoption effect on the adopters (ATT) is defined as the difference between Equations (7) and (9) (Di Falco and Veronesi, 2011)

$ATT = (Q_{ij} \mid I = j) - E(Q_{i1} \mid I = j) = Z_i (\alpha_j - \alpha_1) + \lambda_{ij}(\sigma_j - \sigma_1)$ ………………………….(11)

Similarly, the average effects of adoption of a combination of technology packages on non-adopters (ATU),

$ATU = E(Q_{ij} \mid I =1) - E(Q_{i1} \mid I =1) = Z_i (\alpha_j - \alpha_1) + \lambda_{i1}(\sigma_j - \sigma_1)$ ……………………… (12)

4.3 Results and discussions

This section presents the empirical results that emerged from the study to estimate the adoption effects of various combinations of improved technologies on the crop yield and DES, HDDS, and FCS. In the first section, we present the assessment of food availability and consumption and the descriptive results of the sample respondents. In the third section, we analyze the impact of various combinations of technology adoption on the crop yield and households' DES, HDDS, and FCS by using average treatment effects of the ESR model.

4.3.1 Food availability, access and consumption of sample households

Dietary energy supply (DES)

Net available food (NAF) was used as both indicators of food availability, and an indicator of the food security situation for almost all rural households in the study areas. Results show that 35.8% of farming households belonged to food insecurity while 64.2% belong to food security (Table 4.3). A sum of 597,603.3 Kilocalorie (Kcal) with the mean of 2,491.2 Kcal and standard deviation (SD) of 839.7 Kcal was available for all sample households from all sources. The mean Kcal available for the food secure households was 2,860.6 Kcal/ADE/day with SD of 860.2 Kcal/ADE/day. In contrast, for food-insecure households, the mean was 1,891.7 Kcal/ADE/day with SD of 272.3 Kcal/ADE/day. The mean dietary energy supply for food secure households was larger than that of food-insecure households. Their mean difference between the two groups was statistically most significant ($P<0.01$). Moreover, the range (min= 1,023.8 and max= 7,547.7) implies that there was a great variation among the farming households in the study areas so that looking into the conditions of each household was essential.

Results further indicate that about 38.5% of households in Minjar Shenkora *woreda* with a mean of 1,874.1 Kcal/ADE/day belonged to food insecurity while 61.5% of farm households with a mean of 2,792.6 Kcal/ADE/day belong to food secure. Similarly, 33.3% of households in Ada'a *woreda* have belonged to food insecure with a mean of 1,916.2 Kcal/ADE/day and 66.7% of households with a mean of 2,921 Kcal/day/ADE belonged to food secure. The mean of the daily dietary energy supply of Minjar Shenkora *woreda* (2,409.9 Kcal/ADE/day) was smaller than the mean of the daily dietary energy supply of Ada'a *woreda* (2,570.2 Kcal/ADE/day). Their mean difference between the two *woredas* was not statistically significant at $P< 0.1$ level.

Among those farming households who had no chance to adopt improved technologies and knowledge, about 71% belong to food insecurity and 29% food secure. Their mean difference was statistically most significant at $p<0.01$. About 35% of the sample respondents reported their adoption of individual technologies or knowledge. Out of this, 42% of only improved *tef* variety adopters were food insecure while 58% were food secure households with statistically no significant difference at $p<0.1$. Similarly, 33.8% of farming households reported combinations of improved technologies and knowledge adopters. Among those households, 64% of improved *tef* variety and chemical fertilizer adopters were belonged to food secure while about 36% belong to food-insecure households. Their mean difference was statistically significant at $p<0.01$. Besides, about 83% of all the three combined technology adopters ($V_1F_1R_1$) belong to food security while 16.9% belong to food insecure. Their mean difference was statistically most significant at $p<0.01$. This result is consistent with the previous studies conducted by Wubneshe et al. (2019); Marenya et al. (2018); Menale et al. (2015); Hailemariam et al. (2013); Fernandez-Cornejo (1996) in Ethiopia and elsewhere where adoption of a combination of improved technology and knowledge give more daily energy supply compared to individual technology adopters and non-adopters.

Table 4.3 Households' dietary energy supply for various combinations of technology adoption (Kcal/ADE/day)

Info Type	Minimum	Maximum	Mean	SD	Sum	T-test
FI + FS	1,023.8	7,547.7	2,491.2	839.7	597,603.3	
FI (35.8%)	1,023.8	2,098.5	1,891.7	272.3	172,140.6	24.387***
FS (64.2%)	2,104.7	7,547.7	2,860.6	860.2	423,372.5	
Sample *Woredas*	1,023.8	7,547.7	2,491.2	839.7	597,603.3	
Minjar Shenkora	1,023.8	7,547.7	2,409.9	815.3	289,184.9	1.080
Ada'a	1,070.6	7,466.2	2,570.2	859.4	308,418.4	

Technology Packages	Minjar Shenkora			Ada'a			Overall			χ^2
	FI (n= 45)	FS (n= 72)	Total (117)	FI (n= 41)	FS (n= 82)	Total (123)	FI (n= 86)	FS (n= 154)	Total (240)	
$V_o F_o R_o$	52.4	23.8	76.2	19.0	4.8	23.8	71.4	28.6	100.0	16.302***
$V_1 F_o R_o$	20.9	37.5	58.4	16.7	25.9	42.6	37.6	63.4	100.0	0.072
$V_o F_1 R_o$	19.5	17.1	36.6	24.4	39.0	63.4	43.9	56.1	100.0	6.833***
$V_o F_o R_1$	25.0	20.0	45.0	25.0	30.0	55.0	50.0	50.0	100.0	1.114
$V_1 F_1 R_o$	18.2	24.2	42.4	18.2	39.4	57.6	36.4	63.6	100.0	0.104
$V_1 F_o R_1$	11.1	27.8	38.9	22.2	38.9	61.1	33.3	66.7	100.0	5.408**
$V_o F_1 R_1$	16.7	43.3	60.0	13.3	26.7	40.0	30.0	70.0	100.0	2.330*
$V_1 F_1 R_1$	9.4	39.7	49.1	7.5	43.4	50.9	16.9	83.1	100.0	17.776***
Overall	38.5	61.5	100.0	33.3	66.7	100.0	35.8	64.2	100.0	16.042***

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%; FS= food secure; FI= food insecure

Source: Own calculation based on field survey

Household dietary diversity score (HDDS)

HDDS is a consumption indicator that directly captures the score of diets consumed over the last 24 hours as reported by the households. Dietary diversity scores are constructed using a simple count of foods or food groups consumed over a reference period, usually 24 hours. We can classify households as low dietary diversity (≤ 3), medium dietary diversity ($4 \leq DD \leq 6$), and high dietary diversity (≥ 7). The survey results indicate that 16.7% of farm households were categorized under low dietary diversity, 55.0% in medium dietary diversity, and 28.3% of households were categorized under high dietary diversity (Table 4.4). While according to FAO (2013) categorization, households who found in low and medium dietary diversity are categorized as "inadequate dietary diversity" whereas households who found in high dietary diversity are categorized as "adequate dietary diversity". Based on these categorizations, 71.7% of households were found in inadequate dietary diversity and 28.3% of the sample households were found in adequate dietary diversity.

The results further show that the mean of food groups consumed by all sample households was 5.3. This implies that among the twelve food groups, the large majority of households consumed about 5 food types and categorized in medium dietary diversity. The minimum and the maximum number of food groups consumed by farm households were 2 and 10, respectively; it indicates that there are great disparities among households in diversifying their food consumption pattern. Focus group discussants and key informants affirmed most households were unable to diversify their diet due to lack of access to transport to the nearby market, lack of adequate money to purchase different food items, lack of information, ignorance, and negligence about the health benefits of diversifying their diets. Households cannot produce all types of food groups on their farm; hence purchase or exchange is very important to eat varieties of foods. But lack of transport and nearby market makes food purchase very difficult, especially for elders, pregnant women, and mothers with children.

The highest dietary diversity effect is obtained from the joint adoption of improved agricultural technologies and knowledge than each technology independently. The mean food groups consumed by a combination of technology adopters ($V_1F_1R_o$, $V_1F_oR_1$, and $V_oF_1R_1$) were 5.6 which is larger than households who adopted individual technology ($V_1F_oR_o$, $V_oF_1R_o$, and

$V_oF_oR_1$) (4.8) and non-adopter ($V_oF_oR_o$) (3.6). However, all three technology adopters have the largest food groups consumed (6.6) than the others. Among non-adopters, about 48% belonged to low dietary diversity, 43% medium dietary diversity, and about 9% belongs to high dietary diversity. There is a statistical different among the groups at $p<0.01$. Likewise, out of the three technology adopters, about 47% belonged to high dietary diversity, 51% belongs to medium dietary diversity, and only 2% belonged to low dietary diversity with a statistically significant difference at $p<0.01$

The result in Figure 4.1 indicates that cereals are the most frequently consumed diets per day (19.9%) followed by pulses (17.7%), condiments/beverages (16.1%), and oils/butter (15.6%), and sugar/honey (10.8%). Vegetables (5.6%), roots, and tubers (4.9%) contributed moderately to the daily meal of consumption by the households, however, the consumption of meat (2.4%), egg (2.2%), milk (2.4%), and fish (0.3%) was observed to be very minimal in the total daily meal. Nutritionally, meat, eggs, fish, and milk, each consisting of a weight of 4 are the most nutritious diet groups but consumed least frequently. In contrast, condiments with 0 nutritional weights were the most frequently consumed item (16.1%). Moreover, vegetables (5.6%) with a weight of 1 were also consumed at a reasonable frequency.

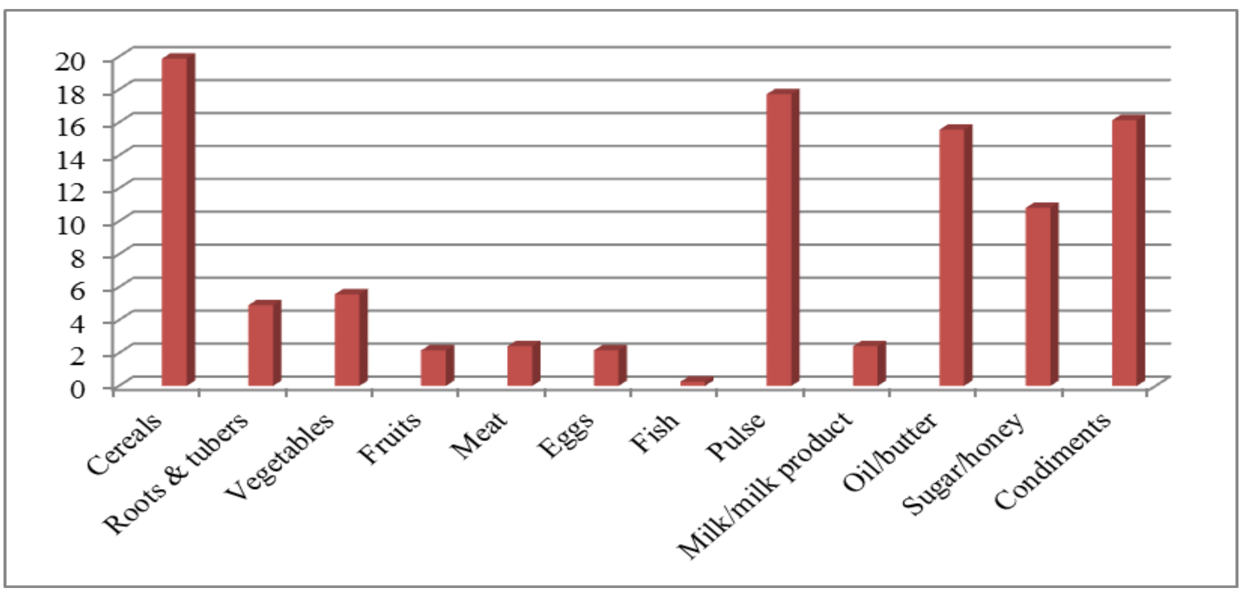


Figure 4.1 Percentage distributions of dietary food groups consumed by farming households

Source: Own calculation based on field survey

Table 4.4 Households' dietary diversity with various combinations of agricultural technologies adoption (%)

Technology Packages	Min	Max	Mean	Dietary diversity category									F-test
				Minjar Shenkora (N= 117)			Ada'a (N= 123)			Overall (N= 240)			
				Low DD (n= 23)	Medium DD (n= 67)	High DD (n= 27)	Low DD (n= 17)	Medium DD (n= 65)	High DD (n= 41)	Low DD (n= 40)	Medium DD (n= 132)	High DD (n= 68)	
$V_0 F_0 R_0$	2	5	3.6	38.1	28.6	9.5	9.5	14.3	0.0	47.6	42.9	9.5	9.017***
$V_1 F_0 R_0$	2	7	4.4	12.5	45.8	0.0	8.3	12.5	20.8	20.8	58.3	20.8	1.298
$V_0 F_1 R_0$	2	8	4.9	9.8	19.5	7.3	9.8	31.7	24.4	19.6	51.2	31.7	0.298
$V_0 F_0 R_1$	2	7	5.1	10.0	35.0	0.0	0.0	30.0	25.0	10.0	65.0	25.0	1.394
$V_1 F_1 R_0$	3	9	5.9	3.0	24.2	15.2	9.1	24.2	24.2	12.1	48.4	39.4	0.933
$V_1 F_0 R_1$	2	9	5.6	11.1	11.1	16.7	11.1	33.3	16.7	22.2	44.4	33.4	0.679
$V_0 F_1 R_1$	3	10	5.4	13.3	33.3	13.3	6.7	26.7	6.7	20.0	60.0	20.0	1.777**
$V_1 F_1 R_1$	4	10	6.6	1.9	26.4	20.8	0.0	24.5	26.4	1.9	50.9	47.2	8.036***
Total	2	10	5.3	19.7	57.3	23.0	13.8	52.8	33.3	16.7	55.0	28.3	7.299***

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%.

Source: Own calculation based on field survey

Food consumption score (FCS)

Food consumption patterns are important indicators of the food security status of households. Those who frequently consume a wide variety of foods from different food groups are more food secure than people who continually consume the same foodstuff. The cutoff points recommended by the WFP (2009) to define poor, borderline, and adequate food consumption groups should be determined based on a country's consumption behavior. If there is frequent consumption of oil and sugar in a given country, a threshold will be raised. In the study areas and in the Ethiopian context in general, frequent consumption of oil and sugar is very common. Thus, for the sake of analysis, the respondents were classified into three groups using 28 and 42 as thresholds to define: poor food consumption (≤ 28), borderline food consumption (28.5 – 42.0), and acceptable food consumption (> 42). Results show that across the sample *woredas* about 19% of households were found in the poor food consumption category while 44.1% were found in the borderline food consumption category and the rest 37.1% of households were found in the acceptable food consumption category (Table 4.5). Moreover, the mean of the food consumption score of a combination of two technology adopters (46.9) was larger than individual technology adopters (40.8) and non-adopters (31.8). However, the largest food consumption score was registered for households who adopted all three improved technologies (62.1).

Table 4.6 show that, among the households in the study areas, households in the poor food consumption group consumed on average most frequently cereals (7 days), followed by oil and condiments/beverages (6.1 days), pulses (5.7 days), sugar (3.6 days), roots and tubers (1.1 days), milk (1.1 days) and vegetables (1.0 days). The consumption of animal products, vegetables, and fruits was very minimal and close to null in that group. Among the borderline consumption group, consumption of different food groups was increased, with cereals (7 days), pulse (6.3 days), oil (6.3 days), sugar (4.9 days), and milk and milk products (1.3 days). Similarly, consumption of animal products, fish, and fruits remains infrequent, at an average of less than a day per week.

Table 4.5 Households' food consumption score with various combinations of agricultural technologies adoption (%)

Technology Packages	Min	Max	Mean	Household Food Consumption Score									F-test
				Minjar Shenkora (N= 117)			Ada'a (N= 123)			Overall (N= 240)			
				Poor (n=26)	Borderline (n=55)	Acceptable (n=36)	Poor (n=19)	Borderline (n=51)	Acceptable (n=53)	Poor (n=45)	Borderline (n=106)	Acceptable (n=89)	
$V_0 F_0 R_0$	13.5	48.0	31.8	33.3	38.1	4.8	4.8	19.0	0.0	38.1	57.1	4.8	6.212***
$V_1 F_0 R_0$	22.5	67.0	43.5	16.7	37.5	4.2	12.5	12.5	16.7	29.2	50.0	20.8	1.829
$V_0 F_1 R_0$	20.5	78.0	39.1	9.8	21.9	4.9	7.3	43.9	12.2	17.1	65.8	17.1	5.518***
$V_0 F_0 R_1$	21.5	72.0	39.8	15.0	25.0	5.0	15.0	25.0	15.0	30.0	50.0	20.0	1.374
$V_1 F_1 R_0$	20.5	87.0	45.0	12.1	15.2	15.2	12.1	9.1	36.4	24.2	24.3	51.5	3.144**
$V_1 F_0 R_1$	25.0	79.0	45.9	0.0	22.2	16.7	11.1	22.2	27.8	11.2	44.4	44.4	0.441
$V_0 F_1 R_1$	27.0	83.0	49.7	13.3	20.0	26.7	6.7	6.7	26.7	20.0	26.7	53.3	2.443*
$V_1 F_1 R_1$	27.5	99.0	62.1	3.8	16.9	28.3	0.0	20.8	30.2	3.8	37.7	58.5	9.137***
Total	13.5	99.0	46.7	22.2	47.0	30.8	15.4	41.5	43.1	18.8	44.1	37.1	7.266***

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%.

Source: Own calculation based on field survey

Table 4.6 Average number of days of food consumption by food consumption groups

Food Groups	Food consumption groups		
	Poor	Borderline	Acceptable
Cereals	7.0	7.0	7.0
Roots & Tubers	1.1	1.9	1.6
Vegetable	1.0	1.7	2.1
Fruits	0.1	0.7	1.1
Meat & meat product	0.3	0.6	1.3
Egg	0.7	0.9	0.6
Fish	0	0.2	0.3
Pulse	5.7	6.0	6.3
Milk	1.1	0.7	0.8
Oil	6.1	6.4	6.3
Sugar/honey	3.6	4.2	4.9
Condiments/beverages	6.1	5.6	5.4

Source: Own calculation based on field survey

4.3.2 Impact of agricultural technologies

4.3.2.1 Impact of technologies on *tef* productivity

Table 4.7 shows the average adoption effects of various combinations of improved agricultural technology on *tef* yield under actual and counterfactual conditions, as determined by the endogenous switching regression treatment effects approach. The difference between column X and column Y determines the influence of technology adoption on *tef* yield. Column Z depicts the adoption effect of each combination of technology packages on *tef* yield. The percentage impact on yield can be calculated as the ratio of Z and Y, and then multiplied by 100.

Results show that the highest yield effect (388.7 kg/ha) is obtained from the adoption of all three technologies ($V_1F_1R_1$), which is also the greatest effect of each tehnologies adopted in a combination of two and independently, suggesting complementarity in benefits. Farming households who adopted improved *tef* variety with chemical fertilizer ($V_1F_1R_0$) can increase the crop yield about 14%. Chemical fertilizer combined with row planting practice ($V_0F_1R_1$) can increase the yield by about 15%. However, the lower crop yield (6.0–10.4%) was obtained, as compared to other combinations when households' adopted technologies in isolation. This result is in line with most previous studies conducted in Ethiopia and elsewhere. For example, a study undertaken by Menale et al. (2015) showed that the highest yield effect is obtained from the combination adoption of agricultural technologies compared to adopting them individually. Moreover, studies conducted by Takahashi et al. (2019); Etsehiwot (2018); Regasa et al. (2018) revealed that adoption of a combination of improved technologies gives more yield than adopting them in isolation. In all counterfactual cases, farm households who actually adopted would have had a lower *tef* yield if they had not adopted (Table 4.7).

Table 4.7 Average expected *tef* yield with adoption of improved technologies effects

Outcome	Adoption effect (Kg/ha)			Impact (%) A= (Z÷Y)*100
	Adopting (Actual)	Non-adopting (Counterfactual)	Average adoption effects	
	X	Y	Z = X - Y	
$V_1F_0R_0$	2,066.9 (78.41)	1,896.0 (75.01)	170.9 (39.42)***	9.0
$V_0F_1R_0$	2,078.3 (80.28)	1,882.2 (68.13)	196.1 (48.19)**	10.4
$V_0F_0R_1$	1,906.4 (74.45)	1,798.5 (71.55)	107.9 (54.85)**	6.0
$V_1F_1R_0$	2,202.8 (91.94)	1,934.2 (76.69)	268.6 (32.25)***	13.9
$V_1F_0R_1$	2,149.6 (89.81)	1,926.1 (85.36)	223.5 (35.49)***	11.6
$V_0F_1R_1$	2,212.2 (94.13)	1,928.6 (89.83)	283.6 (64.65)***	14.7
$V_1F_1R_1$	2,430.4 (99.81)	2,041.7 (90.32)	388.7 (68.92)***	19.0

Source: Own calculation based on field survey

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%

Where 2, 3, …,8 refers to adoption of various combination of technology packages

4.3.3 Impact of technologies on household food security

Growth in agricultural productivity can have a substantial impact on poverty and food insecurity (Timmer, 2002). It is positively associated with lower food prices, better nutritional intake, and increased capital flows from agriculture. For instance, in India, absolute and relative poverty have decreased as productivity has increased (Datt and Ravallion, 1998). Productivity increase has both direct and indirect implications on poverty reduction in emerging countries (Mellor, 2001). The findings of this study reveal that the joint adoption of improved *tef* technologies provides more DES compared to adopting each technology in isolation. Results further indicated individual technology adoption increases household DES by 11.5 – 14.3%. The study also identified that the greater household DES effect is obtained when these technologies adopted in combinations rather than in isolation (individually). For instance, farming households who adopted improved *tef* variety with chemical fertilizer ($V_1F_1R_0$) can increase household DES by 20.8%. Row planting practice combined with chemical fertilizer ($V_0F_1R_1$) can increase the household DES by 22.9%. The study further showed that the highest adoption effect (27.6%) is obtained from the adoption of all three improved technologies ($V_1F_1R_1$). Wubneshe et al. (2019); Manda et al. (2016) and Menale et al. (2015) in Ethiopia and elsewhere found similar results where a combination of improved technologies adoption provided higher DES compared to households adopting individually. The adoption effects of improved technologies on household DES are shown in Table 4.8 – 4.10.

