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Analysis on adoption of sorghum innovation technologies in the tehuledere District, Eastern part of the Amhara National Regional State, Ethiopia

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Abstract
For Ethiopia's diverse agro-ecological zones, numerous open-pollinated and hybrid sorghum varieties have been released because of national and regional sorghum improvement research projects. Despite this fact, there is a persistent concern that technological advances for sorghum productivity enhancement have not been realized to the extent it could. In Ethiopia, sorghum production is constrained by biological, social, and abiotic constraints. The objective of the study was to analyze the adoption of sorghum technologies (Improved Seeds, Ferilizer, Irrigation) in the Eastern part of the Amhara region. The research used both descriptive research and explanatory research methodologies. Systematic random sampling method was used to select to select the 297 heads of household from the list of female-headed households and male-headed in each kebele. Data was collected through a structured questionnaire administered to sampled farmers. The survey covered a detailed community, household, and plot-level information. Households' demographic, institution and socioeconomic features were also collected. The data was collected using computer-assisted personal interview (Kobo Toolbox); then data were exported to and analyzed using SPSS and STATA. Descriptive test statistics and econometric methods were applied to analyze the data collected from smallholder household heads. Descriptive analyses were used to describe and analyze the household-level characteristics, including demographic, socioeconomic and institutional characteristics of the household. The factors explaining adoption of technologies (improved seeds, irrigation, fertilizer) and the intensity in sorghum production were analyzed using Logit, and Tobit models. The results indicated that demographic, socio-economic, and institutional factors have significant effect in the adoption of Sorghum Innovation Technology, and intensity in sorghum production among the farmer households in the study area. The analysis of Sorghum improvement project in the Eastern Amhara region, hence, underscores the need for holistic approaches that could consider the socio economic, environmental and technological dimensions of Agricultural development.

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Keywords: Sorghum improvement project, innovation system, value chain analysis, value chain actors', Tehuledere, Eastern Amhara Region, Ethiopia

1. Introduction

Ethiopia is believed to be center of origin and diversity for sorghum with the existence of a tremendous genetic (Bekele, 2017, Seyoum *et al*., 2019) [25, 124] diversity both in the cultivated as well as the wild relatives (Tadesse *et al*., 2008, Adugna and Bekele, 2013, Doggett, 1991) [132, 6, 40] Ethiopia ranks first among countries that have contributed germplasm collections to the world collections of sorghum (Ayana *et al*., 1999) [18] For example, among 35,643 and 40,477 sorghum accessions found in International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and US National Plant Germplasm System (NPGS) gene banks, Ethiopia's contribution is about 4,464 (12.5%) and 7,080 (17.5%) accessions respectively in the respective gene banks. (Dahlberg *et al*., 2020) [37] From these diverse genetic resources, the Ethiopian sorghum research system developed a large number of varieties that have various capacities in production.

Ethiopian sorghums have been a great source of novel genes and valuable traits for improving the sorghum crop worldwide (Seyoum *et al*., 2019, Menkir *et al*., 1984, Singh and Axtell, 1973, Gebrekidan and Kebede, 1977, Kebede, 1991, Habyarimana *et al*., 2004) [124, 90, 128, 49, 78, 57].

Sorghum is believed to have originated in Ethiopia as evidenced by the early history of domestication of the crop (Bekele, 2017, Seyoum *et al*., 2019, Yali Kebbede, 2021, Adugna *et al*., 2013, Adugna and Tesso, 2008) [25, 124, 150, 6, 8]. Sorghum takes a share of 18% of the area covered by cereals and 14.6% of the area covered by grain (FDRoE, 2017) [45] It is also the third most important crop after tef and maize and second next to maize in terms of total volume of production. The national average yield is 2.71 tons/ha. The crop has recorded a substantial increase in both area and production over the past two decades.

Ethiopia, in contrast to other African countries, presents a somewhat varying experience as regards to the emergence and evolution of its national agricultural research system. The vision of sorghum improvement research is to become a leading sorghum research program in generating high-quality information, knowledge, and technologies that could contribute to improved livelihoods and sustainable development. (Fetene *et al*., 2011) [47]. The mission is to generate, adapt, and promote sorghum production technologies by enhancing the technology-generating efficiency using modern techniques and enhancing the capacity of the program, and strengthening the linkage of all actors involved in the value chain. (Tonapi *et al*., 2020) [138]

The goal of Ethiopian sorghum improvement research is to increase the productivity and production of sorghum through the development and deployment of improved sorghum technologies for enhanced livelihood and sustainable development.

Sorghum research programs deal with different aspects of productivity development among which a variety of development and technology scaling up were the prominent aspects considered. There was no doubt that developed seed is an important background source input for getting other component technologies to farmers. Germplasm conservation and collections from the national sorghum research program, the Ethiopian Institute of Biodiversity, and the acquisition and introduction of genetic materials from international sources such as ICRISAT were all sources of variation for the genetic enhancement of sorghum in Ethiopia.

Farmers of sorghum in Ethiopia were suffering challenges of climate change, with droughts being particularly problematic. As a drought-resilient crop, sorghum has been grown by 4.3 million households across the country and about 297 households in the study area. Yet yields remain low due to a lack of varieties adapted to local soil conditions. The average yield obtained in the study was recorded as 2.5 MT/ha which is below the product potential yield. Furthermore, productivity was worsened by a lack of post-harvest processing machinery, inadequate storage solutions, and weaknesses within the sorghum value chain. These factors not only constrain farmers' income, but also increase time spent on laborious farm tasks, such as threshing and de-hulling, particularly among women and children, who were most involved in post-harvest processing.

