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Research Article

SEED SYSTEM OF GARLIC (*ALLIUM SATIVUM* L.) IN NORTH SHEWA ZONE, CENTRAL HIGHLANDS OF ETHIOPIA

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ABSTRACT

Objectives: The study aims to assess the status of both formal and informal garlic seed systems. In addition, it also investigates farmers' indigenous knowledge related to seed selection, maintenance, seed sources, seed quality, and seed management practices in the North Shewa zone of the Amhara Regional State.

Materials and Methods: The study employed a multistage sampling procedure. Accordingly, four districts and eight peasant associations (PAs) were purposively selected based on garlic production area; numbers of garlic grower, and representativeness of the farming system. The data were collected from randomly selected 160 garlic producer households (20 from each PAs) using structured questionnaires. Checklists were also used for key informants interview and focus group discussions.

Results: In the study sites, the farmers' cultivars/varieties were commonly grown. Farmers selected their seed based on different criteria. Bulb yield (90%), bulb size (85%), and early germination (83.8%) were the most dominant criteria. In all the study sites, informal seed source for all farmers was the initial seed source. Market seed was a predominant seed source; vast majority of farmers indicated that their initial seed source for garlic farming was obtained from market (95.6%). From 2013/14-2015/16: 61.2%, 51.2% and 62.5% of the farmers used seed from the market. The dissemination of improved varieties to farmers is still absent. The informal seed system should prioritize improving seed quality by increasing awareness and skills of farmers, improving seed quality of early generations, and market access.

Conclusion: The provision of technical support and organizing farmers' into cooperatives to handle the future production and distribution of seed and promoting the formal and informal seed sectors should be taken into account for sustainable supply of quality seed.

Keywords: Formal seed system, Informal seed system, Seed source.

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INTRODUCTION

Garlic, a vital vegetable crop in Ethiopia, serves as a key ingredient in local dishes such as the traditional stew known as "wot." Beyond culinary use, garlic also plays a significant role in local medicine formulations. Both small-scale and commercial growers prioritize garlic production, considering it one of the essential bulb crops for both local use and export (Metasebia and Shimelis, 1998). As a cash crop, garlic contributes to foreign currency earnings through exports to Europe, the Middle East, Africa, and the USA (Kilgori *et al.,* 2007). During the off-season, the same quantity of garlic typically fetches twice or three times the value of onions (Getachew and Asfaw, 2000).

Seeds play a critical role in agricultural production and serve as the most cost-effective external input for smallholder farmers (MacGuire, 2005). Enhancing the availability of high-quality seeds from well-adapted varieties is essential for boosting agricultural productivity, leading to increased farmers' income, poverty reduction, and improved food security (Morris and Heisey, 2003). Unfortunately, the seed business sector often falls short in providing small quantities of top-notch seeds to remote areas at affordable prices. In many developing countries, smallholder farmers rely for their seeds on seed-producing farmers or use their own saved seeds from previous harvests, the informal Seed System (SS). However, in such a system, seed quality remains uncertain (van Gastel *et al.*, 2002), and perceptions of quality are often based solely on the producer's reputation. Farmers who plant low-quality seeds risk poor field emergence and weak plant vigor due to poor physiological quality (Matthews *et al.*, 2012). It is crucial to repeatedly demonstrate the agronomic value of high-quality seeds to them.

In Ethiopia, extensive evidence exists regarding the seed system of cereal crops. However, empirical data on the seed system specific to garlic were lacking. Consequently, this research was undertaken with the aim of assessing the status of both formal and informal garlic seed systems. The study also investigates farmers' indigenous knowledge related to seed selection, maintenance, seed sources, seed quality, and seed management practices in the North Shewa zone of the Amhara Regional State.

MATERIALS AND METHODS

Study Areas

The study was conducted in four districts (Basona Werana, Angolelana Tera, Mojana Wedera, and Tarmaber) of North Shewa, Amhara region (Figure 1).

Basona Werana district covers a total land area of 142,081.51 ha (of which, the total cultivated land area is 42,828 ha) with widely varying altitudinal ranges of 1,500-3,400 masl. Accordingly, from the total area 2%, 50%, 46%, and 2% lies in Wurch, Dega, Weynadega, and Kolla, respectively. The area receives a mean annual rainfall of 950-1, 200 mm with a mean maximum temperature of 22°C and a mean minimum temperature of 10°C. The district has 30 peasant associations (PAs)[1] consisting of 28,939 farm household heads with a total human population of 134,837 (BWDAO, 2016/17).