Table 4.8 Adoption effects: household dietary energy supply (DES)

Outcome	Adoption status (Kcal/ADE/day)			Impact (%) A= (Z÷Y)*100
	Adopting (Actual)	Non-adopting (Counterfactual)	Average adoption effects	
	X	Y	Z = X - Y	
$V_1F_0R_0$	2,239.4 (140.56)	2,009.0 (94.64)	230.3 (114.70)***	11.5
$V_0F_1R_0$	2,284.8 (120.39)	1,998.7 (83.73)	286.1 (111.70)*	14.3
$V_0F_0R_1$	2,242.7 (166.23)	1,974.9 (71.06)	267.8 (173.08)**	13.6
$V_1F_1R_0$	2,532.4 (170.27)	2,095.7 (87.95)	436.7 (173.08)***	20.8
$V_1F_0R_1$	2,412.5 (209.70)	2,037.4 (98.30)	375.2 (168.71)***	18.4
$V_0F_1R_1$	2,554.9 (211.53)	2,079.6 (97.39)	475.3 (280.51)***	22.9
$V_1F_1R_1$	2,676.2 (250.54)	2,097.8 (86.76)	578.4 (259.70)***	27.6

Source: Own calculation based on field survey

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%

Where 2, 3, …,8 refers to adoption of various combination of technology packages

The adoption effect of improved technologies on HDDS is shown in Table 4.9. The findings show that a combination of improved technologies adoption has a positive and significant effect on HDDS. Farm households who adopted a combination of improved technologies can diversify their diet more than households who adopted improved technologies individually. Farm households that used chemical fertilizer with row planting ($V_0F_1R_1$) are more likely to diversify their diet by 20.6%. The lower dietary diversity score was obtained (11.5–14.3%) when households' adopted improved technologies in isolation. However, households who adopted all three improved technologies significantly increase households' dietary diversity by 22.6%. This result is in line with the previous studies conducted by Etsehiwot (2018) in Ethiopia found that the adoption of multiple improved technologies adoption increases productivity and farm income thereby improves household dietary diversity. This study also in line with a study conducted by Marenya et al. (2018) in Ethiopia indicated that a combination of improved technology adoption enabled households' diversiy their diet than households who adopted individually. The adoption of improved technologies can improve household food diversity and dietary intake due to higher-yielding varieties and practices that could lead to additional crop sales (Smale et al., 2015).

Table 4.9 Adoption effects: household dietary diversity score (HDDS)

Outcome	Adoption status			Impact (%) A= (Z÷Y)*100
	Adopting (Actual)	Non-adopting (Counterfactual)	Average Adoption Effects	
	X	Y	Z= X - Y	
$V_1F_0R_0$	3.27 (0.48)	2.94 (0.15)	0.33 (0.76)**	11.2
$V_0F_1R_0$	4.25 (0.50)	3.76 (0.12)	0.49 (0.30)*	13.0
$V_0F_0R_1$	3.02 (0.16)	2.74 (0.42)	0.42 (0.49)**	10.2
$V_1F_1R_0$	5.16 (0.14)	4.36 (0.56)	0.80 (0.52)***	18.3
$V_1F_0R_1$	5.43 (0.14)	4.67 (0.62)	0.76 (0.44)*	16.3
$V_0F_1R_1$	5.21 (0.14)	4.32 (0.48)	0.89 (0.47)***	20.6
$V_1F_1R_1$	6.02 (0.37)	4.91 (0.14)	1.11 (0.27)***	22.6

Source: Own calculation based on field survey

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%

Where 2, 3, …,8 refers to adoption of various combination of technology packages

The adoption effect of improved technologies on household FCS is shown in Table 4.10. Joint adoption of improved agricultural technologies significantly increases FCS than adopting individually. Results indicated that individual adoption of improved technology increases household FCS by 7.4 – 9.4%. However, the study indicated that farming households who adopted a combination of improved *tef* variety with chemical fertilizer ($V_1F_1R_0$) can increase FCS by 14.5%. Likewise, households who adopted chemical fertilizer with row planting practice ($V_0F_1R_1$) can increase household FCS by 18.3%. Above all, the highest household FCS (21.4%) is obtained when all three improved technologies are adopted ($V_1F_1R_1$). Generally, the findings indicated found that the joint adoption of improved *tef* variety, chemical fertilizer, and row planting impacted positively household DES, HDDS, and FCS. Yet, the highest payoff is achieved when improved agricultural technologies are adopted in combinations rather than in isolation.

Table 4.10 Adoption effects: household food consumption score (FCS)

Outcome	Adoption status			Impact (%) A= (Z÷Y)*100
	Adopting (Actual)	Non-adopting (Counterfactual)	Average Adoption Effects	
	X	Y	Z= X - Y	
$V_1F_0R_0$	30.41 (3.93)	27.79 (4.47)	2.62 (2.15)***	9.4
$V_0F_1R_0$	41.48 (1.71)	38.34 (1.57)	3.14 (2.24)***	8.2
$V_0F_0R_1$	30.01 (4.24)	27.94 (5.06)	2.07 (5.18)***	7.4
$V_1F_1R_0$	46.54 (3.34)	40.64 (2.96)	5.90 (2.96)*	14.5
$V_1F_0R_1$	45.01 (3.42)	39.98 (2.70)	5.03 (2.70)**	12.6
$V_0F_1R_1$	48.30 (4.42)	40.83 (3.02)	7.47 (3.02)***	18.3
$V_1F_1R_1$	52.15 (5.28)	42.96 (1.29)	9.19 (5.44)**	21.4

Source: Own calculation based on field survey

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%

Where 2, 3, …,8 refers to adoption of various combination of technology packages

4.4 Conclusions and policy implications

This study analyzed the impacts of a combination of agricultural technologies adoption on crop yield and household food security among smallholder farmers in Central Ethiopia. While the use of improved *tef* seed, chemical fertilizer, and row planting practice was identified as the major agricultural technologies adopted in the study areas. Using an ESR model this research looked at whether or not these agricultural technologies increase the crop yield and household dietary energy supply, dietary diversity, and food consumption scores. We use a cross-sectional farm household survey to estimate these effects.

The model revealed that the adoption of improved agricultural technologies significantly increases the crop yield, dietary energy supply, dietary diversity, and food consumption scores of the farming households. However, the highest yield and food security impact is obtained when these technologies are adopted in combinations rather than in isolation. The study further found that the use of a combination of improved *tef* variety, chemical fertilizer, and row planting improves the levels of the crop yield and food security status of the farming households and the highest payoff is achieved when improved agricultural technologies are adopted in combinations rather than individually.

Based on our research findings, we conclude that the adoption of a combination of improved agricultural technologies is very helpful in improving the crop yield and household DES, HDDS, and FCS of adopters than individual technology adopters and non-adopters. Therefore, two important policy implications are drawn from this study. First, promoting the awareness of farmers to adopt a combination of improved technologies and change the farmers' perception on the economic returns of adopting technologies and consider asset formation and devising access to inputs and information through rural institutions to increase. This increases a combination of technology adoption and hence agricultural productivity and food security. Second, the effect of chemical fertilizer adoption is outweighed when it is combined with row planting practices than adopted with improved seed, despite the highest score is obtained when farm households adopted all three improved technologies. Further research is required why chemical fertilizer is outweighed when combined with row planting practice other than with improved seed.

4.5 References

Akudugu, M., Guo, E., & Dadzie, S. (2012). Adoption of modern agricultural production technologies by farm households in Ghana: What factors influence their decisions? *Journal of Biology, Agriculture and Healthcare, 2*(3), 1-13.

Ajayi, O.C., Franzel, S., Kuntashula, E., & Kwesiga, F. (2003). Adoption of improved fallow technology for soil fertility management in Zambia: Empirical studies and emerging issues. *Journal of Agro forestry Systems, 59*, 317-326.

Asfaw Solomon, Bekele Shiferaw, Simtowe, F., & Lipper, L. (2012). Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food Policy, 37*(3), 283–295.

Barrett, C. B., Reardon, T., & Webb, P. (2001). Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics, and policy implications. *Food policy*, *26*(4), 315-331.

Bekabil Fufa, Befikadu Behute, Simons, R., & Tareke Berhe (2011, November). Strengthening Tef value chain: In: Tef Improvement: Achievements and Prospects. In *Proceedings of Second International Workshop* (pp. 7-9).

Bekele Shiferaw, Menale Kassie, Moti Jaleta & Chilot Yirga (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy, 44*, 272-284.

Bourguignon, F., Fournier, M., & Gurgand, M. (2007). Selection bias corrections based on the multinomial logit model. *Journal of Economic Surveys, 21*(1), 174–205.

Chander, P., & Thangavelu, S.M. (2004). Technology adoption, education and immigration policy. *Journal of Development Economics, 75*(1), 79–94.

Chima, C. D. (2015). Socio-economic determinants of modern agricultural technology adoption in multiple food crops and its impact on productivity and food availability at the farm-level: a case study from south-eastern Nigeria. (Doctoral dissertation, University of Plymouth).

Chilot Yirga, Yigezu Atnafe & Aden AwHassan (2015). A multivariate analysis of factors affecting adoption of improved varieties of multiple crops: A case study from Ethiopian Highlands. *Ethiopian Journal of Agriccultural Science, 25* (2), 29-45.

CSA (2020). Agricultural sample survey 2019/20 report on area and production of major crops for private peasant holdings, *Meher* season, volume I. Central Statistical Agency *Addis Ababa*.

CSA & WFP (2019). Comprehensive Food Security and Vulnerability Analysis (CFSVA). Ethiopia, WFP and Headquarters, WFP.

Datt, G., & Ravallion, M. (1998). Farm Productivity and Rural Poverty in India. *Journal of Development Studies, 34* (4), 62-85.

Debelo Duressa (2015). Analysis of factors influencing adoption of Quncho tef: The case of Wayu Tuqa District. *International Journal of African and Asian Studies, 12,* 20-28.

Dejene Bayissa & Bekele Tassew (2015). Determinants of farmer's adoption of full extension package on improved tef technology: the case of Dendi district, West Showa, Oromia Regional State, Ethiopia. *International Journal of Current Research*, *7*(9), 20816 – 20821.

Demese Chanyalew, Berhanu Adenew & Mellor, J. (2010). Ethiopia's agricultural sector policy and investment framework (PIF)(2010–2020), Draft final report. *Federal Democratic Republic of Ethiopia, Ministry of Agriculture and Rural Development. Addis Ababa*.

Deresse Dalango & Teklu Tadesse (2019). Determinants of smallholder teff farmer's chemical fertilizer technology adoption in Southern Ethiopia, in case of Gena District in Dawro Zone (Heckman Two-Stage Model). *Jurnal Perspektif Pembiayaan dan Pembangunan Daerah, 7*(2), 111-126.

Di Falco, S., & Veronesi, M. (2011). *On adaptation to climate change and risk exposure in the Nile basin of Ethiopia* (No. 726-2016-49750).

Diiro, G.M. (2013). Impact of off-farm income on technology adoption intensity and productivity: Evidence from rural maize farmers in Uganda. International Food Policy Research Institute, IFPRI-Working Paper 11.

Dubin, J., & McFadden, D. (1984). An econometric analysis of residential electric appliance holdings and consumption. *Econometrical: Journal of the Econometric Society*, 345-362.

Ellis, F. (1993). *Peasant economics: Farm households in agrarian development* (Vol. 23). Cambridge University Press.

Etsehiwot Semreab (2018). The determinants of agricultural technology adoption and its' impact on teff productivity in the case of Amhara and Oromia national regional state.

FAO (2013). *The State of Food Insecurity in the World, 2013: The Multiple Dimensions of Food Security*. Food and Agricultural Organization of the United Nations.

Fernandez-Cornejo, J. (1996). The microeconomic impact of IPM adoption: theory and application. *Agricultural and resource economics review*, *25*, 149-160.

Gemeda Abidisa, Aboma, G., Verkuijl, H., & Mwangi, W. (2007). Farmers' maize seed systems in Western Oromia, Ethiopia. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT) and Ethiopian Agricultural Research Organization.

Gorst, A., Dehlavi, A., & Groom, B. (2018). Crop productivity and adaptation to climate change in Pakistan. *Environment and Development Economics, 23*(6), 679–701.

Hailemariam Teklewold, Tagel Gebrehiwot & Mintewab Bezabih (2019). Climate smart agricultural practices and gender differentiated nutrition outcome: An empirical evidence from Ethiopia. *World Development, 122*, 38-53.

Hailemariam Teklewold, Menale Kassie, Bekele Shiferaw, & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics, 93*, 85–93.

Karki, L. B., & Bauer, S. (2004, October). Technology adoption and household food security. Analyzing factors determining technology adoption and impact of project intervention: A case of smallholder peasants in Nepal. In *Proceedings of Deutscher Tropentag Workshop* (pp. 5-7).

Magrini, E., & Vigani, M. (2016). Technology adoption and the multiple dimensions of food security: the case of maize in Tanzania. *Food security*, *8*(4), 707-726.

Maiangwa, M. (2010). Importance, problems, and reform of agricultural research in Africa. *Journal of Agriculture, Forestry and the Social Sciences*, *8*(2), 127-138.

Marenya, P., Menale Kassie, Hailemariam Teklewold, Erenstein, O., Qaim, M., & Rahut, D. (2018). Does the adoption of maize-legume cropping diversification and modern seeds affect nutritional security in Ethiopia? Evidence from panel data analysis.

Manda, J., Alene, A. D., Gardebroek, C., Menale Kassie, & Tembo, G. (2016). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia. *Journal of Agricultural Economics*, *67*(1), 130-153.

McFadden, D. (1973). Conditional logit analysis of qualitative choice behavior. Academic Press.

Mekidelawit Ayal (2018). Determinants of adoption of teff row planting practice: the case of Baso Liben Woreda, East Gojjam Zone, Amhara Region, Ethiopia. An MSc thesis submitted to department of rural development and agricultural extension, Arba Minch University.

Mellor, J. W. (2001). Faster more Equitable Growth Agriculture, Employment Multipliers and Poverty Reduction. *Research Report prepared for USADD.*

Menale Kassie, Marenya, P., Yohannis Tessema, Moti Jaleta, Zeng, D., Erenstein, O., & Rahut, D. (2018). Measuring farm and market level economic impacts of improved maize production technologies in Ethiopia: Evidence from panel data. *Journal of Agricultural Economics*, *69*(1), 76-95.

Menale Kassie, Hailemariam Teklewold, Mareny, P., Moti Jaleta & Olaf, E. (2015). Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. *Journal of Agricultural Economics*, *66*(3), 640-659.

Menale Kassie, Moti Jaleta, Bekele Shiferaw, Mmbando, F., & Mulugeta Mekuria (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecast & Social Change, 80* (3), 525-540.

Menale Kassie, Zikhali P, Pender J & Kohlin, G. (2010). The economics of sustainable land management practices in the Ethiopian highlands. *Journal of Agricultural Economics*, *61*(3), 605–627.

Minten, B., & Barrett, C.B. (2008). Agricultural technology, productivity, and poverty in Madagascar. *World Development*, *36* (5), 797-822.

Minten, B., Seneshaw Tamru, Ermias Engida & Tadesse Kuma (2016). Feeding Africa's cities: The case of the supply chain of teff to Addis Ababa. *Economic Development and Cultural Change*, *64*(2), 265-297.

MoA (2020). Agriculture sector investment prioritization (2019/20-2024/25). Ministry of Agriculture, Addis Ababa.

MoANR (2017). Ethiopia's agricultural extension strategy: Vision, systemic bottleneck and priority intervention. Ministry of Agriculture and Natural Resources, Addis Ababa.

MoFED (2003). Rural development Policy and strategies. Resource document. Ministry of Finance and Economic Development. http://gafspfund.org/sites/gafspfund.org/fles/ Documents/Ethiopia_4_of_6_ARD policy.pdf. Accessed 10 November 2019.

NBE (2019/20). Annual report of 2019/20. National Bank of Ethiopia, Addis Ababa, Ethiopia.

Negera Eba & Getachew Bashargo (2014). Factors affecting adoption of chemical fertilizer by smallholder farmers in Guto Gida District, Oromia Regional State, Ethiopia. *Science, Technology and Arts Research Journal*, *3*(2), 237-244.

NPC (2016). Growth and transformation plan II (2015/16–2019/20). FDRE National Plan Commission. Volume I: Main Text. Addis Ababa.

Regasa Dibaba, Afework Hagos, Chilot Yirga & Endeshaw Habte (2018). Determinants of Improved Teff Varieties Adoption and Its Impact on Productivity: The Case of Non-Traditional Teff Growing Areas of Western Ethiopia. *Journal of Natural Sciences Research*, *22*(8), 2224-3186.

Smale, M., Moursi, M., & Birol, E. (2015). How does adopting hybrid maize affect dietary diversity of family farms? Micro-evidence from Zambia. *Food Policy*, *52*, 44-53.

Solomon Asfaw, Menale Kassie, Simtowe, F., & Lipper, L. (2012). Poverty reduction effects of agricultural technology adoption: a micro-evidence from rural Tanzania. Journal of *Development Studies*, *48* (9), 1288-1305.

Sosina Bezu, Girma Tesfahun, Bekele Shiferaw & Ricker-Gilbert, J. (2014). Impact of improved maize adoption on welfare of farm households in Malawi: A panel data analysis. *World Development*, *59*, 120–131.

Spielman, D., Byerlee, D., Dawit Alemu & Dawit Kelemework (2010). Policies to promote cereal intensification in Ethiopia: The search for appropriate public and private roles. *Food Policy*, *35*(3), 185-194.

Takahashi, K., Muraoka, R., & Otsuka, K. (2019). Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature. *Agricultural economics*, *51*(1), 31-45.

Tareke Berhe, Zewdie Gebretsadik, Edwards, S., & Hailu Araya (2011). Boosting *tef* productivity using improved agronomic practices and appropriate fertilizer. In *Achievements and prospects of Tef improvement. Proceedings of the second International Workshop* (pp. 133-140).

Timmer, C. P. (2002). Agriculture and Economic Development. In Handbook of Agricultural Economics, Vol. 2A, ed. Bruce L. Gardner and Gordon C. Rausser. Amsterdam: North Holland.

Tsega Adego, Belay Simane & Getachew Woldie (2019). The impact of adaptation practices on crop productivity in northwest Ethiopia: an endogenous switching estimation, *Development Studies Research, 6*(1), 129-141.

Uaiene, R. N. (2011). Determinants of agricultural technology adoption in Mozambique. In *10th African Crop Science Conference Proceedings, Maputo, Mozambique, 10-13 October 2011*. African Crop Science Society.

Vandercasteelen, J., Mekdim Dereje, Minten, B., & Alemayehu Seyoum (2016). Row planting teff in Ethiopia: Impact on farm-level profitability and labor allocation. ESSP Working Paper 92.

Vandercasteelen, J., Mekdim Dereje, Minten, B., & Alemayehu Seyoum (2013). Scaling-up adoption of improved technologies: The impact of the promotion of row planting on farmers' tef yields in Ethiopia. *LICOS-Discussion paper series 344/2013,* 1-25.

Wubneshe Dessalegn, Zeller, M., & Loos, T. (2019). The impact of agricultural technologies on poverty and vulnerability of smallholders in Ethiopia. *Social Indicators Research, 147*(2), 517–544.

Yamane, T. (1967). Statistics: an introductory analysis, 2nd ed., Harper and Row, New York.

Yazachew Genet, Tsion Fikre, Worku Kebede, Solomon Chanyalew, Kidist Tolosa & Kebebew Assefa (2020). Performance of Selected Tef Genotype for High Potential Areas of Ethiopia. Ecology and Evolutionary Biology, 5(3), 35-42.

Yitbarek Tegegne (2017). Factors affecting adoption of legume technologies and its impact on income of farmers: The case of Sinana and Ginir woredas of Bale Zone (Doctoral dissertation, Haramaya University).

5. DETERMINANTS OF A COMBINATION OF TECHNOLOGIES ADOPTION IN SMALLHOLDERS' AGRICULTURE: MICRO EVIDENCE FROM MAJOR *TEF* GROWING AREAS OF CENTRAL ETHIOPIA

Abstract

The adoption of improved technologies has become an important issue in the development agenda for Ethiopia, especially as a way to tackle poverty and low agricultural productivity. However, the adoption rate of improved technologies remains low and well below the expected levels. Using the household survey data from 240 sample respondents from Minjar Shenkora and Ada'a *woredas*, this study analyzes the factors that facilitate or hinder the probability and level of adoption of technologies. The study employed a multivariate probit model (MVP) for the simultaneous multiple adoption decisions and ordered probit models for identifying the factors that determine the level of adoption. Moreover, Tobit model is used to identify the determinants of intensity of adoption of improved *tef* variety. Results show that both the probability and the level of adoption of agricultural technologies are significantly affected by many factors: education level, household size, frequency of extension contacts, livestock holding, access to credit, farmers' confidence with the skills of DAs, farmers' membership in an agricultural cooperative, farmers' perception on economic return, farmers' perception on participation in the extension service provision, the average distance to output market and extension office. The estimated result of tobit model indicate that education level, household size, frequency of extension contacts, access to credit, farmers' membership in an agricultural cooperative, and farmers' perception on economic return significantly influence the adoption and intensity of use of improved *tef* variety. Thus, engaging all actors in the R&D at the various levels and should have typically promoted the large-scale adoption of multiple combinations of agricultural technologies. The study, therefore, calls for devising possible interventions for those factors that impede the uptake of a combination of technologies.

Keywords: Ethiopia, multiple adoptions, multivariate probit model, ordered probit model, tef

5.1 Introduction

Agriculture in Ethiopia has played and is still playing a fundamental role in the government's policy and development strategies. The government has shown strong efforts to the promotion of improved seeds and chemical fertilizer in improving and expanding agricultural extension services (Louhichi et al., 2019). Since 1995 the country adopted the Participatory Demonstration and Training Extension Systems (PADETES) to promote the technological packages of improved technologies (Belay 2003). This program mainly promotes the extension packages for some selected cereals such as *tef*, wheat, maize, barley, sorghum, and millet (Misigana, 2013). The adoption of improved technologies is important to increase agricultural productivity, generate income, and reduce poverty (Louhichi et al., 2019; Awotide et al., 2012). These technologies are often suggested to be used in combination with other complimentary technologies (Spielman et al., 2010; Dercon et al., 2009; Howard et al., 2003), and their full potential can only be realized when technologies are used concurrently (Menale et al., 2018).