By developing and deploying key technologies, researchers involved in the sorghum improvement project were working to reduce the risk of crop failure, increase productivity, and create new economic opportunities for women-led businesses. The technologies included drought-tolerant sorghum varieties, improved management practices, small-scale technologies warehouses, small-scale farm-scale grain storage systems, value-added sorghum products, and had linkages with new markets.

Innovations were considered as critical players in the agriculture sector in the development of the country's economic growth. They were seen as to bring about productivity, competitiveness, quality, and efficiency to farm Agricultural enterprises. Innovation was key to increasing the capacity and creating a competitive advantage for small-scale Agri- pruners since it enabled them to present a new or improved product to the market thus increasing their market share. Accordingly, innovation was a strategy that enabled Agri-pruners to create long-term competition by gathering knowledge, and experiences in creating and developing Agri-enterprises, using technology skills, and introducing new ideas in form of product innovation, market innovation, or business model innovation. Moreover, Production and market innovations were crucial to increasing agricultural productivity for food security and income, especially in developing countries.

The research and technology development were required but constituted only part of the innovation process. The key challenge in most successful cases of innovation has not been the creation of new inventions but the adaptation and use of existing ones. The shift from thinking about research as being the central actor in an innovation system to being one important part of the system has implications for researchers and research systems.

The present study on sorghum in the eastern part of the Amhara region of Ethiopia stems from a hypothetical view that non-adoption of sorghum technologies in the study area is a result factors related to the circumstances of the farmers, markets, and the environment. The research, therefore, addressed the determinants of improved sorghum technologies adoption and intensity in the study area.

Adoption is a process involving at least two interrelated decisions. The first adoption decision is the choice of whether to adopt a given technology or not. The second decision is the Intensity of adoption, the choice of how much land to allocate for improved sorghum variety. Adoption in this study is defined as the use of improved sorghum varieties. Adoption can be measured in terms of the number of persons who adopt the technology (adoption rate) or in terms of the total area on which the technology is adopted (adoption intensity).

Literature Review

Concepts of Innovation Systems

Authors in different literatures have defined the term innovation differently (Lundvall and hope, 2016, OECD., 2018) [84, 108]. Freeman, 1982 defined innovation as '…the technical, design, manufacturing, management and commercial activities involved in the marketing of new (or improved) product or the first commercial use of a new (or improved) process or equipment' (Rothwell and Management, 1992) [119]. However, Rothwell (1992) [119] reminded that innovation is not always about radical change 'innovation does not necessarily imply the commercialization of only a major advance in the technological state-of-the art but it includes also the utilization of even, small scale changes in technological know-how'. The simplest definition is 'anything new introduced into an economic or social process' (OECD., 2018) [108]. The most useful definition of innovation

in the context of R&D is 'the economically successful use of invention (Bacon and Butler, 1998) [20]. Here invention is defined 'as a solution to a problem'.
An innovation system is the group of organizations and individuals involved in the generation, diffusion, adaptation and use of new knowledge and the context that governs the way these interactions and processes take place. In its simplest, an innovation system has three elements: the organization and individuals involved in generating, diffusing, adapting and using new knowledge; the interactive learning that occurs when organizations engage in these processes and the way this leads to new products and processes (innovation); and the institutions (rules, norms and conventions, both formal and informal) that govern how these interactions and processes takes place (Horton, 1990) [67]. People working on similar issues, be it in a specific commodity sector, at a particular location or in any problem area tend to form a chain or network that can be described as innovation system. An innovation system can be defined at different levels: national, sectoral, commodity and intervention based.
National innovation system (Legwaila *et al*.) is defined (Bank, 2012) [23] as a set of functional institutions, organizations and policies that interact constructively in pursuit of a common set of social and economic goals and objectives, and that uses the introduction of innovation as the key promoter of change. At (Roseboom, 2004a) [117] its simplest, this concept states that innovation emerges from evolving systems of actors, their interaction and processes that are involved in research and the application of research findings for socioeconomic benefit. A NIS concept will allow better understanding of the governance, resource allocation and outcomes in the short, medium and longer term. The concept of NIS is a generic concept, which has three components: the knowledge domain, business domain and the environment.

Agricultural Innovation System

A collaborative arrangement bringing together several organizations working towards technological, managerial, organizational and institutional change in agriculture can be called 'Agricultural Innovation System'. Such a system may include the traditional sources of innovations (indigenous technical knowledge); modern actors (NARIs, IARCs, advanced research institutions); private sectors including agro-industrial firms and entrepreneurs (local, national and multinationals); civil society organizations (NGOs, farmers and consumer organizations, pressure groups); and those institutions (laws, regulations, beliefs, customs and norms) that affect the process by which innovations are developed and delivered.
NIS, a typical generic AIS incorporates a complete system of diverse agents whose interactions are conditioned by formal and informal socioeconomic institutions. AIS concept focuses on the totality of actors needed to stimulate innovation and growth and emphasizes the outcomes of knowledge generation and adoption. The framework captures not only the influence of the market forces, but also the impacts of organizational learning and behavioral change, non-market institutions and public policy processes (Bank, 2012) [23]. It also highlights the importance of framework conditions and linkages to other sectors and the broader science and technology community both within and outside the country. It is also important to note that this framework explicitly integrates the value chain concept. AIS perspective provides a means of analyzing how knowledge is exchanged and how institutional and technological change occurs in a given society by examining the roles and interactions of diverse agents involved in the research, development and delivery of innovations that are directly or indirectly relevant to agricultural production and consumption. It is also important to note that the agricultural innovation system concept has a broader perspective than the concept of agricultural research system.
According to Clark (2002) [34] the AIS concept recognized: (Clarke and Turner, 2002) [34]