1 Peasant association is the smallest administrative unit in Ethiopia.

The district of Angolelana Tera covers a total land area of 78,248 ha with widely varying altitudinal ranges of 1,700-3, 245 masl. Accordingly, from the total area, 2%, 85%, and 23% lie Kolla, Dega, and Weynadega, respectively. The area receives a mean annual rainfall of 900-1, 000 mm with a mean maximum temperature of 20°C and a mean minimum temperature of 10°C. The district consists of 28,939 household heads with a total human population of 94, 330 (ATDAO, 2016/17).

Mojana Wedera district covers a total land area of 62,200 ha (of which, the total cultivated land area is 19,291 ha) with widely varying altitudinal ranges of 1,459-3,172 masl. Accordingly, from the total area, 3%, 28%, and 69% lie in Kolla, Dega, and Weynadega, respectively. The area receives a mean annual rainfall of 1,100 mm with a mean maximum temperature of 18.14°C and a mean minimum temperature of 11.84°C. The district has 13 peasant associations (PAs)[1] consisting of 70,253 household heads with a total human population of 73,763 (MWDAO, 2016/17).

Tarmaber covers a total land area of 63,920 ha with widely varying altitudinal ranges of 1,140-3,170 masl. Accordingly, from the total area, 17%, 1%, 54%, and 28% lie in Kolla, Wurch, Dega, and Weynadega, respectively. The area receives a mean annual rainfall of 1,100-1,400 mm with a mean maximum temperature of 25°C and a mean minimum temperature of 15°C. The district consists of 88,387 household heads with a total human population of 102,932 (TDAO, 2016/17).

Sampling technique and method of data collection

A multistage sampling approach was employed in this study. Initially, four districts within the North Shewa zone specifically Basona Werena, Angolelana Tera, Mojana Wedera, and Tarmaber were purposively selected due to their garlic production. Second, eight PAs were also purposively chosen, with two PAs selected from each district. Third, within each PA, farm households were stratified into two groups: Garlic producers and non-producers. The study focused on garlic producers. Finally, a total of 160 sample respondents (all garlic producers) were randomly selected from each stratum, resulting in 20 producers from each PA. The primary data for the quantitative study were collected through a formal survey using a structured interview schedule, conducted during the 2016/17 period.

Before the actual data collection, enumerators who were well-versed in the local culture and societal practices were recruited and trained. The training focused on the purpose and content of the questionnaire, as well as techniques for approaching and interviewing respondents and collecting data using the questionnaire. Subsequently, we pre-tested the interview schedule with six randomly selected farm households from each PA before conducting the formal survey. Based on feedback from the pretest, necessary improvements were implemented.

The data collection process involved eight development agents from the Agricultural Development Office, assisted by a district subject matter specialist who possessed in-depth knowledge and experience regarding the farming system in the study area and seed production by farmers. To ensure accuracy, the researcher conducted cross-checks with each enumerator at the end of each day. In addition, all questionnaires were thoroughly reviewed and clarified with the enumerators. Furthermore, qualitative data were collected through group discussions involving selected garlic producers and extension development agents working in the respective PAs.

The primary data generated were focused on farmers' seed source, seed selection, seed management practices, farmers' perception and adoption of varieties, farmers' knowledge and source of information of agricultural technologies, distribution, protection, production, utilization, harvesting, and marketing. To supplement primary data and to fill the information gap; secondary data were collected from different sources namely records and reports of the district office of Agriculture, Regional Agricultural Research Institutes, Federal Ministry of Agriculture and Natural Resource, and Seed Enterprises.

Statistical analysis

Data collected through questionnaire were organized and summarized for analysis. Data were analyzed using descriptive statistics with SPSS (SPSS, 2011). Depending on the nature of the data, the Chi-square test and ANOVA were employed to compare variables among districts. Pearson's Chi-square ($\chi 2$) test was used for categorical variables to assess a statistical significance of a particular comparison. One-way analysis of variance was applied for quantitative dependent variables. Indices were calculated to provide overall ranking of a particular characteristic according to the formula:

Index = Sum of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] given for an individual characteristic divided by the sum of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] summed for overall characteristics

RESULTS AND DISCUSSION

Household socioeconomic characteristics

The study revealed variations among districts concerning landholding, educational levels, and years of farming experience (Table 1). However, the demographic composition of respondents based on age, sex, and family size remained consistent across districts. Notably, an overwhelming majority (98.1%) of household heads directly involved in garlic production were male across all districts. Similar findings regarding vegetable production were documented in previous studies conducted in Ethiopia (Tadesse, 2008) and Cameroon (Emile *et al.*, 2012). This gender disparity could be attributed to the labor-intensive nature of garlic cultivation, as well as cultural constraints limiting women's resource mobilization and participation in farming activities as heads of households. Furthermore, a chi-square test indicated no statistically significant difference in sex distribution among the study sites (Table 1).