However, the aggregate adoption and intensity remained low and limited to only a few varieties (Etsehiwot, 2018; Regasa et al., 2018; Mekidelawit, 2018; Dejene and Bekele, 2015; Debelo, 2015; Negera and Getachew, 2014; Kebebew et al., 2013; Vandercasteelen et al., 2013). Although the use of improved seed and chemical fertilizer has been increasing since the country adopted the PADETES, it is still very low as compared to other developing countries (Menale et al., 2018; Menale et al., 2015; Wollni et al., 2010). At the national level, only 30.9% of the cultivated land was covered by the extension package program (CSA, 2018). Among the total cultivated land of *tef* crop (3.1 million ha), only 35.5% was covered by the multiple combinations of technology adoption and extension package program during 2017/18 (CSA, 2018). As a result, the agricultural productivity level of the *tef* is very low. It has been observed that huge yield gaps exist between research stations and average farmers and full package adopters and individual and non-adopters. According to Fentahun et al. (2017), there is a 70% yield gap between the research stations and average farmers. Hence, it is a need to identify the factors that influence the adoption of multiple *tef* technologies.

Numerous studies have been conducted to identify the factors that influence the household decision to adopt improved *tef* technologies (Deresse and Teklu, 2019; Regasa et al., 2018;

Etsehiwot, 2018; Efa et al., 2016; Dejene and Bekele, 2015; Debelo, 2015; Negera and Getachew, 2014; Kebebew et al., 2013; Vandercasteelen et al., 2013). Nevertheless, this study differs from these studies in the following areas. Firstly, the combination of improved agricultural technologies under consideration differs as this research focuses on improved *tef* variety, chemical fertilizer, and row planting. These technologies are properly selected because farmers in the study areas adopted and considered to be adopted. In addition, most of these studies have focused on the adoption of a combination of two *tef* technologies or individually (Almaz and Begashaw, 2019; Regasa et al., 2018; Mekdilawit, 2018; Debelo, 2015). Secondly, the econometric models used to analyze the data were also differing. Most of them employed the multinomial logit model, Heckman's two-stage model; double hurdle model, Tobit model, and uni- and bivariate probit model (see, for instance, Deresse and Teklu, 2019; Efa et al., 2016; Hailu, 2008). Little is known about the combined econometric models (multivariate probit and ordered probit modes) allowing us to analyze the factors influencing the adoption of multiple combinations of technologies (number of technologies) as well as single technologies, and the variables affecting the probability of adoption may also have a different effect on the intensity of adoption. Therefore, the current study will shed some light on this by investigating the factors influencing multiple technology adoption and the number of technologies adopting in which previously unresearched areas of major *tef* growing areas of Central Ethiopia.

This study analyzes the determinants of a combination of adoption of improved *tef* variety, chemical fertilizer, and row planting. These agricultural technologies were selected because they occupy a large share of cultivation and are a major staple food and cash crop in the study areas. Hence, the objective of this study is to identify the determinants of multiple agricultural *tef* technology adoptions in Central Ethiopia. The study contributes to the existing literature in three ways. Firstly, the study analysis includes policy-relevant variables covering major *tef* growing areas in Ethiopia. This allowed policymakers to devise appropriate interventions to overcome those that obstruct the multiple *tef* technology adoptions. Secondly, the study extends the attention from the probability of an adoption decision to the extent of adoption as measured by the number of improved technology adopted. Third, empirical evidence at the local level is vital since potential interventions would differ accordingly.

5.2 Econometric framework and estimation strategies

Farmers are supposed to be rational economic agents who maximize utility (Chilot et al., 2015). The decision for adopting improved agricultural technologies is made when the perceived utility from using combinations of technologies is significantly superior to what would be the case with an individual technology or without the technology. Farmers utilize a mix of technologies to address a wide range of agricultural production challenges, therefore the decision to adopt is essentially multivariate (Hailemariam, 2012). Attempting univariate modeling, according to Dorfman (1996), would not incorporate useful economic information concerning interdependent and simultaneous adoption decisions. Moreover, independent modeling of the multiple adoption decision of households could ignore the potential association among the unobserved disturbances in the decision equations, as well as the use of the multiple technologies. As a result, the multivariate probit (MVP) econometric model was used in this study, which predicts the influence of the set of explanatory variables on each of the technologies while allowing unobserved and/or unmeasured factors (error terms) to be freely associated (Lin et al., 2005; Belderbos et al., 2004).

The model estimates from the multivariate specification improve over those from univariate specifications when the error correlations are significantly different from zero. In the MVP model estimated here, the choice of improved varieties related to each of the improved technologies corresponds to a binary choice (yes/no) equation and the choices are modeled jointly while accounting for the correlation among disturbances. The econometric specification of this study has two parts: (1) farmers' choice of inter-related improved technologies is modeled using a multivariate probit model (MVP); (2) we analyze the factors affecting the extent of combinations of technologies adopted, using pooled ordered probit models; (3) we analyze the intensity of improved seed adoption using Tobit model. The MVP model solely analyzes the likelihood of adopting agricultural technologies, making no differentiation between the number of technologies adopted by farmers who adopt a single technology and those who adopt a combination of multiple technologies (Hiwot et al., 2016; Hailemariam et al., 2013). Thus, to fill this gap the ordered probit model is used to analyze the determinants of the adoption of a combination of technologies.

5.2.1 A multivariate probit (MVP) model

In a single-equation model, information on a farmer's adoption of one technology does not alter the likelihood of adopting another technology. However, the MVP approach models the impact of a set of independent factors on each of the different improved technologies at the same time, while allowing for the potential correlation between unobserved disturbances and the adoption of different technologies (Belderbos et al., 2004). The observed outcome of alternative technology adoption can be modeled following a random utility formulation. Consider the i^{th} farm household ($i= 1,..., N$) that must decide whether to adopt or reject a particular combination of technology. Let U_0 represent the farm household that use local and traditional practices, and U_A denotes the benefit of adopting A^{th} improved technologies: where A denotes choice of improved tef variety (V), Chemical fertilizer (F), and row planting practice (R). The farm household decided to adopt A^{th} technologies if $Y^*_{im}= U_A - U_0 > 0$. Y^*_{im} is a latent variable determined by observed household, and location characteristics (X_{im}) and unobserved characteristics (ε_{im}).

$$Y^*_{imA} = \beta_A X_i + \varepsilon_{im}, (A = V, F, R) \quad \ldots (1)$$

By using the indicator function, the unobserved preferences in equation (1) convert into the observed binary outcome equation for each choice as follows:

$$Y^*_{imA} = \begin{cases} 1 & if\ Y_{imA} > 0 \\ 0 & otherwise \end{cases} \qquad (A = V, F, R) \quad \ldots (2)$$

In the multivariate model, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity where: $(u_V, u_F, u_R) \sim MVN(0, \eta)$ and the symmetric covariance matrix η is given by:

$$\eta = \begin{bmatrix} 1 & \rho_{VF} & \rho_{VR} \\ \rho_{FV} & 1 & \rho_{FR} \\ \rho_{RV} & \rho_{RF} & 1 \end{bmatrix} \quad \ldots (3)$$

The covariance matrix's off-diagonal entries represent the unobserved correlation between the stochastic components of the various improved technologies. According to this hypothesis, equation (2) generates an MVP model that jointly depicts decisions to adopt a specific technology. This specification with non-zero off-diagonal elements enables correlation across the error terms of numerous latent equations, which represent unobserved characteristics influencing the choice of various improved technologies (Hailemariam, 2012; Hiwot et al., 2016).

5.2.2 Ordered probit model

The MVP model described above only considers the probability of technology adoption, with no distinction made between the numbers of technologies adopted, such as farmers who adopt one technology versus those that use a combination of multiple technologies (Hailemariam et al., 2013). The ordered probit is used to fill this gap by analyzing the factors that influence the adoption of a combination of technologies. While adoption of a combination of improved technologies, defining a cut-off point between technology adopters and non-adopters is the main problem in identifying the factors influencing the level of adoption of improved technologies. In this study, several households were not adopting the whole package; some households use a combination of some technologies on their plots but not others. Consequently, for multiple combination adoption, it is difficult to quantify the extent of adoption is usually done in adoption literature. To overwhelm this problem, this study uses the number of improved technologies adopted as our dependent variable measuring the extent of adoption.

The number of technologies adopted may have been treated as a count variable; count data is typically investigated using a Poisson regression model, but the underlying assumption is that all occurrences have the same probability of occurrence. Nonetheless, the fundamental assumption of Poisson regression, that all events have an equal probability of occurrence, is disrupted because the probability of adopting the first technology may differ from the probability of adopting a second or third, given that farm households have already gained some experience with technology adoption in the latter case. The number of technologies used by farm households is then used as an ordinal variable in the estimation, with an ordered probit model.

5.2.3 Tobit model

The bulk of adoption studies used dichotomous regression models, which only explain the likelihood of adoption versus non-adoption and not the extent and intensity of adoption.

However, Tobit model is more appropriate to deliver reliable output of both discrete and continuous variables (Mc Donaled and Moffit, 1980) as it measures the probability of adoption and the level of use of the technology. This model was chosen because, unlike other adoption models such as logistic and probit, it indicates both the probability of new technology adoption and the intensity of its use. The model can be expressed mathematically as follows:

$$Y_i = \beta_i X_i + u_i, i= 0, 1, 2,\ldots, n; \text{ if } \beta_i X_i + u_i > 0 \text{ or } \beta_i X_i + u_i = 0 \text{ otherwise} \ldots\ldots\ldots\ldots\ldots. (4)$$

Where, Y_i = the observed dependent variable (improved *tef* varieties)

X_i = explanatory variables

β_i= a KXi matrix of parameters to be estimated

U_i = an independently and normally distributed error term with mean zero and constant variance.

The maximum likelihood method was used to calculate the model's parameters. Following Tobin (1958), the expected value of adoption and level of Teff improved varieties adoption will be estimated using the following formula:

$$E\ (Y_i)= X\beta\ F(z) + \delta\ f(z) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where, $z = X\beta/\sigma$; F (z) is the cumulative distribution function; f (z) is the value of derivative of the normal curve at a given point; z is the Z-score for the area under normal curve; β is a vector of Tobit maximum likelihood estimates and σ is the standard error of the error term.

According to Madalla (1983), the adjusted estimates are the marginal effects of explanatory variables on the expected value of the dependent variable and given by:

$$\frac{\partial E\ (Yi)}{\partial X_i} = F\ (z)\ \beta_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (6)$$

The change in the probability of area under improved *tef* varieties as independent variable X_i change is given by:

$$\frac{\partial F(z)}{\partial X_i} = f(z)\frac{(\beta i)}{\sigma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

And the change in the level of adoption with respect to a change in an explanatory variable among technology adopters is:

$$\frac{\partial E(Yi/Y{*}>0)}{\partial X_i} = \beta\,[1 - z\frac{f(z)}{F(z)} - (\frac{f(z)}{F(z)})2] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

5.3 Materials and methods

5.3.1 Sampling techniques, sample size and type of data

The study used the household survey data through randomly selected farm households in Minjar Shenkora and Ada'a *woredas*. A structured questionnaire was prepared and the sample respondents were interviewed by well-trained and experienced enumerators who have well-known the study areas and the local languages under close supervision. The questionnaire comprised of detailed items about farm households data including demographic characteristics, resource endowments, institutional factors, extension and market services, extension office, input and output market access, and farmers' perception about economic return, package appropriateness, and participation in extension service provision process. Moreover, secondary data sources used to compile the background information of the study, establish the conceptual and econometric framework to select models and methods of estimations. Sources of secondary data were related literature which comprised of published books, peer-reviewed articles, research reports, and published and unpublished documents.

A multi-stage sampling procedure was employed to select *kebeles* from each *woredas* and randomly select households from each *kebeles*. In the first stage, based on their *tef* production potential, two *woredas* from the two regions were selected. Thus, Minjar Shenkora *woreda* from the North Shewa Zone of Amhara Regional State and Ada'a *woreda* from the East Shewa Zone of Oromia Regional State were purposely selected. In the second stage, four *kebeles* (two from each *woreda*) were randomly selected for this study. Hence, Agirate and Adama *kebeles* from Minjar Shenkora *woreda* and Denkaka and Golo-Dertu *kebeles* from Ada'a were randomly selected. In the third stage, the proportional random sampling method was applied to determine the sample size in each *kebele*. Representative households from each sample *kebeles* were determined by using a formula suggested by Yamane (1967). This simplified formula required sample size at 95% confidence level, degree of variability = 0.5, and level of precision = 5%. Finally, 240 farm households were randomly selected for face-to-face interviews by using a simple random (lottery) method.

Explanation of variables and hypotheses

Dependent variables

The dependent variables we considered in the MVP and ordered probit model are: improved *tef* variety (V), chemical fertilizer (F), and row planting practice (R) (Table 5.1). Whereas improved *tef* variety is the dependent variable for the Tobit model.

Explanatory variables

Based on various adoption literatures, the explanatory variables included in our regression analysis and their hypothesized effect on the adoption of improved technologies are discussed below. This study used different explanatory variables such as demographic characteristics, resource endowments, institutional factors, extension service-related factors, infrastructure, and farmers' perceptions on economic benefits, packages appropriateness and participatory nature of the extension service provision, and location dummies for the *woredas* are hypothesized to influence the household decision to adopt improved technologies.

Older age could associate with loss of energy and short-planning horizons, as well as being more risk-averse to the introduction of new technology (Menale et al., 2013). Moreover, old farmers in Ethiopia who are often illiterate and uneasy towards changes may be reluctant to shift from less risky but low-yielding local varieties to high-yielding but potentially (until proven otherwise) risky modern technologies. According to Chilot et al. (2015), younger farmers are more likely to adopt new technologies because they have gotten more education than the elder generation or because they have been exposed to new ideas. Therefore, age is expected to have a negative effect on the household decision to adopting improved technologies. Education enhances the locative ability of decision-makers by enabling them to think critically and use information sources efficiently. Previous studies also confirmed that education has a positive influence on the household decisions (Bekele et al., 2014; Bekele et al., 2009). In this study too, we expect a positive influence of education of household head on the adoption decision of the household.

Household size is a continuous variable which indicates the number of family labor living in the family. It is typically related with increased family labor, which allows a household to complete numerous agricultural duties on a timely way. As we are well aware most the Ethiopian farmers have not used labor-saving technologies like tractors, harvesters in their production system; hence, household size critically influences the household decision to adopt new technologies. Therefore, we expect a positive influence of household size on the adoption of multiple technologies. Most studies show that farm size is often hypothesized to influence the household decisions of adopting improved technologies. Hence, farm size exerts a positive influence on the adoption of multiple technologies (Nkonya et al., 1997). Most often the number of livestock holdings is often used as indicators of the wellbeing of smallholders in the country like Ethiopia. Hence, livestock ownership is expected to be positively influenced the household decision to adopt multiple combinations of improved technologies.

Off-farm activities are important activities through which rural households get additional income to purchase new improved technologies. Households who engaged in off-farm activities are less risk-averse than farmers without sources of off-farm income. As a result, off-farm income is expected to have a positive impact on a household's decision to adopt modern technology. Access to credit also has a positive influence on household decisions to adopt improved technologies (Legesse et al., 2001; Tesfaye, 2001; Kansana et al., 1996). Similarly, farm households who are members of farmers' based organizations easily access agricultural information and new technologies. Therefore, it is hypothesized that membership in farmers' organizations influenced the household decision to adopt improved technologies and knowledge.

Households can adopt improved technologies and knowledge through contacting development agents. Various studies in developing countries including Ethiopia reported that there is a positive relationship between access to information and the adoption behavior of farmers (Chilot et al., 1996; Legesse et al, 2001). As a result, it is hypothesized that the larger the number of contacts with development agents, the greater the likelihood of adopting upgraded technologies and information. Households who participated in extension training would enable them to improve their understanding of the available technology packages, which may lead to a change in their mindsets, attitude, and behavior (Mignouna et al., 2011**)**. Thus, agricultural training is positively influenced the household decision to adopt improved technologies (Kansana et al., 1996; Tesfaye, 2001). Moreover, a household's confidence in the technical competence of DAs is more likely to adopt a combination of technology. Distance from farmers' residence to extension office has a significant influence on household decisions to adopt improved technologies. There is a negative relationship between the distance of the residence from an all-weather road and technology adoption. Similarly, distance to the markets is an important factor that influences household decisions to adopt technologies. Decreasing the distance from the market decreased the transportation cost of agricultural inputs (Melesse, 2018).

Household perceptions on economic return, extension package appropriateness, and participatory nature of extension services have influential factors on household decision to adopt improved technologies and knowledge. Farmers' perception of economic benefits is measured in terms of productivity, income, and food self-sufficiency after adopting multiple combinations of improved technologies. As a result, it has a positive impact on the household's decision to adopt modern technology. Perceived package appropriateness or relevance of improved technology packages is also a determinant factor for household decisions to adopt multiple combinations of technologies. Participatory approaches are considered an important aspect of improving agricultural extension provision to improve accountability and increase transparency in organizational performance (Asres et al., 2016). It is important to engage farm households in different activities especially in planning and evaluation of the extension program in order to enhance adoption. Therefore, participation of households in extension program planning and evaluation process is positively influenced the household decision to adopt technologies.

Table 5.1 Definitions and summary statistics of the variables used in the analysis

VARIABLES	DESCRIPTION OF VARIABLES	MEAN	STD
DEPENDENT VARIABLES			
V	1= if the household adopted improved *tef* variety	0.53	
F	1= if the household adopted chemical fertilizer	0.66	
R	1= if the household adopted row planting	0.50	
EXPLANATORY VARIABLES			
DEMOGRAPHIC CHARACTERISTICS			
SEX	1= if the household head is male	0.90	
AGE	Age of the household head in years	45.45	12.54
EDUC_0	1= if the household head has no formal school	0.52	
EDUC_1	1= if the household head between 1 and 8 grade	0.45	
EDUC_2	1= if the household head greater than 8 grade	0.03	
HH_SIZE	Number of household size in ADE	4.71	1.92
RESOURCE ENDOWMENT			
FARM_SIZE	Farm size in ha	2.75	1.89
LIVESTOCK	Livestock herd in TLU	5.75	4.15
OFF_FARM	1= if household engaged in off farm activities	0.16	
INSTITUTIONAL FACTORS			
CREDIT	1= if the household access credit	0.56	
COOPERATIVE	1= if the household member of cooperatives	0.70	
EXTENSION SERVICES			
CONTACT	Frequency of DA contacts with farmers	3.30	6.70
CONFIDENT	1 = if the household confident with the skills of DA	0.54	
TRAINING	1= if the household access to training	0.70	
DIS_EXT	Distance to the nearest extension office (km)	4.14	3.58
MARKET ACCESS			
DIS_INPUT	Distance to the nearest input market (km)	4.74	4.36
DIS_OUTPUT	Distance to the nearest output market (km)	10.18	6.94
FARMERS PERCEPTION (1-5 scale)			
ECO_RETURN	Farmers' perception on the economic return	3.78	0.94
PACKAGE	Farmers' perception to packages appropriateness	2.85	1.35
PARTICIPATION	Farmers' perception on participatory of extension service	2.24	0.83
WOREDAS DUMMY			
MINJAR	1= if the household in Minjar Shenkora *woreda*	0.50	
ADAA	1= if the household in Ada'a *woreda*	0.50	

Source: Own calculation based on field survey

5.4 Results and discussion

5.4.1 Characteristics of sample farm households

Table 5.1 presents summary statistics for the variables utilized in the econometric analysis. The means and standard deviations of farm household characteristics, resource endowments, extension service, market access, and farmers' perception of the sample households were calculated. The mean age of the sample household is 45.5 years with a standard deviation of 12.5 years. A large majority of farm households in the study areas are headed by males (90%). The average household size of the sample respondents is 4.7 with adult equivalent (ADE) and a standard deviation of 1.9. The results also show that 52% of the household heads had no formal education while 45% and 3% were educated up to grade 8 and above grade 8.

As far as the household endowments are concerned, the average cultivated land size of the sample households is 2.6 ha with a standard deviation of 1.9, and the households have on average 5.8 TLU. Besides, only 16% of farm households engaged in off-farm activities. Regarding institutional variables, 70% of the farm households are a member of agricultural cooperatives, about 56% of farm households had access to credit. Almost all farm households get extension services though the frequency differs. The survey result indicates that the average number of contacts paid by DAs is 3.3 times with a standard deviation of 6.7. Yet, about 54% of farm households are confident with the skill of DAs. Among those sample respondents, 70% are access training for the last two years in the study areas.

Concerning farmers' perceptions, the survey results show that the positive perception of farmers' on the economic return from adopting improved technologies is 3.8. Moreover, the perception of farm households' on the appropriateness of the extension packages on average is 2.9. This implies the majority of farmers' perception of the extension packages' appropriateness is at an average level. Besides, the perception of farmers on the participatory nature of the extension delivery system is below the average levels, which are 2.2.

5.4.2 Joint probabilities of improved technology adoption

The probability distribution of the joint adoption of improved *tef* varieties, chemical fertilizer, and row planting practices is presented in Table 5.2. Of the total eight combinations of improved technologies, the combinations of technologies that involve improved *tef* varieties account for 53.4%. However, all three technologies were adopted by 22.1% of the sample households, while only 10% adopted improved *tef* varieties. Farm households jointly adopting improved *tef* variety and chemical fertilizer, constitute 13.8% while 7.5% of farm households adopted improved *tef* variety and row planting simultaneously. The joint probability of using simultaneous technologies adoption of all three improved technologies are minimal (22.1%), suggesting a lot needs to be done in popularization, demonstrating, and creating better access to combinations of technology packages for farm households. Chemical fertilizer was the most common improved agricultural technologies adopted by the sample respondents in the study areas. Similarly, households, who adopting the combinations of improved technologies involving chemical fertilizer constitute 65.9%. As an individual technology, fertilizer was adopted by 17% of households, in combination with improved variety by 14% of households, and in combinations with row planting and improved variety by 22.1%. Row planting alone was adopted by only 8.3% of households, in combination with improved variety by 7.5% of the households. About 9% of the respondents benefited from none of the three improved technologies.

Table 5.2 Joint probability of adoption of improved technologies (%)

Percent adopting in	Technology package	Joint probablity
All three technologies	V_1 F_1 R_1	22.1
Improved *tef* variety and chemical fertilizer	V_1 F_1 R_o	13.8
Improved *tef* variety and row planting	V_1 F_o R_1	7.5
Chemical fertilizer and row planting	V_o F_1 R_1	12.5
Only improved *tef* variety	V_1 F_o R_o	10.0
Only chemical fertilizer	V_o F_1 R_o	17.1
Only row planting	V_o F_o R_1	8.3
Non-adoption	V_o F_o R_o	8.8

Source: Own calculation based on field survey

Note: V, F and R refer to technology set for improved variety, chemical fertilizer and row planting, respectively; subscript ‘0’ denotes non-adoption, while ‘1’ denotes adoption of technology packages.