- That the innovation process involves not only formal scientific research organizations, but also a range of other organizations and other non-research tasks. The importance of linkages, making contracts, partnership alliances and settings and the way these assist information flows.
- That innovation is essentially a social process involving interactive learning by doing and that process can lead to new possibilities and approaches inevitably leading to a diversity of organizational and institutional change. The interactions of the agents both condition and are conditioned by social and economic institutions. The innovation process depends on the relationships between different people and organizations. The nature of those relationships and its political economy is important.
- That knowledge production is a contextual affair, i.e., innovation is conditioned by the system of actors and institutional contexts at particular location and point in time.

A commodity-based innovation system incorporates the various actors, their actions and interactions, as well as the enabling environment, facilitating institutions, and services that condition the various forms of innovation along the value chain of that commodity. This emphasizes the notion that innovation can occur anywhere along the value chain and not necessarily at the farm level; thus, broadening the research agenda to incorporate both bio-physical and socio-economic research within the R4D portfolio.
The most recent framework on agricultural innovation systems (AIS), has guided the approach to planning knowledge production and use. With due notice of the importance of building strong organizations and effective research-extension-farmer linkages, it emphasizes on the additional features needed for actors to collaborate and respond to needs (such as professional skills, incentives for partnerships, better knowledge flow, etc.) and the wider enabling factors that must be put in place for actors to innovate.

Sorghum Innovation System

The current body of literature (Hall *et al*., 2006) [61] defines an innovation system as a network of organizations, enterprises, and individuals focused on bringing new products, processes, and new forms of organization into economic use, together with the institutions and policies that affect their behavior and performance. The innovation systems concept embraces not only the science suppliers but the totality and interaction of actors involved in innovation. Innovation encompasses the factors affecting demand for and use of knowledge in novel and useful way.
An agricultural innovation system in the present context can

be defined as the process of using newly generated or already existing sorghum related knowledge and associated services in productive ways (for market and non-market functions) by smallholder and commercial-oriented farmers in in the eastern Amhara region. An agricultural innovation system is constituted by overlapping flows of knowledge and relationships across a diverse set of actors in the sorghum sub-sector - together with the underlying institutions and policies - whose combined effectiveness helps define the extent to which new products, processes, and new forms of organization are translated into social and economic use. In this context, innovation systems concept focuses attention on the broad range of stakeholders or players involved in the process of innovation – farmers, scientists, traders, development workers, policy makers, the livestock dependent poor, etc. It recognizes that innovation and the creation of novelty takes place through the interaction of these players and the process of knowledge sharing and learning that this interaction allows. The capacity to innovate and use knowledge productively is therefore a function of patterns of interaction and the factors that shape these interactions–usually the habits and practices (or institutions in the sense of norms and rules) that shape the behavior of different players (Bank, 2006) [22].

The innovation systems concept emerged as a response to the limited explanatory power of conventional economic models that view innovation as a linear process driven by the supply of research and development (Hall *et al*., 2006) [61]. The framework is now being used to understand and strengthen innovation at national, sectoral and sub-sectoral levels. Innovation systems are supposed to be very important determinants of sorghum technological change in the present context. Traditional methods of (Dahlberg *et al*.) innovation development that mainly focus on the structure of innovation systems have proven to be insufficient (Hekkert *et al*., 2007) [66]. This state of insufficiency has resulted in the development of new techniques of evaluating innovation systems oriented to certain commodity subsector focusing on a number of processes that are important for well performing innovation systems. Innovation creates new opportunities, these opportunities may not be realized or converted into economic activity until the prerequisite inputs (resources and skills) and product markets are in place (Carlsson *et al*., 2002) [32].

The innovation system is more inclusive than the relatively narrow notion of a research system. The research system is a system of public sector organizations/actors engaged in generating knowledge and technologies, for example, that of sorghum subsector. The extension system, made predominantly of public sector actors, is responsible for the adaptation and diffusion of the technologies. In contrast, the innovation system encompasses all components of the system of public, private, voluntary or other organizations/actors whose interactions and networking processes produce, diffuse and use economically useful knowledge. In contrast to the research system that generates technological innovations, the innovation system produces technological and institutional innovations. In an innovation system both technological and institutional innovations are generated, modified, sustained and utilized. (Raina, 2003) [113] discussed that features of successful innovation systems are: continuous evolutionary cycles of learning and innovation; combinations of technical and institutional innovations; interaction of diverse research and non-research actors; shifting roles for information producers, information users and a need-based exchange of knowledge; and an institutional context that supports interactions and knowledge flows between actors.

The present study on sorghum in the eastern part of the Amhara region of Ethiopia stems from a hypothetical view that non-adoption of sorghum technologies in the study area is a result of the relative capacity of the sorghum innovation system and its sensitivity to the circumstances of the farmers, markets, and the environment (policy and institutional) associated with the sorghum value chain. Analyzing such a system in a particular setting employing the innovation systems framework will have a significant contribution to make the system more productive and sustainable by suggesting potential policy, research and development interventions at micro, meso and macro levels. This type of work helps to propose directions on what has to be done in order to make the sorghum innovation system sustainable through better integration of the nodesof its value chain aiming at improvement of the livelihoods of sorghum growers in the selected study area.

From the literatures above, the concept of innovation and innovation frameworks, suggested that one of the end result of sorghum innovation technology, among others, the adaptability of such technologies such as improved seds, fertilizers, and irrigation. Moreover, the farmers are the primary adopters of these technologies. Hence, looking the factors that influenced the adoption of technologies in the study area is one considere in this Ph,D research. Therefore, this study focused to identify factors related to household, socio-economic, and institutional aspects of farmers in adopting sorghum innovation technologies in the eastern part of Amhara Region.

Method

Descriptive and explanatory research designs were used to adescribe the status of technology use in the study area, and assess the impact of household, socioeconomic, and other variables on adoption of innovation technology at micro level. From the three sampled kebeles (Godaguadit, Jari, and Tebisa), with a total population of 20,807; a systematic random sampling method was used to select the 297 heads of household from the list of female-headed households and male-headed in each kebelesparticipated in the survey study (Table 1).

Table 1: Sorghum land area coverage and population of the three kebeles selected for the study

Sample Kebeles	Land area under sorghum (ha)	Sorghum growing population by sex			Sample population
		Male	Female	Total	
Godaguadit	471	401	34	435	113
Jari	279	326	28	354	91
Tebisa	436	321	40	361	93
Total	1186	1048	102	1150	297

***Source*:** Own sampling design, 2023

The study used quantitative approach mainly focusds on the household characteristics and their adoption of Sorghum technology. The primary data were collected from sample households using a structured questionnaire through the interview method, using computer-assisted using data collection application (Kobo Toolbox). Data analysis at micro-level involved Logit and Tobit economic model.

Results

Technology Adoption

Improved seed adoption status

Table 1depictsthe improved seed adoption status of farmers. Out of 297 farmers surveyed in the study, 169 (56.9%) of them adopted improved seeds and the rest 128 (43.1%) did not adopt improved seeds during the cropping season of the study time.

Improved sorghum varieties that the farmers used were Abshir, Gobiye, and Teshale by most of the households in the study area. Among these seeds, Abshir variety was used by 167(56.2%) of the farmers, followed by Gubiye variety used by 163(54.9%), and Teshale variety used by 155(52.2%) of the farmers in the sampled kebeles. Only 48(16.2%) of the farmers were using other variety of the technology innovated seeds. The result indicated that, among those using improved sorghum seeds, majority of them were using two or three of these varieties.

Table 2: Improved sorghum Seeds Adoption

Variable (Background), N=297	Value	Frequency	Percentage (%)
Improved sorghum varieties usage	Yes	169	56.9
	No	128	43.1
Type of sorghum varieties used	Abshir	167	56.2
	Gubiye	163	54.9
	Teshale	155	52.2
	Others	48	16.2

Source: Own computation results, (Survey, 2023)

Chemical Fertilizer adoption status

Most often farmers in the study area spread compost in their farms before planting. About 99.3% of the sampled households used compost, while the remaining 3.7%t did not. In addition to this organic fertilizer use, different types of inorganic fertilizers were also in use in the sampled kebeles. The inorganic fertilizers in use were NPS B and NPS Zn, and liquid fertilizers. Out of the total sample size, 77.8% of then farmers adopted and used inorganic fertilizers while 22.2% did not use.

Table 3: Amount of fertilizer used and amount of sorghum produced

Variable (Background), N=297	Minimum	Maximum	Mean	Std. Dev.
Amount of NPS B	0	75	33.45	16.035
Amount of NPS Zn	0	509	43.58	66.955
Amount of liquid fertilizer	0	50	1.54	4.286
Amount of sorghum produced in a hectare of land Qt)	1.5	13	2.13	1.32

Source: Own computation results, (Survey, 2023)

In the sampled kebeles, the average household usage of fertilizers (Table 2) indicated that NPS Zn was the most used type of fertilizer with 43.58 units, followed by NPS B type fertilizer consumed at an average household use by an amount of 33.45 units. Liquid fertilizer was used with relatively low level average of 1.54 per household. The application of these fertilizers resulted in the production of 2.13 Qt per hectar of land.

Irrigation adoption status

According to analysis result depicted in Table 3, dealing irrigation adoption status of the sampled households, almost equal proportion of the sampled households 148(50.2%) were adopters while 147(49.8%) did not adopt irrigation during the cropping season in the study area. Relatively lower level adoption of irrigation, compared with improved seeds and utilization of fertilizers, was directly related to the topography of the district especially the sampled villages, which is difficult to use irrigation.

Determinants of Adoption of Sorghum Production Technologies

The study examined the significance of household, socio-economic, and institutional factors that could have impacted the adoption of sorghum innovation technologies. The results of Logit regression model of Odds Ratio (OR) results in Table 3, indicated thatparticipation in off-farm income-generating activities was found to be an important variable influencing the adoption of agricultural technologies. It was found that, household's participation in off-farm income generating activities had about 4.58 and 2.02 times more likely adopt single use of chemical fertilizer and mix of chemical fertilizer and irrigation technologies respectively as compared to household's who did not participate in off-farm income generating activities.