5.4.3 Conditional and unconditional adoption probabilities

Table 5.3 presents the unconditional and conditional probabilities of the adoption of technologies. The simulated maximum likelihood estimation result shows that the likelihood of farm households adopting improved *tef* variety, chemical fertilizer, and row planting were 53.4%, 65.0%, and 50.0% respectively. The conditional probability of adopting improved technologies and practices or a combination of technologies and practices, however, is generally greater telling the existence of synergy. The unconditional probability of adopting chemical fertilizer is 65%. This increases to 69% and 77% conditional on the adoption of one technology (improved *tef* variety) and two technologies (improved *tef* variety and row planting practices), respectively. However, the conditional probability of adopting chemical fertilizer is no significant difference on the farm when farmers adopt only improved *tef* variety (67%).

Table 5.3 Conditional and unconditional probabilities of adoption of technologies

	Improved *tef* Variety	Chemical Fertilizer	Row Planting Practice
$P(Y_i = 1)$	0.53	0.66	0.50
$P(Y_i = 1 \mid Y_v = 1)$	1.00	0.69	0.52
$P(Y_i = 1 \mid Y_F = 1)$	0.57	1.00	0.50
$P(Y_i = 1 \mid Y_R = 1)$	0.52	0.67	1.00
$P(Y_i = 1 \mid Y_v = 1, Y_F = 1)$	1.00	1.00	0.54
$P(Y_i = 1 \mid Y_v = 1, Y_R = 1)$	1.00	0.77	1.00
$P(Y_i = 1 \mid Y_F = 1, Y_R = 1)$	0.61	1.00	1.00
$P(Y_i = 1 \mid Y_v = 1, Y_F = 1, Y_R = 1,)$	1.00	1.00	1.00

Source: Own calculation based on field survey

Note: Y_i is a binary variable representing the adoption status with respect to improved technologies i (V = improved *tef* seed, chemical fertilizer (F), and row planting practice (R)

5.4.4 Factors affecting households' adoption decision: A MVP model results

The MVP model estimate of the simulation results for farmer's technology adoption decisions is presented in Table 5.4. Although farmers adopt a combination of improved technologies, there are significant factors that could influence their decision to choose a particular technology. This section has identified those variables using MVP model estimates. The Wald test [2 (75) = 197.40, p = 0.000] rejects the hypothesis that all regression coefficients in each equation are jointly equal to zero since the model fits the data reasonably well. The Wald test rejects the hypothesis that all coefficients in each equation are jointly equal to zero, implying that the variables in the model explain a significant amount of the variability in the dependent variables. The model estimates differ considerably across the equations, representing the appropriateness of differentiating between technologies. This was also formally tested by estimating a constrained specification with all slope coefficients forced to be equal. Furthermore, the likelihood ratio test of the null hypothesis that the covariance of the error terms across equations is uncorrelated is rejected. It reflecting the heterogeneity in the adoption of technologies and, subsequently, supporting a separate analysis of each rather than aggregating them as a single dependent variable.

The result of the study shows formal education of the household head up to grade 8 has a positive and significant effect on the household decision to use improved *tef* variety and row planting practice. Education improves decision-making locative ability by teaching farmers to think and use information sources effectively. Higher education is believed to be associated with the ability to collect process and utilize new information suggesting households with higher levels of education would be highly likely to adopt improved crop varieties. The finding is similar to the results of Deresse and Teklu (2019); Dejene and Bekele (2015); Negera and Getachew (2014) who reported that there was a positive and significant association between education level and *tef* technology adoption.

Household size has also a significant and positive impact on the household decision of chemical fertilizer and *tef* row planting practice at 5% and 5% significance level, respectively. It is normally associated with higher family labor that would enable a household to accomplish various agricultural tasks on timely basis. This may be due to farming households with more labor force can engage in various economic activities and may earn more income to purchase more amount of chemical fertilizer than those households with smaller household size. Moreover, farm households with more labor force could practice row planting than those households with smaller family size on *tef* production. Most Ethiopian farmers have not used labor-saving technologies like tractors, harvesters in their production system; hence, household size critically influences the household decision to adopt new technologies. This result is in line with Deresse and Teklu (2019); Mekidelawit (2018); Dejene and Bekele (2015); Hassen et al. (2012). Livestock ownership is another essential factor that influences positively the adoption of improved *tef* seed and chemical fertilizer. This is maybe because those households who own more livestock holdings have the probability of earning more money from the sale of their livestock and their products which help them to purchase improved *tef* seed and fertilizer.

The frequency of extension contacts has a positive and significant effect on the adoption of improved *tef* variety, chemical fertilizer, and using row planting practices. This is mainly because extension service is a necessary catalyst to adopt improved technologies as they are the major source of agricultural information. Likewise, farm households with confidence with the skills of DAs have more probability of adopting chemical fertilizer and row planting than those households with smaller or no confidence in the skills of DAs. This may be due to those DAs who have technical skills easily demonstrated and convinced households to adopt new technologies and innovations. The probability of adopting improved *tef* variety and chemical fertilizer is affected by a households' membership in agricultural cooperatives and access to rural finance (credit). With limited or insufficient information sources and imperfect markets, social networks such as farmer cooperatives increase information exchange and provide farmers with access to new technology and credit. This finding suggests that to improve the adoption of *tef* technology, agricultural cooperatives, and rural service providers need to be supported because they can effectively help farmers in providing credit, agricultural inputs, information, and stable market outlets. This result is in line with Hailemariam (2012) and Mekidelawit (2018).

Distance to the nearby extension office, distance to input and output market is negatively influenced by the adoption of improved *tef* technologies. An increase in distance to the extension office, input and output markets unable households to get relevant and timely information for purchasing agricultural inputs and selling their outputs. Distance to the input market has a negative and significant impact on the adoption of improved *tef* variety, reflecting transaction and access costs. Similarly, the distance from the output market has a large and negative impact on the use of chemical fertilizer and row planting practices. Perception of farming households on the economic return has a positive impact on the adoption of improved *tef* variety, chemical fertilizer, and row planting practices at 1%, 1%, and 5% significance level, respectively. This implies that the higher the economic return from using improved *tef* variety, chemical fertilizer, and row planting the greater likelihood of farmers' motivates to adopt multiple combinations of *tef* technologies. Similarly, households' participation in the extension services delivery process has positive and significant effects on the likelihood of adopting improved *tef* variety and row planting practice. The more participation of farmers in extension planning and delivery would have more probability to increases the chances of adopting improved technologies.

Table 5.4 Multivariate probit estimation results for improved technology adoption decisions

Explanatory variables	Improved *tef* variety		Chemical fertilizer		Row planting practice	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
SEX	0.2551	0.3183	0.0628	0.3312	-0.0792	0.3259
AGE	-0.0015	0.0078	0.0099	0.0083	-0.0066	0.0076
EDUC_0	0.2977	0.5739	0.6162	0.5284	0.0427	0.5578
EDUC_1	0.3554**	0.5734	0.2215	0.5252	0.2493*	0.5564
HH_SIZE	0.0186	0.0514	0.0297**	0.0532	0.0561**	0.0498
LIVESTOCK	0.0249*	0.0272	0.0436**	0.0299	0.0268	0.0268
FARM_SIZE	0.0354	0.0622	0.0243	0.0613	0.0464	0.1649
COOPERATIVES	0.7789***	0.2274	0.5146***	0.2218	0.6229***	0.2193
CREDIT	0.5504**	0.2249	0.2299*	0.2212	0.1991	0.2100
OFF_FARM	0.1769	0.2595	0.2305	0.2765	0.1172	0.2591
CONTACT	0.0788***	0.0323	0.0601*	0.0367	0.0166*	0.0191
TRAINING	0.0260	0.2260	-0.1206	0.2331	-0.0953	0.2213
CONFIDENT	0.2531	0.2520	0.4731*	0.2642	0.4357**	0.2437
DIS_EXT	-0.0312	0.0417	-0.0805**	0.0418	-0.0789**	0.0401
DIS_INPUT	-0.0355*	0.0356	-0.0271	0.0347	0.0243	0.0335
DIS_OUTPUT	-0.0074	0.0158	-0.0750***	0.0198	-0.0322**	0.0158
ECO_RETURN	0.2842***	0.1174	0.0480***	0.1685	0.0926**	0.1084
PACKAGE	0.0907	0.0790	0.0031	0.0823	0.0005	0.0769
PARTICIPATORY	0.1456*	0.1316	0.3014	0.1365	0.0328*	0.1301
MINJAR	0.3840*	0.7103	0.0673	0.6127	0.7008**	0.7215
ADAA	0.2905*	0.7144	0.5204	0.6216	0.6392*	0.7314
cons	-1.0527	1.6434	-2.3488	1.4914	0.0390	1.6809
Wald chi^2 (75) = 197.40	Prob > chi^2 = 0.0000					
No of Observation = 240						

Source: Own estimation based on field survey

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%

5.4.5 Number of technologies adopted: Ordered probit model results

Table 5.5 shows the number of improved technologies adopted by sample households. The number of improved *tef* technologies adopted by farmers from the combination is the model's dependent variable. Approximately 91% of farming households have implemented at least one of the improved technologies, with about 34% adopting two. The descriptive statistics for a variety of technologies utilized along the probability predicted by the ordered probit model are shown in Table 5.5.

Table 5.5 Percentages of improved technologies adoption by sample farm households

Number of Technologies	Percent
(0) Non-adoption	8.8
(1) Adoption of single technology	35.4
(2) Adoption of a combination of two technologies	33.8
(3) Adopted of a combination of three technologies	22.1

Source: Own calculation based on field survey

Table 5.6 shows the results from pooled and marginal effects ordered probit models. The chi-squared statistic for the ordered probit model is (Wald chi2 (19) = 119.34, P = 0.0000) and is statistically significant, indicating that the joint test of all slope coefficients equal to zero is rejected. The ordered probit model results reveal the number of technologies adopted is positively associated with educational level, livestock ownership, farm size, cooperatives membership, credit access, frequency of DAs contacts, training, farmers' confidence with skills of DA, and perception of farmers on econometric return. It is negatively associated with distance to the extension office and the market.

Education increases human capital and contributes positively to change farmer's attitudes and determines the readiness to accept new ideas and innovations (Hiwot et al., 2016). As in the adoption decision, the results reveal that education level up to grade 8 has a positive and significant effect on the level and number of adoption of improved technologies. Each extra year of schooling for the household head increases the likelihood of adopting two and three technologies by about 14.4% and 8%, respectively. Household assets (such as cattle ownership) have a beneficial impact on the adoption of two or more improved technologies. A one-unit increase in livestock ownership measured in TLU increases the likelihood of adopting two and three technologies by 0.4% and 0.5%, respectively.

Having large farmland contributes to perceived security and increased willingness to invest in new technologies and practices. The farm size has a significant and positive effect on the level of technology adoption. A one-unit increase in the farmland could increase the probability of adoption of two and three improved technologies by 4.1% and 0.3%, respectively. Social capital variables such as farmers' membership of agricultural cooperatives have significant and positive effects on the number of improved technologies adopted, with varying marginal probabilities. Farmers who are members of agricultural cooperatives could easily access agricultural information and new technologies. If a household is a member of agricultural cooperatives, the probability of adopting two and three technologies increases by 22.1% and about 11%, respectively. Access to credit also has a positive and significant influence on household decisions to adopt improved technologies (Legesse et al., 2001; Tesfaye, 2001). Farm households who access financial services (credit) would increase the probability of adopting a combination of three technologies by 0.3% signifying that households who immediate access to money (those who need it) are more likely to purchase agricultural inputs.

Households' contacts with DAs increase the probability of getting new agricultural information, technologies, and innovations. If the frequency of contacts increases by one unit, the probability of adopting three technologies increases by 1.3%. This implies that timely and adequate provision of agricultural information would influence the mindset of the farm households positively. Similarly, farmers who have confidence with the skills of DAs have more probability of adopting three technologies by about 10% than those households with smaller or no confidence with the skills of DAs on tef production. Training has a positive and significant effect on the number of improved technology adoption. Farmers who received awareness creation and capacity-building training are more likely to adopt a combination of various technologies. Farm households who access training would increase the probability of adopting three agricultural technologies by 8%.

The perception of farmers on economic returns has a positive and significant influence on the adoption of a combination of improved technologies. A one birr increases in the economic benefits would have the effect of increasing the chances of adopting a combination of two and three improved technologies by 7% and 10%, respectively. Distance to the nearby extension office and output market significant and negative impact on the number of improved tef technologies adopted. Farmers who do not have their means of transportation or access to public transport to the extension office and output market are 1.3% and 0.7% less likely to adopt three technologies, respectively.

Table 5.6 Ordered probit model estimates for the number of improved technologies adopted

Variables	Pooled ordered probit model		Marginal effects							
			Prob(Y= 0 │ X)		Prob(Y= 1 │ X)		Prob(Y= 2 │ X)		Prob(Y= 3 │ X)	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
SEX	0.411	0.251	0.156***	2.024	-0.233***	0.074	0.051	0.112	0.025	0.033
AGE	-0.003	0.006	-0.007	0.015	-0.004	0.003	0.003	0.002	0.000	0.001
EDUC_0	0.392	0.426	0.617	0.193	0.057	0.192	0.141	0.182	0.028	0.102
EDUC_1	0.115**	0.421	0.719	0.828	0.041	0.190	0.144*	0.175	0.076**	0.126
HH_SIZE	0.002	0.040	0.004	0.0793	0.009	0.018	0.005	0.017	0.003	0.007
LIVESTOCK	0.022*	0.021	0.006	0.012	0.004	0.009	0.004*	0.009	0.005*	0.004
FARM_SIZE	0.019*	0.046	0.007	0.126	0.015	0.022	0.041**	0.019	0.003*	0.008
COOPERAT.	0.991***	0.186	0.085***	1.341	0.256***	0.081	0.221***	0.064	0.108***	0.037
CREDIT	0.105**	0.167	0.048**	0.850	0.131*	0.072	0.012	0.071	0.003*	0.029
OFF_FARM	0.119	0.206	0.009	0.029	0.031	0.086	0.037	0.091	0.039	0.055
CONTACTS	0.056**	0.026	0.003	0.006	0.018	0.011	0.004	0.007	0.013**	0.006
TRAINING	0.033*	0.183	0.011	0.201	0.077	0.078	0.069	0.079	0.001*	0.038
CONFIDENT	0.319**	0.164	0.013	0.242	0.090	0.070	0.076	0.069	0.098**	0.042
DIS_EXT	-0.103***	0.033	-0.004	0.073	-0.036**	0.016	0.016	0.014	-0.013*	0.007
DIS_INPUT	0.016	0.027	0.001	0.021	0.018	0.014	-0.016	0.012	0.002	0.005
DIS_OUTPUT	-0.031**	0.012	-0.005	0.010	0.011*	0.006	0.004	0.005	-0.007***	0.003
ECO_RETURN	0.303***	0.087	0.009	0.167	0.033	0.037	0.069*	0.038	0.100***	0.032
PACKAGE	0.091	0.062	0.046	0.087	0.010	0.027	0.015	0.027	0.014	0.011
PARTICIP.	0.060	0.104	0.009	0.187	0.003	0.045	0.087**	0.046	0.008	0.017
/cut1	0.043	0.682								
/cut2	1.641	0.689								
/cut3	2.879	0.701								

Source: Own calculation based on field survey

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%

5.4.6 Intensity of improved *tef* seed adoption

The result of the Tobit model indicated that level of education of the head of the farming household has a positive and significant influence on the adoption and use of improved *tef* variety with each additional year of schooling increasing the probability of adoption by 9.3% (Table 5.7). Education enhances farmers' ability to acquire, analyze, interpret and use information relevant to the adoption of agricultural innovations. This suggests that farmers with higher educational background would have better opportunity to access information and can easily understand the benefit of improved *tef* technology and apply the technologies as per the recommendation. This result is in line with most of the previous findings such as Hiwot et al. (2016); Alen et al. (2000) who reported positive and significant influence of household heads' educational level on adoption and intensity of use of improved technology package.

Household size has a positive and significant influence on the number of hectares of land planted to improved *tef* variety. Each additional household size increases the probability of adoption by 1.8%. Besides, on average, each additional family size has increased the number of hectares of farmland planted to improved *tef* variety by 2.9% for the whole sample of study and by 1.3% for technology adopters. The probability of adoption and intensity of improved *tef* seed is positively and significantly influenced by a households' membership in agricultural cooperatives. Farming households' membership in agricultural cooperatives can increase the probability of adoption by 30.6%. Farming household who are member in agricultural cooperative can increase the use of improved *tef* variety by 29.8% for the whole sample study, and by 51.3% for users.

Extension service increases the probability of getting new agricultural information, technologies, and innovations. It measured in the number of visits per year by the DA to a farmer during the cropping season. As indicated in Table 5.7, the number of contacts to the farmers has a positive and significant influence the adoption and intensity of use of improved *tef* variety. Each additional contact by the DA to a farmer increased the probability of adoption by 3.1%. On average, each additional visit has also increased the number of hectares of land planted with improved *tef* variety by 3% for the entire sample and by 0.9 for users. The perception of economic return from adoption is another important factor which influences farmers' decision to adopt improved varieties as it enables farmers to acquire seeds and other inputs at the right time.

It has a positive and significant influence on the adoption and intensity of adoption of improved *tef* variety. A one birr increases in the economic return would have increased the probability of adopting improved seed by 12.3%. Each additional economic return has also increased the number of hectares of land covered with improved *tef* variety by 9.8% for the entire sample and by 15% for adopters.

Table 5.7 Tobit model results of the adoption and intensity of use of improved variety of *tef*

Explanatory Variables			Marginal effect					
			Change in probability of adoption		Change in intensity of adoption		Total change	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
SEX	0.277	0.194	-0.152	0.124	0.197	0.183	0.101	0.120
AGE	-0.003	0.004	0.002	0.003	-0.006	0.004	-0.003	0.002
EDUC_1	0.239**	0.126	0.110	0.228	0.003	0.273	0.093	0.194
EDUC_2	0.240	0.323	0.132	0.223	0.005	0.267	0.076	0.191
HH_SIZE	0.041*	0.029	0.018	0.020	0.027	0.029	0.013	0.019
LIVESTOCK	0.011	0.015	0.011	0.015	0.009	0.015	0.009	0.011
FARM_SIZE	0.023	0.033	0.016	0.024	0.023	0.033	0.016	0.024
COOPERATIVE	0.531***	0.140	0.306	0.084	0.513	0.138	0.298	0.084
CREDIT	0.243**	0.122	0.193	0.082	-0.263	0.120	-0.207	0.080
OFF_FARM	0.046	0.157	0.025	0.103	-0.041	0.156	-0.018	0.102
CONTACT	0.048***	0.008	0.031	0.014	0.009	0.008	0.030	0.014
TRAINING	0.089	0.133	0.012	0.094	0.093	0.132	0.018	0.092
CONFIDENT	0.093	0.122	0.045	0.081	0.072	0.121	0.031	0.080
DIS__EXT	-0.019	0.023	0.015	0.016	-0.024	0.023	-0.018	0.016
DIS_INPUT	0.015	0.020	-0.013	0.014	0.014	0.019	0.012	0.014
DIS_OUTPUT	-0.005	0.009	0.005	0.006	-0.005	0.008	-0.005	0.006
ECO_RETURN	0.187***	0.066	0.123	0.045	0.150	0.060	0.098	0.041
PACKAGE	0.069	0.044	0.055	0.031	-0.075	0.044	-0.058	0.031
PARTICIP	-0.072	0.076	0.053	0.052	-0.098	0.074	-0.072	0.051
_cons	-0.758	0.526						
/sigma	0.752	0.053						
Number of Observation = 240; Pseudo R^2= 0.1127; F(19, 221)= 4.01; Prob > F= 0.0000								

Source: Own estimation based on field survey

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%

5.5 Conclusions and policy implications

This study has analyzed the adoption of multiple agricultural technologies among *tef* growing farmers using cross-sectional data collected from Central Ethiopia. The technologies considered for this study are improved *tef* variety, chemical fertilizer, and row planting practice. Using MVP and ordered probit models this study looked to analyze the factors that influence the adoption of multiple agricultural *tef* technologies and the number of technologies adopted. The results of the MVP model revealed that education level, household size, livestock ownership, farmers' membership in an agricultural cooperative, access to credit, number of extension contacts, farmers' confidence with the skills of DAs, farmers' perception on economic return, farmers' perception on participation in the extension service delivery, the average distance to output market and distance to extension office are significantly associated with the probability and the extent of multiple adoptions of *tef* technologies. Specifically, social capital and strong rural farmers' institutions, and market access are important policy variables that have a significant effect on the adoption of multiple agricultural technologies.

The major role of social capital in adoption highlights the importance of establishing and improving local farmer institutions and service providers in order to expedite and sustain technology adoption. Local farmers' institutions can play an important role in providing timely information, inputs, finance, insurance, and technical support in a country where there is information asymmetry for input and output markets. The study suggested the need for strengthening agricultural cooperatives and rural financial institutions and service providers to enhance multiple technology adoption. The importance of farm household assets in influencing the purchase of inputs calls for improving credit delivery systems. Livestock ownership influences the adoption of multiple agricultural technologies. Farming households who own more livestock holdings and access money through credit have more probability of earning money from the sale of their livestock and their products which help them to purchase various inputs. Farmers' perception of the economic return is the most important driving factor for multiple technology adoption. Hence, it forces the extension service needs to focus on demand-driven and market-oriented that diversified technologies that suit with specific needs of farmers. This implies, as a household perception of expectation on the economic return is positive, the probability of using multiple technology adoption is higher. It is therefore rational to say the higher the economic return from using multiple technologies, the greater likelihood of farmers' participating in the extension system and adopting multiple technologies.

In conclusion, despite its positive impact on household food security, the adoption of multiple combinations of improved agricultural technologies is usually hindered and or facilitated by different factors. Relevant actors in R&D should have typically promoted the adoption of a combination of multiple technologies and designing possible interventions for those factors that impede the use of those technologies. The results of our study point to the following important implications. Although we have evidence of the superiority of adoption of multiple combinations of agricultural technologies on food security, our findings suggest that substantial efforts should be made by all actors to plan and implement campaigns to promote such technologies. In particular, it seems that awareness of farmers is needed and continuous efforts of all actors, particularly DA field assistance, are needed. Technology promotion alone is not a solution for the wider application of technologies, since there is always a significant gap between technology supply and demand; hence, it needs various management skills and intervention strategies. However, this study used a cross-sectional data set to analyze the determinants of the household decision to adopt multiple technologies, without sufficiently controlling the unobserved heterogeneity. Future research can provide more adequate and accurate information on the determinants by using panel data.

5.6 References

Alene, A.D., D. Poonyth, D., & Hassan, R.M. (2000). Determinants of adoption and intensity of use of improved maize varieties in the central highlands of Ethiopia: A Tobit analysis. *Agrekon*, Vol 39, No 4.