Table 4: Odds-Ratio (OR) on Determinants of Adoption of Agricultural Technology

Variables	Improved Seed (1)		Chemical fertilizer (2)		Irrigation (3)		1 and 2		1 and 3		2 and 3		1 2 and 3	
	OR	SE	OR	SE	OR	SE	OR	SE	OR	SE	OR	SE	OR	SE
N	290		290		289		290		290		290		290	
LR-Chi-2	174.14		173.30		57.66		225.19		154.17		134.64		201.94	
PSEUDO-Square	0.43		0.57		0.14		0.37		0.24		0.22		0.26	

Log likelihood	-111.70		-66.40		-171.48		-195.15		-239.55		-232.56		-292.16	
	Household-Specific Factors													
Sex of the HH head	0.45	0.17	0.45	0.24	0.84	0.24	0.47	0.14	0.65	0.17	0.68	0.19	0.58	0.15
Age	1.28	0.74	0.69	0.43	0.96	0.39	0.85	0.34	1.09	0.43	0.84	0.33	0.94	0.35
Education	1.17	0.19	2.32	0.52**	0.96	0.12	1.46	0.18	1.03	0.12	1.25	0.14	1.24	0.14
Household size	1.82	0.29	1.19	0.15	1.05	0.09	1.38	0.13	1.29	0.11	1.11	0.09	1.26	0.09
Farming experience	0.42	0.14	1.06	0.38	0.96	0.22	0.67	0.15	0.68	0.15	1.01	0.22	0.76	0.15
	Socio-Economic Factors													
Farm size	0.98	0.06	1.11	0.06	0.93	0.06	1.02	0.04	0.94	0.05	0.98	0.05	0.97	0.04
Participation in off farm income	0.58	0.23	4.58	2.28**	1.45	0.43	1.37	0.39	1.12	0.31	2.02	0.55**	1.55	0.40
Livestock owned	0.69	0.12	1.38	0.21	1.37	0.18	0.88	0.09	1.04	0.09	1.28	0.11	1.08	0.09
	Institutional Factors													
Membership of Social group	13.21	9.55**	9.42	6.83**	2.20	1.04**	13.06	6.34**	5.68	2.50**	4.53	2.11	7.89	3.39**
Access to Extension Service	50.57	246.14	0.09	0.15	4.82	4.27**	2.81	3.64**	53.29	86.14	5.49	6.75**	11.39	13.96**
Access to Credit	4.51	2.89**	7.14	6.03**	1.86	0.87**	3.97	1.86**	3.36	1.43**	2.45	1.12**	3.58	1.49**
Distance from the nearest Market	1.02	0.02	0.99	0.02	0.99	0.01	1.01	0.01	1.00	0.01	0.99	0.01	1.00	0.01

***Source*:** Field survey, (2023)

When there existed several income-generating activities side to farming, the likelihood of adopting new technologies increased since this additional income from off-farm income-generating activities could be used to purchase or possess the new technology.

Another critical factor influencing the adoption of agricultural technologies is the education status of the farming household head measured in terms of years of schooling. Education was found to be statistically significant in affecting the adoption of chemical fertilizer. The likelihood of households in adopting chemical fertilizer increased with an increase in years of education. The possible reason for this might be due to the capability of education in raising the awareness and information processing of farmers about new agricultural technologies. Farmers having more years of schooling did not face difficulty in getting and processing information besides their ability to make thoughtful evaluations about new agricultural technologies than farmers with fewer years of schooling. The ease of adopting new technology was also higher among households with more years of schooling, which was found to have 2.32 times likely in adopting chemical fertilizers.

Membership of social groups, access to extension Services, and access to credit variables had also positive effects on the technology adoption across all levels of single used and mixed use of technologies. In more detail, membership in social groupswas 13.21, 9.42. 2.20, 13.06, 5.68, and 7.89 times more likely to adoptthe use of improved seeds, chemical fertilizers, irrigation, the mix of improved seeds and fertilizers, improved seeds and irrigation, and improved seeds, fertilizers and irrigation respectively. Technology adoption due to the effect of access to extension service was 50.7, 4.82, 2.81, 53.29, 5.49, and 11.39 times more likely adoption of improved seeds, irrigation, the mix of improved seeds and fertilizer, improved seeds and irrigation, and improved seeds, fertilizers and irrigation respectively. Justification of the significance of technology adoption of both membership to social groups and access to extension services could be attributed to the gain of information from those parties.

Access to credit improved seed, chemical fertilizer, irrigation, the mix of improved seed & chemical fertilizer, improved seed & Irrigation, chemical fertilizer & irrigation, and improved seed, chemical fertilizer & irrigation were 4.51, 7.14, 1.86, 3.97, 3.36, 2.45, and 3.58 more-times likely adoption of technologies. Accessing more resources from different sources could help farmers to buy relevant farm inputs which helps them to increase the level of technology adoption.

Improved Sorghum Seeds Adoption Intensity

Those households who reported having used improved varieties may not have done so on all of the plots under their management. The availability and suitability of land for sorghum cultivation was essential. The intensity of adoption of improved sorghum varieties indicates the area of improved sorghum varieties cultivated measured in terms of hectares. Factors such as land ownership, land size, soil fertility, and proximity to water sources were considered to be understood. The land ownership in the Eastern Amhara region of Ethiopia has been privately owned though government has significant control constitutionally. The study area (Tehuledere Woreda) has a total land area of 45800 ha out of which 15,937 (34.8%) hectares could be used for farming purposes and a farm household is estimated to own about 0.5 hectares of land.

Table 5: Land ownership and share of sorghum land between adopters and non-adopters

Variables, (N=297)			Adopters (N=169)		Non adopters (N=128)		Overall		P-value
	Min.	Max.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
Land size owned by the respondents	0	8	4.05	1.27	3.52	0.64	3.79	0.96	<.001
Total cultivated land by the respondents	1	45	1.67	2.36	1.38	3.89	1.53	3.12	<.001
Land occupied by sorghum	1	40	1.54	0.65	1.36	3.46	1.45	2.06	<.001

Source: Own computation results, (Survey, 2023)

However, data obtained from the respondents of the study area showed that minimum hectare used for sorghumplantation was onehectar while the maximum was 40 hectares; which was beyond the size of the land they owned; which is the case of some farmers who cultivated additional land area rented from other farmers.

As presented in table 4, the comparison between adopters and non-adopters indicates that adopters are in a better position with total owned as well as total cultivated and total sorghum area. On average adopters have larger average farm size (4.05 hectares), total cultivated land (1.67 hectares) and total land occupied by sorghum (1.54 hectares) than non-adopters (3.79 hectares, 1.53hectares and 1.45hectares) respectively. On other hand, adopters allocate a larger share of their land to sorghum than non-adopters.

Determinants of Improved Sorghum Technologies Adoption Intensity

Maximum likelihood estimates of Tobit model to identify determinants of adoption and intensity of use of improved sorghum varieties. The dependent variable for the Tobit model is the proportion of farm size covered by improved sorghum varieties from the total sorghum area. A total of 11 explanatory variables were included in the model. Maximum likelihood estimates of the Tobit model are summarized in table 5.

Table 6: Maximum Likelihood Estimates of the Tobit Model

	Coef.	**Std Err.**	**-t**	**P>|t|**	**[95% Conf.**	**Interval]**
Sex	-0.064296	0.089734	-0.72	0.474	-0.240938	0.112345
Age	-0.19076	0.065139	-2.93	0.004	-0.318993	-0.062538
Marital Status	-0.153272	0.054365	-2.82	0.005	-0.26029	-0.046253
Educational status of HH head	0.001788	0.035701	0.05	0.960	-0.068490	0.072068
Total family size	0.089414	0.023571	3.79	0.000	0.043014	0.135815
Off-farming involvement	-0.03389	0.088287	-0.38	0.701	-0.207692	0.139894
Distance to the market	0.004324	0.003316	1.30	0.193	-0.002204	0.010853
Allocated land for sorghum	0.010421	0.040092	0.26	0.795	-0.068501	0.089344
Contact with extension workers	0.863983	0.432680	2.00	0.047	0.01225	1.71571
Access to credit	0.458972	0.143415	3.20	0.002	0.176658	0.741286
Membership with cooperatives	0.376033	0.137206	2.74	0.007	0.105942	0.646124
Cons.	-0.42011	0.581577	-0.72	0.471	-1.56495	0.724723
/Sigma	**0.5985634**	**0.037269**			**0.5251988**	**0.6719281**

Source: Own computation results, (Survey, 2023), **Notes**: Number observations 290, LR Chi2 (13) 153.20, Prob> Chi2 0.000, Pseudo R2=0.2491 (Significant at 5%)

The model was significant at less than 0.05 level implying the appropriateness of the model to estimate the relationship between the dependent variable with at least one independent variable. From the model, a total of 6 variables were found to significantly determine intensity of improved sorghum varieties. The significant variables were age, marital status, total family size, contact with extension workers, access to credit for sorghum production and membership with cooperatives.

Age: Result showed that the age of the household head had found a negative relationship with the extent of adopting improved sorghum varieties by the respondents. This indicates that the probability of household utilization of improved agro-technology decreases with increasing an additional year of the household head. It could be due to young farmers being willing to bear more risk than older farmers and it may also be associated with older farmers being less able and willing to put in increased efforts because of perceived or real physical and/or mental demands associated with the use of improved crop varieties.

Marital status: The Tobit results showed that marital status found a negative relationship with the extent of adopting improved sorghum varieties by the respondents.

Family size: Based on the survey result, about 75.2% of the household members in the study area have fully participated in sorghum production which had a high effect on family decision-making in farming. Results indicated a positive and significant relationship between household size and the extent of adoption of improved Sorghum varieties in the study area. Family size can create certain demand, which may motivate the adoption of new practices or technologies that would increase the agro pastoralists' income as a means of meeting these demands.

Frequency of contact with extension agent: the frequency of contact with the extension agent had found a positive and significant relationship with the extent of adopting improved Sorghum varieties by the respondents. The positive effect of the extension contact on the extent of adoption of improved Sorghum varieties implies that household heads who have regular contact with extension service providers tend to adopt improved Sorghum varieties than those who have no contact with extension. This implies that frequent contact with extension agents would facilitate the flow of new ideas throughout the production and enhance the probability of the use of improved technologies.