Almaz Giziew & Begashaw Mebrate (2019). Determinants of the role of gender on adoption of row planting of tef [Eragrostis tef (Zucc.) Trotter] in central Ethiopia. *Ethiopian Journal of Science and Technology*, *12*(1), 19-43.

Asres Elias, Nohmi, M., Yasunobu, K., & Ishida, A. (2016). Farmers' satisfaction with agricultural extension service and its influencing factors: A case study in North West Ethiopia. *J. Agr. Sci. Tech.*, *18*(1), 39-53.

Awotide, B. A., Diagne, A., & Omonona, B. T. (2012, October). Impact of improved agricultural technology adoption on sustainable rice productivity and rural farmers' welfare in Nigeria: A Local Average Treatment Effect (LATE) Technique. In *African Economic Conference October*.

Bekele Shiferaw, Menale Kassie, Moti Jaleta & Chilot Yirga (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy*, *44*, 272–284.

Bekele Shiferaw, Okello, J., & Reddy, R. (2009) Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. *Environment, Development and Sustainability 11*(3), 601-619.

Belay Kassa (2003). Agricultural extension in Ethiopia: the case of participatory demonstration and training extension system. *Journal of social development in Africa*, *18*(1), 49-83.

Belderbos, R., Carree, M., Diederen, B., Lokshin, B., & Veugelers, R. (2004). Heterogeneity in R&D cooperation strategies. *International journal of industrial organization*, *22*(8-9), 1237-1263.

Chilot Yirga, Shapiro, B., & Mulat Demeke (1996). Factors influencing adoption of new wheat technologies in Wolemera and Addis Alem areas of Ethiopia. *Ethiopian Journal of Agricultural Economics 1*, 63-84.

Chilot Yirga, Yigezu Atnafe & Aden AwHassan (2015). A multivariate analysis of factors affecting adoption of improved varieties of multiple crops: A case study from Ethiopian Highlands. *Ethiopian Journal of Agricultural Science, 25*(2), 29-45.

CSA (2018). Agricultural sample survey 2017/18 report on area and production of major crops for private peasant holdings, *Meher* season, volume I. Central Statistical Agency, *Addis Ababa*.

Debelo Duressa (2015). Analysis of factors influencing adoption of Quncho tef: The case of Wayu Tuqa District. *International Journal of African and Asian Studies, 12,* 20-28.

Dejene Bayissa & Bekele Tassew (2015). Determinants of farmer's adoption of full extension package on improved tef technology: the case of Dendi district, West Showa, Oromia Regional State, Ethiopia. *International Journal of Current Research, 7*(9), 20816 – 20821.

Dercon, S., Gilligan, D., Hoddinott, J., & Woldehanna, T. (2009). The impact of agricultural extension and roads on poverty and consumption growth in fifteen Ethiopian villages. *American Journal of Agricultural Economics, 91*(4), 1007–1021.

Deresse Dalango & Tekilu Tadesse (2019). Determinants of smallholder teff farmer's chemical fertilizer technology adoption in Southern Ethiopia, in case of Gena District in Dawro Zone (Heckman Two-Stage Model). *Jurnal Perspektif Pembiayaan dan Pembangunan Daerah, 7*(2), 111-126.

Dorfman J.H. (1996). 'Modelling multiple adoption decisions in a joint framework' *American Journal of Agricultural Economics, 78*, 547-557.

Efa Gobena, Degye Goshu, Tinsae Demisie & Tadesse Kenea (2016). Determinants of market participation and intensity of marketed surplus of *tef* producers in Bacho and Dawo Districts of Oromia State, Ethiopia. *Journal of Agricultural Economics and Development*, *5*(2), 20–32.

Etsehiwot Semreab (2018). The determinants of agricultural technology adoption and its' impact on teff productivity in the case of Amhara and Oromia national regional state.

Fentahun Mengistu, Abebe Kirub & Fisseha Zegeye (2017). Retrospect and prospect of Ethiopian agricultural research. EIAR, Addis Ababa.

Hailemariam Teklewold (2012). Essays on the economics of sustainable agricultural technologies in Ethiopia. A PhD dissertation submitted to School of Business. Economics and Law University of Gothenburg.

Hailemariam Teklewold, Menale Kassie, Bekele Shiferaw, & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics, 93,* 85–93.

Hailu Beyene (2008). *Adoption of improved tef and wheat production technologies in crop-livestock mixed systems in northern and western Shewa zones of Ethiopia* (Doctoral dissertation, University of Pretoria).

Hassen Beshir, Bezabih Emana, Belay Kassa, & Jema Haji (2012). Determinants of chemical fertilizer technology adoption in North eastern highlands of Ethiopia: The double hurdle approach. *Journal of Research in Economics and International Finance, 1*(2), 39-49.

Hiwot Mekonnen, Musa Hasen, & Seltene Abady (2016). Determinants of multiple groundnut technology adoption in Eastern Ethiopia. *Review of Agricultural and Applied Economics, 19*(2), 51-60.

Howard, J., Crawford, E., Kelly, V., Demeke, M., & Jeje, J. (2003). Promoting high-input maize technologies in Africa: the Sasakawa-Global 2000 experience in Ethiopia and Mozambique. *Food Policy, 28*(4), 335-348.

Kansana, H.S., Sharma, R.P., & Sharma, S.K. (1996). Knowledge and adoption of wheat technology among contact and non-contact farmer. *Agricultural Science, Digest Karnal, 16*, 154-156.

Kebebew Assefa, Solomon Chanyalew, & Zerihu Tadele (2013). *Achievements and Prospects of Tef Improvement-Proceedings of the Second International Workshop, November 7-9, 2011, Debre Zeit, Ethiopia*. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia; Institute of Plant Sciences, University of Bern, Switzerland.

Legesse Dadi, Burton, M., & Ozanne, A. (2001). Adoption and intensity of fertilizer and herbicide use in the Central Highlands of Ethiopia. *Agrekon 40*(3), 316-333.

Lin, C. T. J., Jensen, K. L., & Yen, S. T. (2005). Awareness of foodborne pathogens among US consumers. *Food Quality and Preference*, *16*(5), 401-412.

Louhichi, K., Temursho, U., Colen, L., & Gomez, Y., & Paloma, S. (2019). *Upscaling the productivity performance of the Agricultural Commercialization Cluster Initiative in Ethiopia*. HAL.

Maddala, G. S. (1983). Limited-dependent and qualitative variables in Econometrics. Cambridge University Press, New York.

McDonald, J.F., & Moffitt, R.A. (1980). The use of Tobit Analysis. *Review of Economics and Statistics*, *62*(2), 318-321

Mekidelawit Ayal (2018). Determinants of adoption of teff row planting practice: the case of Baso Liben Woreda, East Gojjam Zone, Amhara Region, Ethiopia. An MSc thesis submitted to department of rural development and agricultural extension, Arba Minch University.

Melesse Birhanu (2018). A review on factors affecting adoption of agricultural new technologies in Ethiopia. *Journal of Agricultural Science and Food Research*, *9*(3), 1-4.

Menale Kassie, Marenya, P., Yohannis Tessema, Moti Jaleta, Zeng, D., Erenstein, O., & Rahut, D. (2018). Measuring farm and market level economic impacts of improved maize production technologies in Ethiopia: Evidence from panel data. *Journal of Agricultural Economics*, *69*(1), 76-95.

Menale Kassie, Hailemariam Teklewold, Mareny, P., Moti Jaleta & Olaf, E. (2015). Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. *Journal of Agricultural Economics*, *66*(3), 640-659.

Menale Kassie, Moti Jaleta, Bekele Shiferaw, Mmbando, F., & Mulugeta Mekuria (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological forecasting and social change*, *80*(3), 525-540.

Mignouna, D. B., Manyong, V. M., Mutabazi, K. D., & Senkondo, E. M. (2011). Determinants of adopting imazapyr-resistant maize for Striga control in Western Kenya: A double-hurdle approach. *Journal of development and agricultural economics*, *3*(11), 572-580.

Misigana Hidata (2013). Study on factors affecting agricultural extension for agricultural technology dissemination and adoption in Bacho district, Oromia regional state of Ethiopia the case in micro irrigation technologies (Doctoral dissertation, St. Mary's University).

Negera Eba & Getachew Bashargo (2014). Factors affecting adoption of chemical fertilizer by smallholder farmers in Guto Gida District, Oromia Regional State, Ethiopia. *Science, Technology and Arts Research Journal*, *3*(2), 237-244.

Nkonya, E., Schroeder, T., & Norman, D. (1997). Factors affecting adoption of improved maize seed and fertiliser in northern Tanzania. *Journal of Agricultural Economics*, *48*(1-3), 1-12.

Regasa Dibaba, Afework Hagos, Chilot Yirga & Endeshaw Habte (2018). Determinants of Improved Teff Varieties Adoption and Its Impact on Productivity: The Case of Non-Traditional Teff Growing Areas of Western Ethiopia. *Journal of Natural Sciences Research*, *22*(8), 2224-3186.

Spielman, D., Byerlee, D., Dawit Alemu & Dawit Kelemework (2010). Policies to promote cereal intensification in Ethiopia: The search for appropriate public and private roles. *Food Policy*, *35*(3), 185-194.

Tesfaye Zegeye (2001). *Adoption of improved bread wheat varieties and inorganic fertilizer by small-scale farmers in Yelmana Densa, and Farta districts of Northwestern Ethiopia*. CIMMYT.

Tobin, J. (1958). Estimation of relationship for limited dependent variables. *Econometrica, 26*, 26-36.

Vandercasteelen, J., Mekdim Dereje, Minten, B., & Alemayehu Seyoum (2013). Scaling-up adoption of improved technologies: The impact of the promotion of row planting on farmers' tef yields in Ethiopia. *LICOS-Discussion paper series 344/2013*, 1-25.

Wollni M., Lee D., & Thies, J. (2010). Conservation agriculture, organic marketing, and collective action in the Honduran hillsides. *Agricultural Economics*, *41*(3-4), 373-384.

Yamane, T. (1967). Statistics: an introductory analysis, 2nd edn, Harper and Row, New York.

6. SYNTHESIS OF MAIN FINDINGS, CONCLUSIONS AND IMPLICATIONS

6.1 Introduction

The central focus of this study was to investigate why the *tef* R&D, extension, and innovation systems were unable to transform smallholders' *tef* production so as to produce sufficient agricultural food production for ensuring household food security in Central Ethiopia, namely Minjar Shenkora and Ada'a *woredas*. The paper was intended to investigate the systemic constraints of the *tef* innovation system, understanding factors affecting the performance of the extension services provision. The study further analyzes the impact of improved *tef* technologies on smallholders' food security and what are the determinants of adopting multiple combinations of technologies. This study is a result of the pragmatist paradigm that combines both quantitative and qualitative methods with multiple techniques for data collection and analysis. Quantitative data from 240 farm households and 143 DAs were generated from the two *woredas* using a structured questionnaires survey while qualitative data was gathered through key informant interviews, focus group discussions, and personal observation. Various descriptive statistics and econometric models were applied for analyzing the data. Transcription, categorization, narration, interpretation, and discussion were used to analyzing the qualitative data. This chapter presents a summary of the key findings of each research objectives, conclusion, and implications for possible interventions. At a glance, this section highlights the contribution of this research to a broader understanding of the systemic barriers and the associated factors of *tef* R&D, extension and innovation systems of the smallholders' *tef* production systems.

6.2 Synthesis of the main findings

This section highlights and discusses the main research findings of addressing the core research objective of why agricultural research, extension, and innovation systems were unable to transform smallholders' *tef* production systems in major *tef* growing areas of Central Ethiopia.

Using a coupled structural-functional innovation analysis framework, adapted from the agricultural innovation systems approach, **Paper I** attempted to answer the fundamental research question of how the *tef* innovation system has functioned to support the *tef* sector development and what have been the structural and functional constraints in the process. The study identified that the *tef* innovation system is not well developed and functioned to transform smallholders' *tef* production systems. This argument is in line with Lee (2018) and Birhanu et al. (2016), where agricultural innovations in Ethiopia are not well developed to support the livelihoods of the population, particularly smallholder farmers. The underdevelopment of the *tef* innovation system and the *tef* sector, in general, could be explained by the failures in structural elements and the weaknesses in innovation functions. The limited capacity of existing actors, weak interactions among actors, and weak enforcement of institutions (such as weak enforcement of property rights, restrictive procurement rules, and limited law enforcement) are the structural elements that have constrained the development of the innovation system. Inadequate infrastructure in terms of qualified and scientifically well-trained human resources in *tef* R&D, insufficient public finance, very limited donors funds, and few and obsolete physical facilities (advanced laboratories, farm machinery, irrigation facilities, advanced ICT, etc.) are also the structural elements that have influenced the development of the *tef* innovation system.

In addition to failures in the structural elements, weaknesses and malfunctioning of the functional elements include technology development, diffusion of technologies, entrepreneurial activities, market formation, mobilization of resources, and creation of legitimacy, which have hindered the *tef* innovation system. It would be, therefore, of utmost importance to mitigate the systemic constraints of research, technological, institutional, and technical interference to make the *tef* sector and innovation system more functional and responsive to the needs of smallholder *tef* producers. A weakness in one of the innovation system functions in turn would have a knock-on effect on other functions which leading to cripple the value chains as a whole. Lack of improved *tef* varieties resistant to lodging, acidity, waterlogging and pre-and post-harvest technologies was found to be mainly linked to weaknesses in the functions of the *tef* R&D. Problems in the provision of agricultural technologies and collection of outputs have resulted from ineffective diffusion of technology and poor market formation, respectively. The legitimacy problems faced by smallholders stemmed from systemic failures, such as weak enforcement of institutions. Collectively, these systemic constraints increase the cost of market transactions and systematically reduce the economic benefits of farmers of adopting improved *tef* technologies presented in **Paper IV**. The large transaction costs associated with the adoption of a combination of improved technologies may lead to a cost higher than the potential economic return on technologies for the use of technologies. The findings support the notion that the key to stimulating technology-driven agricultural productivity is access to new technologies and effective institutions. It would be, therefore, of utmost importance to mitigate the systemic constraints of research, technological, institutional, and technical interference to make the *tef* sector and innovation system more functional and responsive to the needs of smallholder *tef* producers.

Given the greater knowledge facilitation role, enabling environment and governance, interaction, organizational capability, and management system, and extension delivery methods are important factors influenceing the performance of the extension system. The need to identify the factors that significantly affected the performance of the extension system was emphasized by the research findings in **Paper II.** Since agriculture extension in Ethiopia is considered a policy instrument and a suitable tool to bring about anticipated changes, it is important to improve the performance of the system. Hence, improving the performance of DAs and extension organizations is vital through tackling performance-impairing factors. Thus, by taking Minjar Shenkora and Ada'a *woredas* as a case study, assesses the factors affecting the performance of individual DAs and extension organizations performance in terms of wider diffusion of extension services. The analysis, therefore, answers the research question as to what factors explain the poor performance of the extension system in Central Ethiopia. The paper relied on a conceptual framework developed by Birner et al. (2009) so as to provide policy options for Ethiopia.

The findings found that, despite the government commitments by allocating 10% of the national budget to the agriculture sector and a steadily increasing number of DAs, the performance of the extension system has not yet satisfied farmers' demands. This result is in line with Gerba et al. (2017), where the extension and advisory services have not yet fulfilled the large majority of smallholders' demands. Moreover, this study supplements the findings of Ragasa et al. (2016) that the number of DAs is not a sufficient condition of performance, but an effective and efficient extension system needs to focus on the enabling environment for DAs to be motivated to work as mandated. The study further identified that the performance of individual DAs and extension organizations (FTCs) are significantly affected by weak enabling environment and governance structure, weak interactions and partnerships among actors, limited organizational capacity and management, and the extension service delivery method.

The results highlighted the need for a performance-based management system, suggesting that there is a lack of a good performance-based reward and sanction system within the extension system. An organization's entire success is based on how an organization keeps its employees motivated and how the performance for rewards or penalties is assessed. As shown in **Paper II**, AEOs with a rewarding system is more likely to disseminate technologies and conducted farm demonstrations than those without implementing the rewarding system. The findings supported a study by Ragasa et al. (2016) that the delivery of agricultural extension services can be improved by an organization with a good incentive and sanction system and regular performance reviews. Furthermore, motivated DAs to enjoy their jobs, are more dedicated not only to their organizations, but also to the farmers of their clients, less insubordination and grievance, and contribute to the system's long-term success. Many previous studies support this claim such as Dessalegn and Nuri (2018); Belay et al. (2012); Ifenkwe (2012); Khalil et al. (2009).

In increasing extension performance, strong interactions and collaborations among actors are very critical for disseminating not only shelved technologies in the research system but also extension and advisory services to end-users. However, the study identified weak interactions and partnerships among actors are cited as the primary reason for the weak performance of the extension system and the limited impact on R&D. This result is in line with many previous studies such as (Guush et al., 2018; Gerba, 2018; Belay and Dawit, 2017; Tilaye and Daniel, 2016; Davis et al., 2010). In addition, the performance of the extension service provision was significantly affected by a weak enabling environment and governance structure. The lack of clearly defined and commonly shared vision of the extension system influenced the AEOs performance. A weak extension system can be turned into an efficient and successful system with achievable performance targets through a widely shared and clearly defined vision (Ragasa et al., 2016). The study showed that there are no performance targets set for individual DAs and extension organizations (FTC) for their extension service delivery. Consequently, there is no effective monitoring and evaluation system to assess performance-based evaluation. This was affected performance-based rewards and sanctions during the provision of extension services.

FTCs with performance targets and DAs working in FTCs with performance targets are more likely to perform well for the dissemination of improved *tef* technologies, conducted farm demonstration, and tracking the progress and impacts of the adoption of technologies.

The other issue looked at in this study was the adoption effects of various combinations of improved agricultural technologies adoption on household food security (**Paper III).** Using an Endogenous Switching Regression Model and various food security techniques such as DES, HDDS, and FCS, **Paper III** attempted to answer the impact of improved technologies on the crop yield and household food security. Three agricultural technologies namely improved *tef* varieties, chemical fertilizer, and row planting practice were considered in various technology choice sets. Thus, the study analyzed the impacts of agricultural technologies on the outcome variables of yield, DES, HDDS, and FCS of the eight possible combinations. Results showed that the adoption of a combination of improved technologies significantly increased *tef* yield, DES, HDDS, and FCS. The greatest food security impact was obtained when improved agricultural technologies were adopted in combinations rather than in isolation. This result is consistent with Wubneshe et al. (2019); Manda et al. (2016) and Menale et al. (2015) in Ethiopia and elsewhere where adoption of a combination of improved technologies gives higher food security compared to adopting them individually. The study further revealed that the use of a combination of at least two agricultural technologies provides a higher crop yield, DES, HDDS, and FCS. This signifies that adopted all three improved agricultural technologies have a greater *tef* yield, DES, HDDS, and FCS than households who adopted a combination of two technologies and single technology. Besides, the study demonstrates that the impact of adopting chemical fertilizer is outweighed when combined with row planting practices than adopting with an improved *tef* variety.

The primary aim of **Paper IV** was to identify the underlying factors that impede the household decision to adopt a combination of improved *tef* technologies and the number of technologies adopted by smallholder producers in Central Ethiopia, respectively. Adoption of improved agricultural technologies has become an important issue on the development agenda, especially as a means of addressing poverty and food insecurity in Ethiopia. In Ethiopia, improved *tef* variety, chemical fertilizer, and row planting practice are commonly complementary; the productivity of one technology is enhanced by the use of the other technologies. This will encourage farm households to adopt a combination of technologies. Despite the adoption of a combination of improved *tef* technologies obtained the greatest food security, it was affected by various determinants. A multivariate probit model and ordered probit models are used to analyze the determinants of a combination of improved *tef* technologies adoption and the number of technologies adopted.

The study identified formal schooling, larger household size for agricultural activities, sufficient resource endowments, and social networks are positively and significantly affected the household decision to adopt a combination of improved *tef* technologies. Resource endowments of smallholder farmers describe why some farmers adopt a combination of technologies, whereas others do not. The result verifies previous findings that noted that resource ownership influences the adoption of a combination of *tef* technologies by smallholders (Dejene and Bekele, 2015; Hassen et al., 2012). Membership of farmers in agricultural cooperatives has a substantial and beneficial influence on the number of agricultural technologies adopted. With limited or insufficient sources of agricultural knowledge and imperfect markets, social networks promote information exchange and enable farmers to access new technology on a timely basis and to resolve credit constraints. In these circumstances, membership in cooperatives and social networks may allow information to be shared, allow farmers to access market information, provide inputs, and address credit limitations. This claim is supported by previous conclusions that membership in agricultural cooperatives has influenced the adoption by smallholder farmers of a combination of technologies (Hailemariam et al., 2013).

Furthermore, access to extension services via frequent contact with DAs and strong confidence of farmers in the skills of DAs explains why, although others do not, some farm households adopt multiple agricultural technologies. This is primarily because DAs are the main source of agricultural information; they can easily persuade farmers to adopt multiple technologies and innovations if they have technical skills. Results in **Paper II** indicated that DAs with higher contacts with farmers are more likely to be good and to perform well in monitoring the adoption status of farmers, which can support this. In addition, farmers’ perception of economic return, and perception of farmers on participation in the extension service provision are positively and significantly affected the household decision to adopt a combination of improved technologies explains why some improved agricultural technologies are adopted by some farmers, while others do not. Previous studies have shown that there is a positive and important correlation between the adoption of multiple technologies and economic returns. Adequate economic returns from the use of a combination of technologies have given farmers greater opportunities to adopt improved technologies and gain a sustainable competitive advantage. It can also be said that the greater the economic return from the adoption of improved technologies, the greater the probability of encouraging farmers to adopt a combination of technologies.

The study further identified that the number of improved *tef* technologies adopted is positively associated with education, livestock ownership, farm size, cooperatives membership, access to credit, frequency of extension contacts, training, farmers' confidence with the skills of DAs, farmers' perception on economic return, and farmers' perception on participation in the extension service provision. While distance to nearby extension office and distance to the output market is inversely related. Overall, it was found that all categories of determinants had an impact on the adoption of single and the number of agricultural technologies. The relationship between significant variables and the adoption of multiple *tef* technologies implies that the food security status of smallholders' *tef* producers. Therefore, for effective interventions, attention is needed to those variables that influence the adoption decision of smallholders' *tef* producers. Distance to nearby extension office and distance to the output market; however, is inversely related to the number of improved *tef* technologies adopted.