Access to credit: As the model result shows the variable access to credit had positively and significantly influenced the likelihood of utilization of improved variety. The availability of credit had increased the utilization decision of the household head on improved agricultural technology positively and significantly. This means that additional credit access will increase the probability that the farmer will participate in the utilization of improved agricultural technology. The result from personnel observation, key informant, and focus group discussions also confirmed that a financial resource was necessary to initiate the uptake of new technologies, and households who had more access to formal and/or informal sources of credit significantly adopted technologies rather than other farmers who had no access to credit.

Member of cooperation: The value of membership in an agricultural producer cooperative to a farmer is universally understood to include market access, improved bargaining power, and reduced transaction costs. Being a member of a cooperative institution was found to positively influence the adoption of sorghum technology packages. Being members of cooperatives was found to affect farmers' likelihood of the package adoption.

Frequency of contact with extension agent: showeds that the frequency of contact with the extension agent had found a positive and significant relationship with the extent of adopting improved Sorghum varieties by the respondents.

Conclusions

The rate of adoption in technology use was assessed for improved seed, fertilizers, and irrigation technology imputs. With regard to the use of improved seeds, only 56.9% of the farmer households were found to use three varieties (Abshir, Gubiye and Teshale), which was very small application of available varieties as compared to 58 improved varieties that were already released from research centers that may probably be due to limited number of enterprises involved in sorghum seed multiplication and resistance of farmers to variety adoption. This has similarity with the study of (Musara *et al*., 2019) [101]. Geremew *et al* (2004) [51] which stated that the possible causes of farmers' resistance against the improved varieties are: improved varieties are sensitive to sowing depth, susceptibility to soil crusts which results in poor stand establishment, the farmers preference to their own local cultivars in good rainy season, lack of aggressive extension work to reach the end users, unavailability of enterprises involved in seed production and high bird damage particularly of white seeded and high-quality varieties.

Among others, the Ethiopian Institute of Biodiversity and the national sorghum research program provided many of the landrace collections used in the breeding operations. The varieties: Abshir, Argity, Dekeba, Erer-01, Fedis, Gubiye, Melkam, Teshale, and Tilahun improved varieties were the most popular ones developed for moisture stress and erratic rain fall areas. (Woldesenbet Agilo, 2021) [147]. Recent study done by Bulti *et al* indicates that from the nine improved sorghum varieties, Abshir and Gubiye showed relatively poor overall field performance while all other varieties showed good overall performances. (Tesfaye Hailu *et al*., 2021) [135]. Teshale, Dekeba, and Melkam had relatively high grain yield per hectare at Fedis which had similarity with the current study area compared to others. Gubiye, Teshale, and Melkam had short maturity duration (early maturing) than all other varieties. Generally, all the evaluated varieties have their own merits and limitations in different environments. Therefore, based on overall performance, 2 to 3 varieties will be recommended for production and further interventions such as development of agronomic packages for the selected varieties, seed production and dissemination, and promotion activities. In addition, Based on the study result of Bulti and observation and data obtained from the current study result there was a need to undertake further study to confirm recommendation of these varieties in the study area.

Concerning chemical fertilizer adoption in the study area, 229 (77.63%) of the gfarmer households had adopted chemical fertilizer. The sources were Farmer's cooperatives, public institutions, input providers traders or organizations, research centres, universities, and non-governmental institutions. Although there is a wide range of access to fertilizers, however, availability is much lower; due to excessive competition for fertilizer only limited proportion reaches smallholder farmers through normal markets. In the current study, data collected shows that NPS-B and NPS-Zn are the fertilizers that were in the production process. It is universally known that among important input in cereal crop production in which (sorghum located), use of inorganic fertilizer plays vital role. However, statistical analysis results depict that fertilizer application did not have significant impact of yield of sorghum. The application of these fertilizers was based on the research studies to supplement Boron and Zinc which in contrary with that of work of Musara *et al*., 2019 [101] that shows use of NPK with Urea emerging as an alternative use of fertilizers by small holders in Zimbabwe.

This research further assessed statistically the determining household, socio-economic and institutional factors that determined the adoption of sorghum production technologies; and as well the intensity of sorgum production. To measure adoption of some of the technologies like use of improved seeds, inorganic fertilizers, and irrigation generated for sorghum production, the study used sex, age, marital status, educational status, total family size, farming experience, cultivated land, off-farm income, membership of cooperative, contact with extension agent, access to credit for agricultural input and distance to market demographic and socioeconomic factors.

Concerning determinants of adoption of single and mixed use of sorghum technologies result of the logit regression of Odds Ratio (OR) results of this study indicated that Improved seeds adoption was affected by the farmers statuses regarding membership to a social group, and access to credit. These two factors were found to have significant impact on irrigation adoption. While chemical fertilizer adoption was found to have impacted by educational status, off-farm income, membership in social group, and access to credit. A mix of improved seeds and chemical adoption was found significant difference depending on both social group and access to credit status of the farmers. These two factors was also found to have impacted the adoption of mix of the three technologies. The result indicated that access to credit and off-farm income were significant factors to the adoption of mix of chemical fertilizer and irregatiuon. However mix Improved seeds and irrigation adoption was only determined by membership status of farmers. Overall, the adoption of sorghum innovation technologies was mainly determined by the socio-economic factors.

From the results of Tobit model to identify determinants of adoption and intensity of use of improved sorghum varieties, the factors that significantly affected the intensity were age, marital status, total family size, contact with extension workers, access to credit for sorghum production and membership with cooperatives. Among these, age and marital status had negative impact.