6.3 Conclusion

The study was mainly designed to understand why the *tef* innovation system and extension were unable to transform smallholders' *tef* production so as to produce sufficient agricultural food production for ensuring household food security. In order to address this core objective, the study, in its first two papers, investigated the systemic constraints of the *tef* innovation system and assessed the performance of the agricultural extension system and factors explaining it. This is followed by measuring the impact of a combination of improved *tef* technologies on *tef* yield, household DES, HDDS, and FCS, and analyzed the factors that determined the household decisions to adopt a combination of technologies and the number of improved technologies adopted. To achieve these objectives, the study was used various econometric models and guided by Wiezcorek and Hekkert’s (2012) comprehensive framework that combines the structural and functional elements. The following conclusions were reached based on the research findings.

The study's findings show that structural analysis failures, as well as weaknesses in the innovation system's functions, have hampered the development of the *tef* innovation system and the *tef* sub-sector. The first paper of this thesis came up by identifying the systemic constraints of the *tef* innovation system in the studied *woredas*. Despite the importance of innovation in transforming smallholders’ production systems in the country, the *tef* innovation system and the sector development were constrained by several factors. The underdevelopment of the *tef* innovation system and the sector, in general, could be explained by the failures in structural elements and the weaknesses in innovation functions. Weaknesses in the structural elements would affect the well-functioning of innovation system functions. This means that a failure in one of the innovation system's functions will have a knock-on effect on other functions, resulting in a dysfunctional innovation system overall.

Results from research paper showed that performance of the extension and advisory services delivery significantly affected by different factors. This includes enabling environment and governance structure, linkages and partnerships among actors in *tef* R&D, organizational capacity, management and learning, and the extension and advisory services delivery methods. Given that, the study concludes that lack of reward and sanction schemes, lack of performance targets, weak supervision, lack of motorbikes for mobility, donor funding, interaction with key actors, and DAs capacity building training was more likely influenced the performance of the extension service delivery. Yet, the influence from limited involvement of DAs in planning, evaluation, and decision-making process, competitive salary, number of female DAs in the extension system, and lack of adequate facilities for FTCs should not be underestimated as they had a moderate effect on the performance of the extension service delivery.

In line with many previous studies, the study showed that the greater food security impact is achieved when farming households adopted in combinations rather than individually. Therefore, all relevant actors in the tef innovation system such as agricultural researchers, development agents, development practitioners, and policymakers should promote a combination of improved *tef* technologies as packages that can enhance household food security via increasing productivity and farm income. Despite such facts, the uptake of combinations of improved *tef* technologies was found to be low and limited to a few varieties due to various determinant factors. The study found that the household head's educational level, household size, livestock holding, cooperative membership, credit, extension contacts, and farmers' confidence in DAs' skills, perceptions of economic return, and perceptions of participation in extension service provision are the most important determinants of adoption of a combination of improved technologies. While the number of technologies adopted is also associated with education level, livestock ownership, farm size, cooperatives membership, credit, extension contacts, training, farmers' confidence with the skills of DAs, perception on economic return, perception on participation in the extension service provision. In addition to promoting the adoption of a combination of improved technologies for wider application, it needs various management skills for devising intervention strategies.

6.4 Implications

In this sub-section, in light of the discussion of the main research findings hereinbefore, some appropriate interventions recommended to tackling systemic constraints and associated factors of *tef* R&D, extension, and innovation systems. It has been recognized that the future direction of addressing those challenges to transform the *tef* production systems should focus on devising the intervention strategies. The interventions provided here are very important blueprints for planning, implementing, and monitoring the intervention programs that should target tackling the challenges of *tef* production systems in Central Ethiopia. Therefore, to transform the *tef* production system in general, and addressing the systemic constraints of *tef* R&D, tackling the associated factors that influence the performance of the extension system and the adoption of a combination of *tef* technologies need the following interventions.

Establish and strengthen multi-sectoral public-private partnership for greater effects

The innovation system needs strong public-pivate partnerships and the engagement of all key actors at various levels to diffuse the technologies developed. Demand-driven technology generation and adoption requires innovation system approach across the entire *tef* value chain, as well as a coordinated effort to encourage the uptake of improved technologies and the expansion of *tef* production. According to Klerkx et al. (2012), R&D must be effectively engaged with and interconnected to other relevant players in the innovation system to demonstrate and disseminate new technologies and innovations. The key challenge in the *tef* innovation system has been to address the widespread problem of interaction, partnership, and coordination. The study revealed the interactions and partnerships between key players in the *tef* innovation system are weak and therefore the adoption of improved technologies and innovations is limited. This weakness could be tackled by establishing and strengthening the existing multi-stakeholders platform like ADPLAC. Thus, comprehensive approaches that simultaneously address interrelated challenges along the *tef* value chain are required. A range of interventions aimed at facilitating multi-sectoral public-private partnership arrangements that could overcome the different constraints identified in *tef* value chains are emphasized here. Public-private partnership and enforcement of participatory approach arrangements could provide win-win solutions to the widespread interaction and coordination problems along the *tef* value chain. Such arrangements provide the opportunity to smallholders to access new technologies, agricultural information, credit, market, and entrepreneurship. Therefore, enhance the decision-making capacity of these networks, and adequate funds to assess their tasks, institutionalize them at all levels across the organizations and plan a long-term vision and strategy to consistently create synergy for greater impact across the various development actors.

Build a strong and dynamic performance-based management system for effective extension and advisory service delivery

Performance-based management system is a crucial system or process for managing organization employees using continuous communication and feedback. A good performance management system aims at improving those skills of your employees that can help them to do a better job. The presence and enforcement of reward and sanctions systems is an important indicator of an extension organizational performance. The entire success is dependent on how the organization motivates its extension personnel and how they evaluate performance for incentives or penalties. An extension system with a strong reward and sanction system and regular performance reviews can maintain and improve the extension and advisory service delivery. But, the lack of enforcement of rewards or sanctions impacts negatively on employees' performance. Therefore, for the continuous improvement of extension and advisory services delivery, build a strong and dynamic performance-based management system for monitoring, evaluation, and learning through rewaring and sanctions.

Strengthen *tef* R&D capacity to generate technologies demand-driven technologies

Lack of improved *tef* varieties resistant to lodging, acidity and waterlogged, and pre-and post-harvest technologies is still a major bottleneck for the *tef* producers. No breakthrough has been made so far, despite efforts to develop resistant varieties, and the level of production is still much lower than most other cereals. This could occur primarily because of limited research ability and adaptation of basic knowledge. These weaknesses could be remedied by increasing the number and quality of researchers, providing adequate public financing, and upgrading research infrastructure. Since tef is an endemic crop in Ethiopia, there is very little donor funding and advanced knowledge, so much is anticipated from domestic research. Therefore, all relevant actors in the *tef* value chain should strengthen research capacity and will allow researchers to do their job more efficiently and effectively in enhancing technology development to address the problems of lodging, acidity, waterlogging, and pre and post-harvesting losses.

Investing more in *tef* R&D to strengthen the tef innovation systems

Investments are becoming so critical in agricultural R&D to strengthen innovation. In doing so, NEPAD has formulated a consolidated regional development action plan for significant increases in national R&D budgets, with each country taking concrete steps to devote at least 1% of its GDP to R&D. However, the intensity of agricultural R&D investment in Ethiopia remains well below the 1% target and below the majority of the Sub-Saharan African average, and is one of the lowest in Africa. Similarly, *tef's* financial resource limitations are exacerbated by the fact that *tef* is an "orphan crop" and R&D funds are quite limited from international donors. The government must focus on filling this gap through public finance in order to complete the task at hand. To obtain funding commitments from donors and offer high attention and improve domestic research capacity for *tef* R & D, the government must also position *tef* as a priority crop through allocting sufficient finance.

Capacitating the skills of entrepreneurship, value addition, and market integration

Different contributing factors could be responsible for poor and limited entrepreneurial activities and added value. These include weak entrepreneurship skills and capacity, limited entrepreneur advisory services, weak public-private partnerships to support entrepreneurial activities, low aspirations, inadequate financial capital, and poor smallholder entrepreneurial capacity. These could be strengthened to strengthen entrepreneurship skills and boost aspirations through training and formal education. Establish platforms to strengthen public-private partnerships and improve the infrastructure for entrepreneurial activities and value addition activities. As *tef* is mainly grown in most of the country as a cash crop, particularly in the study areas, the output markets should be modernized and ICT-based to get premium prices for smallholder farmers. The output market system, however, largely depends on traditional methods. Strengthening the capacity and output of agricultural cooperatives and establishing contractual relationships between producers and agribusinesses could help address market constraints. Farmers need to get premium prices and business enterprises to receive quality products for entrepreneurial activities and added value, which will greatly improve productivity and income for farmers.

Promote adoption of multiple combinations of improved technologies as a package

When improved agricultural technologies are adopted in combination rather than in isolation, the greatest effect on food security is achieved. However, the rate of adoption by smallholder farmers of a combination of improved agricultural technologies is weak because of multiple factors that hinder the household's decision to adopt multiple technologies. It, therefore, requires attention to those factors that affect the decision to adopt a combination of the adoption of technologies. Therefore, all R&D actors should promote and increase awareness of the economic returns of the sustainable use of a combination of agricultural technologies as a package that can, by increasing productivity and farm income, increase household food security. In addition, it improves the availability and easy provision of rural finance, inputs, and market information through farmers' cooperatives and rural financial institutions.

6.5 Implications for future research

At a glance, this sub-section analyzes the implications of a wider understanding of systemic constraints in the *tef* R&D, extension, and innovation systems for future research. The study of the agricultural innovation system has recognized the role of each player in *tef* R&D concerning the development and wider application of improved *tef* technologies. It is very helpful to define the systemic barriers of *tef* R&D in Minjar Shenkora and Ada'a *woredas* by using a coupled structural-functional innovation system analysis framework. Future studies taking this system outcome into account could also help to determine whether Wiezcorek and Hekkert's (2012) comprehensive framework of the innovation analysis could be generalizable for smallholders in Ethiopia for other commodities and *woredas*.

The important challenge, given the results highlighted in the previous sections, is not only to improve innovations but also to understand the factors that hinder their adoption. Future research is that not only does it concentrate on developing new technologies, but also on examining wider sets of determining factors that have an impact on the adoption of shelved technologies by multiple technologies. The problem of interactions, collaborations, and coordination is an area where more policy analysis is required; both to better understand the conditions under which interactions and coordination problems are serious and to resolve the challenge with the best policy interventions.

Given the results highlighted in the preceding sections, the important challenge is not only developing technologies but also understanding the factors that impede their uptake. Future research is that it needs to focus on not only developing new technologies but also analyzing broader sets of determinant factors that have a bearing on multiple technology adoption of the shelved technologies. The interactions, partnerships, and coordination problem is an area where we need more policy research, both to better understand the conditions under which interactions and coordination problems are serious and on the best policy interventions to fix the challenge. This requires agricultural researchers and development practitioners to develop strategies of proactive engagement with key actors to influence policy. These need a shift from the development and demonstration of technology alone to social science research, such as promoting the provision of technological inputs and services and developing product markets. In future research, the use of integrated frameworks and a combination of quantitative and qualitative analysis could help to assess systemic barriers in the tef sector and suggest viable interventions to stimulate technological change in the country's agricultural sector.

One of the limitations of this study is that using smaller numbers of *tef* technology adopters from various combinations of technology packages and non-adopters, the adoption and impact of technologies are assessed. This could limit the generalizability across the population of the findings from quantitative models. Methodological limitations on adoption and impact based on neoclassical economic models could only be part of the challenges facing researchers in agricultural development. A practical challenge for applied researchers is how to make alternative approaches for adoption and impact evaluation understandable. Future studies dealing with unbalanced datasets of different technology adopters and non-adopters combinations and taking into account the impact of social, economic, and political factors underlying differential outcomes could therefore help validate whether the results of this study could be generalizable for most Ethiopian smallholder farmers.

6.6 References

ATA, MoA & EIAR (2015). Strategy to improve Ethiopia's National Agricultural Research System (NARS): Vision, systemic bottlenecks, strategic interventions and implementation framework, Addis Ababa.

Belay Kassa & Dawit Alemu (2017). Agricultural research and extension linkages: Challenges and intervention options. *Ethiopian Journal of Agricultural Sciences, 27*(1), 55-76.

Belay Kassa, Ranjan, S., Dawit Alemu, Abera Deresa & Jemal Yousuf (2012). Work motivation and job performance of development agents in Ethiopia. Rural Capacity Building Project Ministry of Agriculture, Addis Ababa, Ethiopia.

Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., & Mbabu, A. (2009). From Best Practice to Best Fit: A framework for designing and analyzing pluralistic agricultural advisory services worldwide. *Journal of Agricultural Education and Extension 15* (4): 341–355.

Birhanu Gedif, Tegegn Molla, Solomon Addisu & Yibeltal Ayenew (2016). Status of agricultural innovations, innovation platforms, and innovations investment. 2015 PARI project country report: Federal Democratic Republic of Ethiopia. In *Forum for Agricultural Research in Africa*.

Davis, K., Swanson, B., Amudavi, D., Mekonnen, D. A., Flohrs, A., Riese, J., ... & EliasZerfu (2010). In-depth assessment of the public agricultural extension system ofEthiopiaand recommendations for improvement. *International Food Policy ResearchInstitute (IFPRI) Discussion Paper*, 1041.

Desalegn Abo & Nuri Lefebo (2018). Factors influencing job performance of development agents: The case of Soro Woreda of Hadiya Zone, Southern Ethiopia. *European Journal of Business and Management*, *10*(1), 15-30.

Dejene Bayissa & Bekele Tassew (2015). Determinants of farmer's adoption of full extension package onimproved tef technology: the case of Dendi district, West Showa, Oromia Regional State, Ethiopia. *International Journal of Current Research, 7*(9), 20816-20821.

Gerba Leta (2018). *The Ethiopian Agricultural Extension System and Its Role as Development Actor: Cases from Southwestern Ethiopia* (Doctoral dissertation, Universitäts-und Landesbibliothek Bonn).

Gerba Leta, Girma Kelboro, Stellmacher, T., & Hornidge, A. (2017). The agricultural extension system in Ethiopia: operational setup, challenges and opportunities ZEF, Center for Development Research, University of Bonn Working Paper 158.

Guush Berhane., Catherine, R., Gashaw Tadesse, & Thomas Woldu (2018). The state of agricultural extension services in Ethiopia and their contribution to agricultural productivity. *ESSP Working Paper-Ethiopia Strategy Support Program*, (118).

Hailemariam Teklewold, Menale Kassie, Bekele Shiferaw, & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics, 93*, 85-93.

Hassen Beshir, Bezabih Emana, Belay Kassa & Jema Haji (2012). Determinants of chemical fertilizer technology adoption in North eastern highlands of Ethiopia: The double hurdle approach. *Journal of Research in Economics and International Finance*, *1*(2), 39-49.

Ifenkwe, G. (2012). Agent-related factors affecting the performance of agricultural extension staff in Abia State, Nigeria. *Journal of Agricultural Science, 3*(1), 45–48.

Kassahun Berhanu & Poulton, C. (2014). The political economy of agricultural extension policy in Ethiopia: economic growth and political control. *Development policy review*, *32*(2), 197-213.

Khalil, A., Ismail, O., Suandi, T., & Silong, A. (2009). Human resource development competencies as predictors of agricultural extension agents' performance in Yemen. *Human Resource Development International*, *12*(4), 429–447.

Lee, H. (2018). Tef, A rising global crop: Current status of tef production and value chain. *The open agriculture journal*, *12*(1), 185-193.

Manda, J., Alene, A. D., Gardebroek, C., Menale Kassie, & Tembo, G. (2016). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia. *Journal of Agricultural Economics*, *67*(1), 130-153.

Menale Kassie, Hailemariam Teklewold, Mareny, P., Moti Jaleta & Olaf, E. (2015). Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. *Journal of Agricultural Economics*, *66*(3), 640-659.

MoA (2020). Agriculture sector investment prioritization (2019/20-2024/25). Ministry of Agriculture, Addis Ababa.

MoANR (2017). Ethiopia's agricultural extension strategy: Vision, systemic bottleneck and priority intervention. Ministry of Agriculture and Natural Resources, Addis Ababa.

Poulton, C., Dorward, A., & Kydd, J. (2010). The Future of Small Farms: New directions for services, institutions, and intermediation. *World Development 38*, 1413-1428.

Ragasa, C., Ulimwengu, J., Randriamamonjy, J., & Badibanga, T. (2016). Factors affecting performance of agricultural extension: Evidence from Democratic Republic of Congo. *The Journal of Agricultural Education and Extension*, *22*(2), 113–143.

Tilaye Deneke & Daniel Gulti (2016). Agricultural research and extension linkages in the Amhara region, Ethiopia. In *Technological and Institutional Innovations for Marginalized Smallholders in Agricultural Development* (pp. 113-124). Springer, Cham.

Wieczorek, A. J., & Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Science and public policy*, *39*(1), 74-87.

Wubneshe Dessalegn, Zeller, M., & Loos, T. (2019). The impact of agricultural technologies on poverty and vulnerability of smallholders in Ethiopia. *Social Indicators Research*, *147*(2), 517–544.

Appendices

Appendix I: Questionnaire for Structured Household Survey

Dear Respondent

My name is Mekonnen Hailu, a PhD student at Addis Ababa University in the College of Development Studies, Center for Food Security Studies. The study intends to investigate agricultural research, extension and food insecurity in Ethiopia: what went wrong? You are one of the randomly selected from this *kebele* to participate in this research by answering the following questions. Hence, your responses are highly valuable, will be held in utmost confidentiality and, will be used only for the analysis of this research. For this purpose, you will not be identified by name. Therefore, be free to respond to all questions in the questionnaire. The interview may take about 1 hour. Thank you in advance for your cooperation!

I. Identification and Basic Information Regarding Household Head

S/N	Questions	Response	Code
1.	Household identification number		
2.	Enumerator’s name		
3.	Date of interview		
4.	Name of household head		
5.	Region	1. Amhara 2. Oromia	[ ]
6.	*Zone*	1. North Shewa 2. East Shewa	[ ]
7.	*Woreda*	1. Minjar Shenkora 2. Ada’a	[ ]
8.	*Kebele*	1. Denkaka 3. Adama 2. Golo-Dertu 4. Agirate	[ ]
9.	Family size	# ____________	
10.	Farming experience	____________ years	

II. Demographic and Socioeconomic Characteristics of Household Members

Family code	Name of Household Member (Start with household head)	Sex Codes A	Marital status (for above 15) Codes B	Age (years)	Education level Codes C	Religions Codes D	Relation to HH Codes E
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
01							
02							
03							
04							
05							
06							
07							
08							
09							
10							
11							

Codes A	Codes B	Codes C	Codes D	Codes E
0= Female 1= Male	0= Single 1= Married 2= Divorced 3= Widow 4=Separated 5= Polygamy	0= Illiterate 1= Read & write 2= Grade ____________ 3= Other ____________	1= Orthodox 2= Muslim 3= Protestant 4= Traditional 5= Others _______	1= Household head 2= Spouse 3= Son/daughter 4= Parent 5= Son/daughter in-law 6= Grand child 7= Other relative 8= Other ____________

III. Access to Agricultural Farmland

S/N	Question	Response Option	Code
1.	Do you have an access to farmland for practicing agriculture production?	0 = No (skip to Q2) 1 = Yes	[ ]
2.	If "yes" for Q1, what is the total farm plots cultivated during the year?	_________ ha	
2.1	Land (held)	_________ ha	
2.2	Rented in	_________ ha	
2.3	Rented out	_________ ha	
2.4	Got on Sharecropping basis	_________ ha	

S/N	Question	Response Option	Code
2.5	Freely got from a relative	________ ha	
2.6	Others, specify______________	________ ha	
3.	Have you rented out your farm plot to others during the cultivated year?	0 = No (skip to Q4) 1 = Yes	[ ]
4.	If "yes" to Q3, what are the reasons for rented out your land? (Multiple answers are possible)	1. Illness of household head 2. Unable to purchase farm inputs 3. Lack of draft power 4. Excess land 5. Shortage of labor 6. The head is aged & unable to work 7. Others (specify) _____________	[ ] [ ] [ ] [ ] [ ] [ ] [ ]
5.	Have you rented in the farm plot from others during the cultivated year?	0 = No (skip to Q6) 1 = Yes	[ ]
6.	If "yes" to Q5, what are the reasons for rented in the land? (Multiple answers are possible)	1. I have no land totally 2. I have land but not sufficient 3. I have land but degraded and infertile 4. To substitute fallowed land 5. Others (specify) __________	[ ] [ ] [ ] [ ] [ ]
7.	How do you plough your farm plots? (Multiple answers are possible)	1. Oxen plow 2. Tractor 3. Human labor 4. Ox pairing with other (Mekenago)	[ ] [ ] [ ] [ ]
8.	Did you get your land use certification?	0 = No 1 = Yes	[ ]

IV. Agricultural Technology Adoption and Extension Services

S/N	Questions	Response Option	Code
1.	Do you know where to find agricultural extension office in your *kebele*?	0 = No 1 = Yes	[ ]

S/N	Questions	Response Option	Code
2.	How far/long is the nearest agricultural extension office from your Village?	_______ km or take ________ min.	
3.	How long you have been participating in extension program?	__________ years	
4.	Have you advised by DAs during your agricultural practice for the last 12 months?	0 = No 1 = Yes	[ ]
5.	How many times have the DAs visited you in the past 12 months?	_________ times	
6.	How many times have you visited your nearest DAs in the past 12 months?	_________ times	
7.	Do you work according to DAs extension advice?	0 = No 1 = Yes	[ ]
8.	Do you know very well your DAs in your *kebele*?	0 = No 1 = Yes	[ ]
17.	Do you ask the DAs for advice, suggestions or ideas about you farm	0 = No 1 = Yes	[ ]
9.	Do you use the advice, suggestions or ideas given by the DAs?	0 = No 1 = Yes	[ ]
10.	Whom do you prefer to work with?	1= Male DAs 2 =Female DAs	[ ]
11.	Why do you prefer male/female DAs to work with?	_________________________________ _________________________________	
12.	Have you adopting improved technologies and knowledge (HYV, fertilizer, management practices) during the year?	0 = No (skip to Q13 and go to Q14) 1 = Yes	[ ]
13	If "yes" for Q12, which improved technologies were adopting during the year?.	1. Only HYV seed 2. Only fertilizer 3. Only management practices 4. Seed & fertilizer 5. Seed & management practices 6. Fertilizer & management practices 7. Full package	[ ] [ ] [ ] [ ] [ ] [ ] [ ]
14.	If "no" for Q12, what are your reason(s)? (Multiple answers are possible)	1. Land is fertile 2. Too expensive 3. Shortage of money to buy 4. Government did not give me on credit 5. Not easily available 6. I gave my land out to sharecroppers 7. I do not have knowhow to the benefit 8. Others (specify) _________	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]

S/N	Questions	Response Option			Code
15.	From where are you getting information on improved agricultural technologies? (Please rank them on a scale of 1 to 5, 1 as most important source and 5 as least important source)		Yes	No	Rank for yes
		1. Extension workers (DAs)	[ ]	[ ]	
		2. Co-farmers	[ ]	[ ]	
		3. Model farmers	[ ]	[ ]	
		4. Farmers Cooperatives	[ ]	[ ]	
		5. On Farm demonstration	[ ]	[ ]	
		6. Farm demonstration at FTC	[ ]	[ ]	
		7. Research centers	[ ]	[ ]	
		8. NGOs	[ ]	[ ]	
		9. Media/TV/Radio	[ ]	[ ]	
		10. Field day	[ ]	[ ]	
		11. Others(specify) ________	[ ]	[ ]	
16.	Do you use improved variety seed for your farm land?	0 = No (skip to Q17 and go to Q18) 1 = Yes			[ ]
17.	If "yes" for Q16, how much kilogram seed did you use per hectare?	_____________ kg			
18.	If "no" for Q16, what are your reasons? (Multiple answers are possible)	1. Seed unavailability			[ ]
		2. Unreliable yield			[ ]
		3. High cost			[ ]
		4. Labor intensive			[ ]
		5. Poor quality			[ ]
		6. Disease/Pest prone			[ ]
		7. High production cost			[ ]
		8. Others (Specify)_________________			[ ]
19.	Do you apply chemical fertilizer for your farm land?	0 = No (skip to Q20 and go to Q21) 1 = Yes			[ ]
20.	If "yes" for Q19, how much did you apply per hectare?	_____________ kg			

S/N	Questions	Response Option	Code
21.	If “no” for Q19, what are the reasons? (Multiple answers are possible)	1. Fertilizer unavailability 2. Unreliable yield 3. High cost 4. Labor intensive 5. Poor quality 6. Disease/Pest prone 7. I do not know how to apply 8. High production cost 9. Others (Specify)________________	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
22.	Do you apply pesticides for your farm land?	0 = No (skip to Q23 and go to Q24) 1 = Yes	[ ]
23.	If “yes” for Q22, how much did you apply per hectare?	_________liter	
24.	If “no” for Q22, what are the reasons?	1. Pesticide unavailability 2. Unreliable yield 3. High cost 4. Labor intensive 5. Poor quality 6. No disease/pest in the area 7. I do not know how to use 8. High production cost 9. Others (Specify)________________	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
25.	Do you implement raw-planting practices for your farm land?	0 = No 1 = Yes (skip to Q26)	[ ]
26.	If “no” for Q25, what are the reasons?	1. No information 2. Labor intensive 3. I do not know how to use 4. High production cost 5. Insignificant yield difference 6. Others (Specify)________________	[ ] [ ] [ ] [ ] [ ] [ ]
27.	Have you get any training to improve your farming knowledge during the year?	0 = No 1 = Yes (skip to Q28)	[ ]
28.	If “no” for Q27, what are the reasons? (Multiple answers are possible)	1. No DAs in our *kebele* 2. Inability or inefficiency of DAs 3. Unfair nomination 4. I don’t want to participate 5. Others (specify) _________________	[ ] [ ] [ ] [ ] [ ]
29.	In your opinion, do farmers in your *kebele* accessing sufficient extension services?	0 = No 1 = Yes	[ ]
30.	What is the nearest distance to the input		

S/N	Questions	Response Option	Code
	market from your home?	_____________ km	
31.	What is the nearest distance to the output market from your home?	_____________ km	
32.	What is your current status in adopting improved technology and management practice in your agricultural production system?	1. Started adoption recently 2. Adopting with increasing rate 3. Adopting with decreasing rate 4. Terminated adoption 5. Have a plan to adopt	[ ] [ ] [ ] [ ] [ ]
33.	In your opinion, what factors will facilitate your adoption of improved technologies and knowledge?	1. Availability of loan 2. Number of trainings offered 3. Frequency of visits by DAs 4. Technical support of DAs 5. Communication among farmers, DAs and researchers 6. Planning of activities between farmers and DAs 7. Others (specify) _________________	[ ] [ ] [ ] [ ] [ ] [ ] [ ]

V. Access to Credit

S/N	Questions	Response	
1.	Do you have enough finance to run your farm throughout a farming calendar?	0 = No 1 = Yes	[ ]
2.	Have you received loan for the agriculture production year?	0 = No (skip to Q3 and go to Q4) 1 = Yes	[ ]
3.	If "yes" to Q2, which are the sources of credit for your farming activity? (Multiple answers are possible)	1. Banks 2. Friend 3. Relative 4. Neighbor 5. Microfinance 6. Saving & credit association 7. Cooperatives 8. Other, Specify__________	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
4.	If "no" for Q2, what are the main reasons?	1. High interest rate 2. Lack of enough credit agent 3. Problem of timely affording the credit 4. Bureaucratic nature of the credit process	[ ] [ ] [ ] [ ]
5.	Do you think that the Government is doing	0 = No 1 = Yes	[ ]

S/N	Questions	Response	
	enough to make loan available to the farmers?		
6.	For what purpose do you use the loan? (Multiple answers are possible)	1. To buy agricultural inputs 2. To buy tools and equipment 3. To buy food 4. To pay tax or other debts 5. For other social rituals 6. To buy consumable 7. To pay for education expense 8. To pay for health expense 9. To start business activity 10. Others, specify ________	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
7.	Does the presence of this loan enhance your technology adoption?	0 = No 1 = Yes	[ ]
8.	Do the DAs encourage you to use loans to enhance your farm activity?	0 = No 1 = Yes	[ ]

VI. Off-farm Activities

S/N	Question	Response	Code
1.	Do you or any member of your family have engaged in off-farm activities	0 = No (skip to Q2) 1 = Yes	[ ]
2.	If "yes" for Q1, why do you or any member of your family have engaged in off-farm activities?	1. Own production not enough to feed my household 2. Increase the saving 3. Enhance the livelihood of the household 4. Other (specify) ____________	[ ] [ ] [ ] [ ]
3.	What is the total annual income from off-farm activities?	_______ birr	

4. Indicate the off-farm activities you or your families engaged and income generated **per month**.

S/N	Activities	**Who are engaged in** 1 = Husband 2 = Wife 3 = Son 4 = Daughter 5 = Other _____________	Income (Birr)
4.1	Daily Wage laborer in agriculture		
4.2	Daily Wage laborer in non-farm activities		

S/N	Activities	**Who are engaged in** 1 = Husband 2 = Wife 3 = Son 4 = Daughter 5 = Other ____________	Income (Birr)
4.3	Petty trades		
4.4	Sale of local Tela & Arake		
4.5	Sale of firewood		
4.6	Sale of charcoal		
4.7	Trading grains		
4.8	Trading livestock		
4.9	Fattening animals		
4.10	Others (specify) ___________		

VII. Livestock ownership

1. Do you keep/have livestock?

   0 = No (skip to Q 2)

   1 = Yes

2. If "yes" to Q1, state the number and types of livestock owned

	List of livestock	Number	List of livestock	Number
2.1	Oxen		Sheep	
2.2	Cows		Goats	
2.3	Bulls		Donkey	
2.4	Heifers		Horse	
2.5	Calves		Mule	

VIII. Agricultural extension services, productivity and household food security

S/N	Questions	Response	Code
1.	Do your farm productivity increasing after participating in the extension program?	0 = No (skip for Q 2) 1 = Yes	[ ]
2.	If "yes" for Q1, what is the productivity level of your tef production by comparing before participating in the program?	Before = _______ qt/ha After = _________ qt/ha	
3.	What was your expectation for participating in agricultural	1. To improve my food security status 2. To improve my farm production	[ ] [ ]

S/N	Questions	Response	Code
	extension program? (Multiple answers are possible)	3. To increase my farming profit 4. To improve farm sustainability 5. Other, specify _______________	[ ] [ ] [ ]
4.	Have you noticed any changes in your food security status after participated in extension program?	0 = No 1 = Yes	[ ]
5.	What is the main source of food for your household? (Multiple answers are possible)	1. Own production 2. Borrow 3. Food Aid 4. Remittance 5. Relatives/neighbors 6. Gifts 7. Purchase 8. Food for work	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
7.	Did you worry whether your farm production feeds your family until the next harvest?	0 = No 1 = Yes	[ ]
8.	How long it would stay sufficiently?	1. All round 3. 3 - 6 months 2. 6 - 9 months 4. < 3 months	[ ]
9.	How do you perceive your current food security status?	1. Food secures 3. Do not know 2. Food insecure	[ ]
10.	Who assisted you during the time of food shortage? (Multiple answers are possible)	1. Government food aid 2. Relatives 3. Remittance 4. Neighbors other than relatives 5. Others (specify) _________	[ ] [ ] [ ] [ ] [ ]

11. Indicate type and amount of crop production, reserved, consumed and total available stock in the household during the year (May 2018 – April 2019)

Crop Type	Total grain produced (kg)	Total grain purchased (kg)	Total grain obtained through aid (kg)	Total grain received through food for work (kg)	Total grain received through gift/ remittance (kg)	Total grain sold (kg)	Total grain given to others (kg)	Total grain used for social events (kg)	Seed reserve (kg)	Post-harvest loss (kg)
Tef										
Bread Wheat										
Durum Wheat										
Chickpea										
Lentil										
Maize										
Sorghum										
Faba bean										

12. Livestock and Poultry production and household food security during the year (May 2018 – April 2019)

Types of livestock product	Total livestock product produced (kg)	Total livestock product purchased (kg)	Sold livestock products (kg)	Received from relatives (kg)	Given to relatives (kg)	Used to social events (kg)
Meat						
Milk						
Egg						
Butter						
Cheese						

13. Vegetable and Fruits production and household food security during the year (May 2018 – April 2019)

Types of vegetables & fruits product	Total vegetable & fruit products produced	Total vegetable & fruit products purchased	Sold vegetable & fruit products	Received from relatives	Given to relatives	Used to social events
Onion						
Tomato						
Potato						
Banana						
Orange						

14. Indicate the type of food items available in your meal over the last 24-hours and 7 days

Household dietary diversity and food frequency

<table>
<tr><td rowspan="8">Food Item & Form</td><td rowspan="3">S/N</td><td colspan="8">Time of Meals</td></tr>
<tr><td colspan="2">Breakfast</td><td colspan="2">Lunch</td><td colspan="2">Dinner</td><td colspan="2">Others</td></tr>
<tr><td>Item</td><td>Form</td><td>Item</td><td>Form</td><td>Item</td><td>Form</td><td>Item</td><td>Form</td></tr>
<tr><td>1.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Others_____</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total No.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

- Food items can be cereals, pulses, vegetables, meat, etc.
- Form can be porridge, injera, bread, etc.

Food Consumption and Main Sources

15. Over the last week, how many meals did your household eat per day? ________
16. Over the last week, how many types of food groups did your household eat per day? _________
17. I would like to ask you about all the different foods that your household members have eaten in the last 7 days. Could you please tell me how many days in the past week your household has eaten the following foods?

Food Stuff	Number of days eaten in past week (0-7 days)	Main Sources of these Food
Injera (*teff*', wheat, maize, sorghum, rice, barley…)		
Bread (wheat, maize, …)		
Wat made from pulses (chickpea, peas, lentils)		
Oil (oil seed)		
Roots & tubers (potatoes, sweet potato etc.)		
Vegetables (cabbage, tomato, etc.)		
Fruits (orange, banana, mango, etc.)		
Meat (beef, chicken, etc.)		

Food Stuff	Number of days eaten in past week (0-7 days)	Main Sources of these Food
Egg		
Dairy products (milk, yogurt, cheese)		
Fish		
Butter		
Sugar, honey, jam		
Others (specify) ______________________________		

Main Source of Food Codes

Own production	1	Gift	3	Food aid	5
Purchase	2	Borrowed	4	Other (specify)	6

IX. Farmers perception towards extension services and technical knowledge of DAs

S/N	Questions	Response	Code
1.	Do you confidence with the technical skills and knowledge of DAs?	0 = No 1 = Yes 2 = Do not know	[ ]
2.	Have you gained any new skills and knowledge because of advices from DAs?	0 = No 1 = Yes 2 = Do not know	[ ]
3.	Do you find difficulty to contact DAs offering extension services in your *kebeles*?	0 = No 1 = Yes 2 = Do not know	[ ]
4.	Do the extension services provided to you solve your agricultural problems you faced so far?	0 = No 1 = Yes 2 = Do not know	[ ]
5.	In your opinion, what are the main barriers in using agricultural extension advices from DAs? (Multiple answers are possible)	1. Lack of trust in DAs 2. Lack of communication skills 3. Negative attitude of DAs 4. Information has not clearly presented 5. Lack of practical application 6. Others, specify _________`	[ ] [ ] [ ] [ ] [ ] [ ]
6.	What are the most pertinent constraints that you think that should be addressed to improve agricultural extension service delivery? (Multiple answers are possible)	1. Planning with DA and researcher 2. Number of trainings offered 3. Communication between DA & farmer	[ ] [ ] [ ]

S/N	Questions	Response	Code
		4. Number of DAs visit 5. Availability of funds 6. Other, specify ___________	[ ] [ ] [ ]

7. Indicate your level of agreement with (✓) whether your agricultural production system have been influenced by the adoption of improved technologies and knowledge.

1= strongly disagree; 2= disagree; 3= neutral; 4= agree; 5= strongly agree

	Items	**1**	**2**	**3**	**4**	**5**
7.1	Increase the level of farm production and productivity					
7.2	Improve the food consumption and food security status					
7.3	More income generated from agriculture production					
7.4	I got respect in my community after adopting technologies					
7.5	Built my own better house					
7.6	Save more money than before					
7.8	Diversifying my activities after adopting technologies					

8. Indicate your **perception about your DAs** with (✓) in your *kebele*.

1 = very low (very negative); 2 = low; 3 = neutral; 4 = high; 5 = very high (very positive)

	Your perceptions to your DAs	**1**	**2**	**3**	**4**	**5**
8.1	Technical competence of DAs					
8.2	Trustworthiness and credibility of DAs					
8.3	DAs status as compared to other professional in your *kebele*					
8.4	Your attitude towards your DAs					
8.5	DAs attitude towards you					

9. Indicate the advantages of DAs as perceived by farmers with (✓).

	Activities	**Yes**	**No**
9.1	Increasing farm management skills of farmers		
9.2	Increasing knowledge of farmers on agriculture production		
9.3	Helping to solve problems associated with agriculture production		
9.4	Changing the attitude of farmers		
9.5	Increasing farm-income of the farmers		
9.6	Increasing agriculture production and productivity		
9.7	Increasing bargaining power of farmers on agricultural markets		

10. Indicate the technical knowledge of DAs about the possible improved agricultural practices transferred to farmers, by putting (✓).

1 = strongly Disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly Agree

	Possible Improved Agricultural Practices	**1**	**2**	**3**	**4**	**5**
10.1	DAs advice about new improved varieties					
10.2	DAs advice on proper time for planting					
10.3	DAs advice on weed control methods					
10.4	DAs advice on pest control methods					
10.5	DAs advice on disease control methods					
10.6	DAs advice on irrigation practices					
10.7	DAs advice on fertilizer application					
10.8	DAs advice on harvesting practices					
10.9	DAs advice on post-harvest handling					
10.10	DAs advice through demonstration methods					

X. Farmers Satisfaction towards Agricultural Extension Services

11. Indicate with (✓) to your **level of satisfaction** with regard to the following statements with the current situation in your *kebele*.

1 = strongly dissatisfied; 2 = dissatisfied; 3 = neutral; 4 = satisfied; 5 = strongly satisfied

	Items	**1**	**2**	**3**	**4**	**5**
11.1	Your current level of production and productivity					
11.2	Extension service delivery to you and in your *kebele*					
11.3	Status and trends of agricultural technology adoption					
11.4	Overall farming level in your *kebele*					
11.5	Visibility of extension service in your *kebele*					
11.6	Number of training events you attended					
11.7	Quality of training events you attended					
11.8	Your technical competency in doing your farm work					
11.9	DAs competency in servicing farmers					

XI. Factors Influencing Farmers Perception and Satisfaction towards Extension Services

12. Factors influencing farmers' perception and overall satisfaction with regard to the following statements with the current situation in your *kebele/woreda* by putting (✓)

1 = Strongly Dissatisfied; 2 = Dissatisfied; 3 = Neutral; 4 = Satisfied; 5 = Strongly Satisfied

	Variables	**Items**	**1**	**2**	**3**	**4**	**5**
12.1	Perceived economic return	Agricultural production & productivity after receiving extension services					
		Agricultural income after extension services					
		Food self-sufficiency after extension services					
		Cash crop production after extension services					
12.2	Perceived packages appropriateness	The extension packages are need based					
		The extension packages are agro-ecology based					
		The extension packages are market based					
		The extension packages are helpful for food security					
		The extension packages are affordable by farmers					
		The availability & quality of inputs are good					
12.3	Perceived participatory nature of the extension services	The extension service is whole family based					
		Farmers participating in planning & implementation of the service					
		Farmers are participating in extension evaluation					
12.4	Use of multiple communication methods by DAs	Home visit					
		Farm visit					
		On farm demonstration					
		DAs office visit					
		Model farmers visit					
		Field day					
		Exhibition					
		Print media					
		Television/Radio					
		Telephone					

XII. Existing Linkages, Level of Linkages and Inhibiting Factors

S/N	**Questions**	**Response**	**Code**		
		Items	**Yes**	**No**	**Rank for Yes**
1.	What are the existing linkages among research-extension-farmers in your *woreda/kebele*? (Multiple answers are possible)	1. Field days 2. Planning & coordination meetings 3.	[ ] [ ] [ ]	[ ] [ ] [ ]	

S/N	Questions	Response	Code		
		Items	Yes	No	Rank for Yes
		n - farm demonstrations 4. Training workshops/seminar 5. PRA /survey 6. Informal personal contacts 7. Mass media (radio, TV) 8. Others, specify ____________	[ ] [ ] [ ] [ ] [ ]	[ ] [ ] [ ] [ ] [ ]	
2.	What are negative factors which inhibit the existing linkages among research-extension-farmer?	1. Low education level of farmers 2. Low income of farmers 3. Absence/weak farmers' organizations 4. Low knowledge in participatory approaches among extension workers 5. Low wages and lack of incentives for DAs 6. Weak extension services 7. Improper diagnosis of farmers' problems 8. Inadequate funds for linkage activities 9. Poor coordination between research and extension at all levels 10. Limited involvement of extension and farmers in technology development 11. Weak M & E system of transferred technologies 12. Poor input supply, credits markets and rural infrastructure like roads 13. Others (specify)_________	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]	

S.N	Variables	Items	Code

3.	In what aspects are research-extension-farmer linkages useful to your farming practice? (Multiple answers are possible)	1. Knowledge improvement among linkage partners 2. Technology adoption and dissemination 3. Collaboration and communication among partners 4. Others____________________	[ ] [ ] [ ] [ ]
4.	In your opinion, what is the existing linkage between farmers and extension workers (DAs) in your *woreda/kebele*?	1. High [ ] 2. Average [ ] 3. Low [ ]	[ ]
5.	In your opinion, what is the level of linkages between farmers and researchers in your *woreda/ kebele*?	1. High [ ] 2. Average [ ] 3. Low [ ]	[ ]
6.	In your opinion, what is the level of linkages among research-extension-farmers in your *woreda/ kebele*?	1. High [ ] 2. Average [ ] 3. Low [ ]	[ ]

Appendix II: Questionnaire for Development agents

I. Personal Characteristics of DAs

S/N	Questions	Response	Code
1.	Enumerator's code		
2.	Region	1 = Amhara 2 = Oromiya	[ ]
3.	*Zone*	1 = North Shewa 2 = East Shewa	[ ]
4.	*Woreda*	1 = Minjar Shenkora 2 = Adaa	[ ]
5.	*Kebele/PA*		
6.	Sex	0= Female 1= Male	[ ]
7.	Age	_____ years	
8.	Marital status	0 = Single 3 = Widow 1 = Married 4 = Separated 2 = Divorced 5 = Polygamy	[ ]
9.	Family size	# _____	
10.	Educational qualification (highest attained)	1 = High school 4 = First degree 2 = Certificate 5 = Second degree 3 = Diploma 6 = Third degree	[ ]
11.	Working experience on the current job	_____ years	
12.	Family background (place of birth)	1 = Urban setting 2 = Rural setting	[ ]

S/N	Questions	Response	Code
13.	Distance of work place from home	_____ km	
14.	Mode of transport from your work place to farmers (Multiple answers are possible)	1 = Walking 4 = Private transport 2 = Bicycle 5 = Government vehicle 3 = Motor cycle 6 = Others ________	[ ]
15.	Salary per month in birr	_______ birr	
16.	Accommodation (house)	1 = Rental 2 = Government quarter 3 = Own house	[ ]

II. Performance of individual development agents (DAs)

S/N	Question	Response	Code
1.	Does your organization have the performance targets?	0 = No 1 = Yes	[ ]
2.	Do you receive any capacity building trainings in the last 2 years?	0 = No 1 = Yes	[ ]
3.	Do you have linkage/interaction with other DAs in other *woredas/kebeles* for sharing the experiences?	0 = No (skip to Q4) 1 = Yes	[ ]
4.	In your opinion, what is the level of linkage/interaction between you and other DAs?	2. High 3. Average 4. Low	[ ]
5.	Do you have linkage/interaction with agricultural researchers around your working stations?	0 = No (skip to Q6) 1 = Yes	[ ]
6.	In your opinion, what is the level of linkage/interaction between you and researchers?	1. High 2. Average 3. Low	[ ]
7.	Do you disseminate at least one improved technologies and knowledge in your *kebele* in the last 2 years?	0 = No 1 = Yes	[ ]
8.	Do you monitor the promoted technologies and knowledge adopted by the farmers in the last 2 years?	0 = No 1 = Yes	[ ]
9.	Do you monitor the impacts of technologies and knowledge on farmers' livelihoods in the last 2 years?	0 = No 1 = Yes	[ ]
10.	What is the total number of motorbikes per staff in your working station?	________	

III. Factors for Work Motivation

1. Indicate the appropriate scale based on the following questions

1 = very discouraging; 2 = discouraging; 3 = neutral; 4 = encouraging and 5 = very encouraging

S/N	Indicators	1	2	3	4	5
1.1	Your achievement in terms of improving the food security status of farmers					
1.2	Opportunities for promotion or advancement that you have now.					
1.3	What is your recognition given by your superiors based on your efforts?					
1.4	Your physical working area and facilities of working.					
1.5	How do you describe the nature of your work itself?					
1.6	How do you describe your salary in relation to other organizations?					
1.7	Your supervisor's ability, availability and willingness to encourage and guide you.					
1.8	How do you describe your perception about the workload?					
1.9	Your degree of involvement in making decision affecting your work.					
1.10	Overall how motivated are you for working as a DA?					