Recommendations

Safeguarding agricultural development is one of the ways through which developing countries can escape from the vicious circle of poverty. Therefore, actualizing a sustained development in the agricultural sector calls the need for agricultural technology adoption. As a result this study analysed the determinants of agricultural technology adoption in the study area. On the basis of analysis result, it can be concluded that the decision to adopt the agricultural technologies namely improved seed, chemical fertilizer, irrigation and combination of these agricultural technologies in the study area were affected by household-specific factors, socio-economic factors, and institutional factors. Among the specific factors, the institutional factor has influential impact on technology adoption in use of single and mixed technologies. This indicates that much effort has to be done on the household specific and socio-economic factors to upgrade the technology adoption in the study area. Ultimately, the analysis of Sorghum improvement project in the Eastern Amhara region underscores the need for holistic approaches that could consider the socio economic, environmental and technological dimensions of Agricultural development. Therefore, the research called to action all stakeholders, policy makers, and all practitioners to work closely together in addressing and overcoming challenges as well as tapping best opportunities in Sorghum cultivation, thereby contributing to the overall advancement of Agricultural productivity and resilience in the Amhara region of Ethiopia.

By undertaking the specific needs and constraints of Sorghum growing farmers in the Eastern part of Amhara region of Ethiopia, targeted interventions and policy recommendations could be formulated to promote inclusive and resilient agricultural systems. Apart from this, the adoption of certain sorghum variety need to be valued for its productivity return in terms of grain yield and maturity time. It was obvious that if a variety developed by breeders to increase agronomic behavior was not preferred by farmers for other reasons and is not accepted at the end of the day, all of the resources invested in its improvement would be wasted. As a result, it is critical that farmers participate in testing and selection methods based on their trait preferences. To this aim, farmers were frequently included in variety testing schemes at a certain level as part of the regular technique, where it was discovered that farmers and researchers have their own distinct and common selection criteria which contributes in the improved variety adoption.

Moreover, the analysis of sorghum improvement practices in the Eastern part of Amhara region of Ethiopia has provided valuable insights in to the agricultural landscape and potential pathways for sorghum production enhancement. The research could identifiedadoption factors on sorghum innovation technologies that serves inputs to various researchs, actors, stakeholders throughout sorgum innovation system.

The research also found Family size, Access to credit Member of cooperation, and Frequency of contact with extension agent found positively affected the intensity in the sorghum adoption. Hence, focusing on these groups of farmer huseholdes would contribute to the effectiveness of sorghum innovation project. The finding also implied the significance of extension agents, creditors, cooperations, and and extension agents in facilitating improved sorghum seeds adoption.

This Ph.D. research provide valuable inputs towards a comprehensive analysis of the sorghum improvement project, on its significance for agriculture in the eastern Amhara region, and its potential contributions to broader development objectives in Ethiopia.Based on the research result and interview found in the study, the following recommendations are suggested for research done on the analysis of the sorghum improvement project in the eastern Amhara region of Ethiopia:

1. First Assess the impact of climate change before any act of sorghum plantation: Investigate the specific effects of climate change on sorghum cultivation in the region, and explore strategic solutions to enhance resilience and adaptability to the continuously changing climate patterns.
2. Acknowledge and use traditional knowledge and practices: Engage with local farmers and communities to understand their traditional and untapped pieces of knowledge, and agricultural practices related to sorghum cultivation. This can inform the development actors contextually and enable them to use appropriate & improvement strategies for assuring food security.
3. Set a strategy to use soil and water management properly: Before taking any action on Sorghum production, it is recommended to assess the soil fertility, moisture levels, and water availability in the region, and identify best practices for sustainable soil and water management to optimize sorghum production to a greater extent which could reduce any crop losses.
4. Find more sorghum genetic diversity and use the proper one for cultivation: Explore the genetic diversity of sorghum varieties cultivated in the eastern Amhara region and investigate the potential genetic resource that utilizing diverse genetic resources could enhance sorghum improvement resulting in profitability to farmers.
5. Before cultivating sorghum in drought-prone areas, always consider socio-economic aspects for Sorghum improvement: It is recommended that examining the socio-economic factors influencing sorghum cultivation, including access to markets, financial resources, and gender dynamics, and develop strategies to address these aspects for improved sorghum production would benefit farmers in Amhara region in general and in the Eastern part of Amhara region in particular.
6. In order to on any Sorghum cultivation, assess the adoption of technological innovations: It is advisable to evaluate the adoption and impact of modern agricultural technologies, such as improved seeds, mechanization, and digital tools, on sorghum improvement in the Eastern part of Amhara region of Ethiopia.
7. Conduct cost-benefit analysis: Conducting the best cost-benefit analysis of potential sorghum improvement interventions, considering the economic viability and sustainability of different approaches across diverse farming systems in the region would boost farmer's profitability in doing informed decision making for sorghum plantation.
8. Disseminate findings and recommendations of research results: It is important that to ensure that research findings dare to get effectively communicated to relevant stakeholders, including policymakers, practitioners, and local communities, to inform evidence-based decision-making and facilitate the uptake of recommended practices.

In conclusion, by addressing those key areas of recommendations mentioned above, this research could contribute to a comprehensive understanding of sorghum improvement projects in the eastern part of Amhara region of Ethiopia and could provide actionable recommendations for enhancing the productivity, resilience, and sustainability of sorghum cultivation in the region to its greater extent.

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