IV. Performance of agricultural extension organization (AEO): FTC based

S/N	Question	Response	Code
1.	What is the number of DAs in each *kebeles* in your *woreda*?	________	
2.	Among those DAs, what is the share of female DAs in each *kebeles*?	_______	
3.	Does your organization have well-defined operational annual planning?	0 = No 1 = Yes	[ ]
4.	Does your organization have the performance targets?	0 = No 1 = Yes	[ ]
5.	Does your organization have strong regular supervision to support and following up DAs?	0 = No 1 = Yes	[ ]
6.	Does your organization receive any donor funding to support the extension service provision?	0 = No 1 = Yes	[ ]
7.	Does your organization have disseminated at least one improved technologies and knowledge in the last 2 years?	0 = No 1 = Yes	[ ]
8.	Does your organization have organized farm demonstrations to the farmers in the last 2 years?	0 = No 1 = Yes	[ ]
9.	Does your organization have produced and promoted training materials in the last 2 years?	0 = No 1 = Yes	[ ]
10.	What is the number (ratio) of motorbikes per staff in your organization?	________	

S/N	Question	Response	Code
11.	What is the proportion of DAs' time spent on getting to the field (%)	_______	

V. Linkages, Interaction and Partnership

1. Indicate the appropriate scale based on the following questions

   1 = very discouraging; 2 = discouraging; 3 = neutral; 4 = encouraging and 5 = very encouraging

S/N	Indicators	1	2	3	4	5
1.1	Does your organization have the rewarding system?					
1.2	Does your Organization enforce punishment?					
1.3	Do you have any interaction/linkage with other extension organizations (NGOs, development partners etc.)?					
1.4	Do you have any interaction/linkage with input suppliers?					
1.5	Do you have any interaction/linkage with buyers/traders?					
1.6	Do you have any interaction/linkage with research institutions?					
1.7	Do you have any interaction/linkage with farmers based organizations such as cooperatives, unions, rural institutions?					
1.8	Do you have any interaction/linkage with local political authority?					

2. Choose the appropriate number on the following questions

S/N	Questions	Answer	Code		
1.	What are the existing linkages among research-extension-farmers in your *woreda/kebele*? (Multiple answers are possible)	1. Field days 2. On - farm trials/Demonstrations/FTC plots 3. Training workshops/seminars 4. Planning and coordinating meetings 5. Informal direct personal contacts 6. Others (specify) _____________	[ ]		
2.	What are negative factors which inhibit the existing linkages among research-extension-farmer?	Items	Yes	No	Rank
		1. Poor coordination among actors	[ ]	[ ]	
		2. Low involvement of key actors in technology dissemination	[ ]	[ ]	
		3. Weak M & E system	[ ]	[ ]	
		4. No/inadequate funds	[ ]	[ ]	

S/N	Questions	Answer	Code	
		5. Low education of farmers 6. Low income of farmers 7. Weak farmers' organizations 8. Low knowledge in participatory approaches 9. Low wages /lack of incentives 10. Weak extension services 11. Improper diagnosis of farmers' problems 12. Untimely availability of input	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]	[ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
3.	Which method do you usually use to make contacts with farmers?	1. On farm visit 2. Farmer group meeting 3. Invite farmers to office 4. Farmers day 5. Telephonically 6. Combination of the above methods 7. Other (specify) ________________	[ ]	
4.	How often do you interact with your farmers?	1. Once a week 2. Once in two weeks 3. Once in a month 4. Once in three months 5. Other (specify) ________________		
5.	In what aspects is research-extension- farmer linkages useful to your work? (Multiple answers are possible)	1. Knowledge improvement among partners 2. Technology development 3. Technology dissemination 4. Technology adoption 5. Collaboration & communication among partner 6. Others (specify) ______________	[ ]	

VI. Constraints Facing DAs

1. Indicate the following constraints that you face during executing your extension services (the problems that face the most will be ranked as number 1)

S.N	Problems	Yes	No	Rank order
1.1	Lack of cooperation from other institutions with DAs	[ ]	[ ]	
1.2	Lack of coordination in executing extension activities among different stakeholders	[ ]	[ ]	

S.N	Problems	Yes	No	Rank order
1.3	Lack of sufficient agricultural inputs	[ ]	[ ]	
1.4	Timely availability of agricultural inputs	[ ]	[ ]	
1.5	Lack of credit for the farmers	[ ]	[ ]	
1.6	Illiteracy of farmers	[ ]	[ ]	
1.7	Lack of resources/facilities	[ ]	[ ]	
1.8	Lack of motivation of DAs	[ ]	[ ]	
1.9	Poor access to relevant information	[ ]	[ ]	
1.10	Lack of executive power of DAs	[ ]	[ ]	
1.11	Too many farmers to handle	[ ]	[ ]	
1.12	Too much work	[ ]	[ ]	

VII. Constraints of Farmers Training Centers (FTCs)

1. Which of the following constraints influencing the performance of FTCs in your working kebeles that you face during executing the extension activities (the problems that face the most will be ranked as number 1)

S.N	Problems	Yes	No	Rank order
1.1	Poor working facilities	[ ]	[ ]	
1.2	Lack of ownership	[ ]	[ ]	
1.3	Lack of long term vision	[ ]	[ ]	
1.4	Knowledge and skill gaps of DAs	[ ]	[ ]	
1.5	Limited capacity to organize trainings	[ ]	[ ]	
1.6	Inadequate incentives	[ ]	[ ]	
1.7	No reuse of internal revenues	[ ]	[ ]	

Appendix III: Checklist for Focus Group Discussions

- What are the major agricultural crops produced (cash crops and food crops)?
- What are the trends of agricultural production and productivity? Is it in increasing or decreasing or flat? What are the reasons for your answer?
- How can you say the rate of the farmers participating in agricultural extension program?

- Do you have any problem in accessibility and using of improved agricultural technologies?
- What is the status of agricultural technology adoption in your woreda/kebele? Are the majority of farmers in your kebele technology adopters or non-adopters?
- How can you say the level of adoption of combination technology adopters, individual technology adopters and non-adopter?
- Why farmers adopting a combination of technologies or individual technology or non-adopting?
- Have you noticed significant changes in your food security status after adopting technologies?
- Do you satisfied with the extension services DAs provided to you? If not, why?
- Have you got chance to discuss with researchers from research centers to the problems you faced? For how many times have you discussed with them in last year?
- How do researchers select farmers to participate on-farm demonstration? At what level do researchers engaged farmers in research?
- How can you evaluate the linkages and interactions among actors in agriculture sector (farmers, extension, research, NGOs etc.)?
- What are the factors affecting the linkages among research-extension-farmers?
- How can you evaluate the support of BoA and other government organization to solve your agricultural problems (timely availability of improved technologies, searching market for your agricultural produces, availability of credit etc)?
- Apart from government extension workers, are there any other organizations (NGOs) working and serving the farmers in your kebele?
- What is your overall satisfaction with the current extension services in your kebele?
- What are the strengths and weaknesses the existing extension system in your *kebele*?
- How do the extension services today compare to the past 10 or 20 years? What are the reasons for the difference? Is today better than yesterday?
- What are the statuses of output markets in your areas? Where did you sell your produce? Is there enough market for your agricultural produces?
- How do you perceive the food security situation of the farming households?
- How and when do you thing food become insecure in your kebeles?

- Do you have diversifying your food intake as much as you can?
- If not, what the main challenges you faced to diversify your food intake and pattern?
- What do you think are the socio-economic, climate change, and other factors of food insecurity in your areas?
- Generally, in your opinion what are the major constraints of the agricultural research and extension system in your areas?

Appendix IV: Checklist for Key-Informant Interview with researchers

- How is the government policy and strategy for researchers to conduct demand-driven research (including *tef*)?
- How is the salary, incentives, promotions and other benefits for researchers to conduct demand driven research in the country?
- How is the resource availability (human, financial, and physical) for national agricultural research and particularly *tef* research and development to undertaking the tasks?
- Do you think that relevant actors in research and development participating in developing and promoting new technologies and knowledge? At what stage of the research process do farmers are participating in *tef* research?
- How can you perceive the attention of the government and policy makers for agricultural research, particularly *tef* research?
- Major initiatives made by the *tef* research to strengthen the linkages among relevant actors particularly, research – extension – farmer linkages.
- Current performance of research – extension – farmer linkages federal, zonal and woreda levels
- Involvement of NGOs, farmer organizations, private sectors and other key actors in linkages at different levels
- What are the factors which affect linkage of researchers with farmers?
- What are the main challenges of research system to develop demand-driven and market-oriented improved technologies and knowledge?
- How often to interact to farmers to identify researchable ideas and to support them?

- How can you evaluate the adoption status of *tef* improved technologies and knowledge in the study woredas/kebeles?
- Do you believe that the released *tef* technologies and knowledge is sufficient for all technology users?
- All the release technologies and knowledge including *tef* popularized and diffused to the farmers adequately or rather shelved?
- How can you evaluate the impact of agricultural research and *tef* research for the overall agricultural modernization and development?
- How can you also judge the contribution of *tef* research for productivity?
- What are the trends of agricultural productivity in your woreda/kebele? What is the trend of *tef* productivity as compared to other cereals?
- What are the constraints of agricultural research and *tef* research and development in Ethiopia and in the study areas?

Appendix V: Checklist for Key-Informant Interview with DAs

- What are the trends of agricultural production and productivity in your woreda/kebele? Is it in increasing or decreasing or flat trend? What are the reasons?
- What are the most serious agricultural problems in your areas? How do you solving these problems?
- Do you think that households in your areas have a problem of food security? How would you characterize the extent of the problem? What are the major causes of food insecurity?
- What are the main sources of improved agricultural technologies for the farmers?
- What factors influence farmers' access and use improved technologies and knowledge?
- Do you have Farmer Training Centre (FTC) in your kebele? What are the problems of FTCs?
- What are the strengths and weaknesses of the existing extension system in your woreda?
- How do extension activities today compare to the past 10 – 15 years? What are the reasons for the difference? Is today better than yesterday? What are the reasons for lack of sustainability?
- How is the collaboration and linkages among the different stakeholders that involved in the extension system?

- What are the status and trend of improved agricultural technologies and knowledge adoption (improved seed, fertilizer, management practices) in your woreda/kebele? Indicate the trend with the actual data in your kebele.
- What are the major challenges of farmers related to improved technology and management practices adoption in your kebele?
- Do you think that the farmers in your kebele accessing sufficient agricultural technologies and management practices?
- Do you think that the Government is doing enough to make loan available to the farmers for purchasing agricultural inputs in your woreda/kebele?
- How is the economic power of farmers to purchase new agricultural technologies to improve their lives?
- What is the motivation level of DAs towards their present job? What are the constraints of DAs to fulfill their prescribed job tasks?
- Are the incentives to DAs for good performances satisfactory? If not, what is to be done?
- Describe main factors which affect work motivation of DAs according to your perception.
- What are your suggestions to improve work motivation, and job satisfaction of DAs?
- Do you believe that the extension system doing enough for developing and modernizing the agriculture sector?
- Do you believe that the extension system adequately supported the farmers to produce sufficient agricultural production and ensuring food security?
- In your opinion, do the research system developed demand-driven agricultural technologies?
- In your opinion, what are the impacts of agricultural technologies generated so far in terms of increasing productivity and enhancing food security for the rural farm households?
- How is the resource availability (human, financial & physical) for the extension works to disseminating extension services?
- Do you know very well the existing agricultural extension strategy? How can you evaluate the contribution of the strategy for the overall agriculture?

Appendix VI: Checklist for Key-Informant Interview with DA Supervisors/Offices

- Total number of farm households and number of kebeles in your woreda/kebele
- Number of farmers versus per capita land holding
- What are the main problems of the farming community in this woreda related to agricultural food production?
- How do you see the role and contribution of other local institutions organized to support the agriculture activities?
- How do you support and encourages the farming community in your woreda and kebeles to undertaking their agricultural production?
- The food security situation and the extent of food insecurity in your woreda/kebele? The causes of food insecurity in your woreda/kebele?
- Status of agricultural activities in your woreda
- The major agricultural crops produced in your woreda/kebele (cash crops and food crops)
- What are the trends of agricultural production and productivity in your woreda/kebele? Is it in increasing or decreasing or flat trend? What are the reasons?
- The adoption status of improved agricultural technologies and knowledge (improved seed, fertilizer, management practices) in your woreda/kebele?
- The sources of improved technologies (extension, research, unions, cooperative, NGOs etc)
- Does the majority of farmers in your woreda/kebele adopting full technology packages or single technologies?
- Do farmers have problems accessing input and outputs markets in terms of time, distance, or transportation available? What are the major challenges?
- What are the major challenges related to technology adoption in your woreda/kebele?
- Do the farmers in your woreda/kebele satisfied with the agricultural extension services they received currently? If not, why?
- Do you think that your DAs in your woreda/kebele have technically fit to solve farmers' problems? If not what should be done in future?
- What are the constraints of the agricultural extension system in your woreda/kebele?
- Are you working with agricultural research system to solve the farmers' problems?

- What are the level of collaboration and linkages among research-extension-farmers? What are the factors affecting the linkages?
- Does your woreda/kebele have enough Farmer Training Centre (FTC)? What are the major problems of FTC in the woreda/kebele?
- Apart from government extension workers, are there any other organizations (NGOs) working and serving the farmers in your woreda/kebele?
- How is the resource availability for extension works to disseminate technology?
- What is the number of DAs currently on job with their professional streams?
- What is the rate of turnover of DAs for the last five years and their associated reasons if known?
- What is the number of DAs promoted to higher positions in the last five years?
- What are the performance assessment reports of DAs at different levels?
- Do you have the criteria for promoting DAs to higher positions?
- How can you express the reward mechanisms of DAs for good performances?
- What are your criteria for selecting to trainings, higher studies, and other official engagements?
- What are the supervision and support mechanisms for the functioning of DAs?
- What are the main reasons for current level of motivation according to perception?
- Have there been any noticeable trends during the last 5 years in the overall level of DAs job satisfaction and motivation in your organization? Give reasons
- What are you currently doing to improve the work motivation of DAs in your woreda/kebele?
- What are your suggestions to improve work motivation, and job satisfaction of DAs, and to retain them on the job?
- What is your future plan to tackle agricultural problems?
- Do you have any additional comments concerning agricultural research and other relevant actors in the agriculture sector?

Appendix VII: Checklist for Key-Informant Interview with Farmers

- The food security situation and the extent of food insecurity in your woreda/kebele? The causes of food insecurity in your woreda/kebele?
- You and your household engaged in non-farm activities? If yes, why you engaged in? Does your agricultural produce not enough foe you household?
- Status of agricultural activities in your woreda
- The major agricultural crops produced in your woreda/kebele (cash crops and food crops)
- The trend of improved agricultural technologies and knowledge adoption (improved seed, fertilizer, management practices) in your woreda/kebele? Is there shortage or surplus in your woreda/kebele? Indicate the trend with the actual data
- What are your agricultural related problems in your kebele?
- Agricultural extension problems/constraints (in terms of capacitating farmers, demonstrating agricultural technologies etc) in your woreda?
- Do the farmers in your woreda/kebele satisfied with the agricultural extension services they received currently? If not, why?
- Agricultural research problems/constraints (in terms of availability of different HYV, pest resistant varieties etc) in your kebele?
- Do you think that your DAs in your woreda/kebele have technically fit to solve farmers' problems? If not what should be done in future?
- What is the number of DAs currently on job with their professional streams?
- The major challenges of agricultural technology adoption in your woreda/kebele?
- Accessibility of input and outputs markets in terms of distance, transportation, timely available? What are the major challenges?
- What are the level of collaboration and linkages among research-extension-farmers? What are the factors affecting the linkages?
- Does your woreda/kebele have enough Farmer Training Centre (FTC)? What are the major problems of FTC in the woreda/kebele?
- Apart from government extension workers, are there any other organizations (NGOs) working and serving the farmers in your woreda/kebele?

Appendix VIII: Measurement

Household Food Balance Model (HFBM)

The NAF for the households was computed using a Mathematical Equation known as Household Food Balance Model, which is originally adapted by Degefa (1996) from FAO Regional Food Balance Model and thenceforth used by different researchers in the field of food security to calculate the per capita food available. The conversion of the net available food into dietary calorie equivalent was based on Ethiopian Health and Nutrition Research Institute's food composition table. The calculated per capita calorie was finally compared against the recommended minimum daily caloric requirement for a moderately active adult (2100 kcal) to look into the dietary caloric status of the households in the study area. In other words, the NAF was compared against 2.25quintals (225 Kgs), which is roughly cereal equivalent of the recommended average daily kilocalorie of 2100 for a healthy adult person.

$$\mathbf{NAF = (GP + GB + GG + MP + DP + VP) - (HL + SR + GS + GO + SE)} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where;

NAF = Net available food (quintal/household/year) during the year

GP = Total grain production (quintal/household/year) during the year

GB = Total grain bought (quintal/household/year) during the year

GG = Total grain received through gift (quintal/household/year) in the year

MP = Meat, meat based products and poultry (kilogram/household/year) during the year

DP = Dairy and dairy based products ((kilogram/household/year) during the year

VP = Vegetables and fruits based product (quintal/household/year)

HL = Post harvest losses due to grain pests, disasters, thievery (quintal/household/year)

SR = Quantity of grain reserved for seed (quintal/household/year) during the year

GS = Amount of grain sold (quintal/household/year) during the year

GO = Grain given to others within a year (quintal/household/year) during the year

SE = Given to social events within a year (quintal/household/year) during the year

Household Dietary Energy Supply (DES)

Dietary energy analysis is an important indicator of food adequacy level and food security status of the household. It is the per capita dietary energy supply measured in calorie. It provides the average daily food available for each person in a country or region (FAO, 1998) and used to comprehend the average dietary calorie in a given area. As a result, rough classification of households into food secure and food insecure with a threshold value of 2100 kcal. In fact, it should be noted that this technique fails to make out the intra-household variations in food security. This is because the analysis of the available dietary energy depends on the average value though the amount of calorie a person requires depends on his or her sex, age, body weight, health condition and physical activity. The average value helps to simplify the complexity that arises while analyzing the available daily dietary energy supply of a household. Accordingly, the available food source supply was converted into its equivalent calorie using EHNRI's food composition table.

Household Dietary Diversity Score (HDDS)

The Household Dietary Diversity Score (HDDS), which was initially developed as an indicator of the food access dimension of household food security, is defined as the ability to acquire sufficient quantity and quality of food to meet the nutritional needs of all household members for a productive life. Thus, despite the indicator's name, it was originally intended to be a measure of both the amount and quality of food access, and the 12 food categories (for the origin of the set of food groups) included in the HHDS represent a combination of both. Simple scores have thus been created to assess dietary diversity at the household or individual level in situations when resource constraints preclude the use of extensive dietary assessment methods such as direct weighing or 24-hour eating recall. Dietary diversity scores are calculated by taking a basic count of the items or food groups ingested over a given time period, which is commonly 24 hours. Based on their food security status, households can be classified as having low, medium, or high dietary diversity.

- Low dietary diversity: When households consume less than or equal to three food groups
- Medium dietary diversity: When households consume four to six food groups
- High dietary diversity: When households consume seven or more food groups

Tabulation of the HDDS is a relatively simple matter that can be done by hand or with the aid of computer software such as a database or spreadsheet. First, the HDDS variable is calculated for each household. The value of this variable will range from 0 to 12.

HDDS (0-12) = Total number of food groups consumed by members of the household. Values for A through L will be either “0” or “1”.

Sum (A + B + C + D + E + F + G + H + I + J + K + L)

Second, the average HDDS indicator is calculated for the sample population.

Average HDDS = Sum (HDDS) ÷ Total Number of households

Food Consumption Score (FCS)

Household food consumption pattern can be measured by a FCS, which is based on a recall of food groups eaten in the seven days preceding the moment of interview. The food consumption score is calculated by examining the number of times certain food groups are consumed in the seven days preceding the survey and then by weighting them by approximate nutrient density values. The cutoff points recommended by the WFP (2009) to define poor, borderline, and adequate food consumption groups should be determined based on a country’s consumption behavior. If there is frequent consumption of oil and sugar in a given country, a threshold will be raised. In the study areas and in the Ethiopian context in general, frequent consumption of oil and sugar is very common. Thus, for the sake of analysis, the respondents were classified into three groups using 28 and 42 as thresholds to define:

- Poor food consumption: When household food consumption score (≤ 28)
- Borderline food consumption: When household food consumption score (28.5 - 42)
- Acceptable food consumption: When household food consumption score (> 42)

Food Groups and Weights

No.	Food Items	Food Groups	Weight
1.	Cereals: *Teff*, maize, sorghum, millet, other cereals Tubers: Cassava, potatoes and sweet potatoes	Staples	2
2.	Pulses	Pulses	3
3.	Vegetables	Vegetables	1
4.	Fruits	Fruits	1
5.	Meat and egg	Meat and egg	4
6.	Milk/milk products	Milk	4
7.	Oil/fat	Oil	0.5
8.	Sugar	Sugar	0.5

Source: WFP, 2008

$$FCS = A_{staples} X_{staples} + A_{pulses} X_{pulses} + A_{vegetables} X_{vegetables} + A_{fruits} X_{fruits} + A_{meat} X_{meat} + A_{milk} X_{milk} + A_{oils} X_{oils} + A_{sugar} X_{sugar}$$

Where FCS = Food consumption score

A_i = Weight of each food group

X_i = Frequencies of food consumption = number of days for which each food group was consumed during the past 7 days

Appendix IX: Multicollinearity Test

Explanatory Variables	Collinearity Statistics		Eigenvalue
	Tolerance (1/VIF)	VIF	
SEX	0.859	1.164	14.267
AGE	0.390	2.563	1.061
EDUCATION	0.841	1.189	1.045
EXPERIENCE	0.668	1.496	.914
DIS_WORK	0.390	2.566	0.660
ACHIEVEMENT	0.720	1.389	0.644
REWARDING	0.849	1.178	0.488
PERF_TARGET	0.480	2.084	0.382
TRAINING	0.780	1.282	0.303
MOTORBIKE	0.815	1.227	0.241
FACILITY	0.830	1.205	0.221
JOB_SATISFACTION	0.757	1.322	0.212
COM_SALARY	0.594	1.683	0.128
SUPERVISION	0.316	3.161	0.106
CONTACTS	0.607	1.646	0.101
WORKLOAD	0.906	1.103	0.073
BEING_INVOLVED	0.305	3.277	0.063
INT_OTHERS_DAs	0.417	2.397	0.040
INT_RESEARCHERS	0.691	1.448	0.030