The size of a family can significantly impact household livelihood, either positively or negatively. In this study, given that the majority of family members belong to the active labor force group, households have access to ample labor resources. This, in turn, enhances the likelihood of purchasing improved garlic seeds. Consequently, family size is expected to have a positive effect on improved garlic farming within the household. However, the result of F-test analysis reveals that there is no statistically significance difference among the study sites with respect to family size of the household (Table 1). This signifies that family size per household has no significant implication on the quantity of improved garlic farming of the farmers.

The age of household members plays a pivotal role, influencing whether a household draws on experience or relies on a solid foundation for decision-making, especially when compared to younger farmers. This aligns with the findings of Negussie (2008), who reported that age can either foster or diminish confidence in adopting new technology and learning new skills. Essentially, with more experience and confidence, a farmer's risk aversion may increase or decrease. The average age of the respondents was 42 years, with most households falling within the age category of 15–64 years. Notably, garlic production in the study area is predominantly carried out by the active age group of society. This trend could be attributed to the labor-intensive nature of garlic cultivation. Interestingly, similar findings were reported by Emile *et al.* (2012), who observed that most vegetable farmers also belonged to the active age group. However, there is no statistically significant mean age difference among the study sites (Table 1).

Diverse households' educational status was observed, with the majority being either literate or possessing formal education. This finding aligns with the reports by Madisa *et al.* (2010), who observed that most vegetable farmers in peri-urban areas of Botswana and Ghana were literate. Education serves as a critical indicator, enhancing farmers' ability to effectively utilize agricultural information, actively participate in farming activities, and make efficient use of technologies. In the study area, the educational level within the farming community is relatively high, as indicated in Table 1. Specifically, among the total garlic

Table 1: Socio-economic characteristics of households by districts

Parameters	Variables	Districts					p-value
		Basona Werana (n=40)	Angolelana Tera (n=40)	Mojana Wedera (n=40)	Tarmaber (n=40)	Overall (n=160)	
Sex (%)	Male	95	100	100	97.5	98.1	
	Female	5	0	0	2.5	1.9	0.291
Family size (Mean±SE)	Males 15-64 years	1.90±0.19	1.92±0.20	1.77±0.13	1.57±0.14	1.79±0.06	>0.05
	Females 15-64 years	1.50±0.10	1.67±0.19	1.30±0.11	1.50±0.14	1.49±0.07	>0.05
	Males < 15 years	0.75±0.12	0.97±0.18	0.70±0.09	0.77±0.11	0.80±0.06	>0.05
	Females < 15 years	0.72±0.12	0.67±0.17	0.74±0.11	0.85±0.13	0.75±0.07	>0.05
	Males > 64 years	0.15±0.07	0.05±0.03	0.07±0.04	0.12±0.05	0.10±0.02	>0.05
	Females > 64 years	0.20±0.07	0.00±0.00	0.10±0.05	0.07±0.07	0.09±0.03	>0.05
Farmers' age	(Mean±SE)	44.90±1.78	40.80±1.82	40.10±1.54	41.25±1.38	41.76±0.83	>0.05
Year of farming experience	1–5 year	52.5b	55b	80a	85a	68.1	
	>5 year	47.5a	45a	20b	15b	31.9	0.001
Education level (%)	Illiterate	0a	2.5a	0a	2.5a	1.2	
	Read and write	17.5a	0b	22.5a	10a	12.5	
	School	45ab	30bc	55a	15c	36.2	
	Graduate	37.5b	67.5a	22.5b	72.5a	50	<0.001
Land holding in 2015/16 (ha)	Own land	1.41±0.07b	1.75±0.12a	1.05±0.06c	0.62±0.03d	1.21±0.05	<0.001
	Rented in land	0.19±0.07b	0.91±0.10a	0.27±0.06b	0.05±0.03b	0.35±0.04	<0.001
	Shared in land	0.16±0.05bc	0.29±0.06ab	0.28±0.04bc	0.10±0.03c	0.21±0.02	<0.05
Land holding for garlic 2015/16 (ha)	(Mean±SE)	0.25±0.03b	0.49±0.05a	0.43±0.03a	0.05±0.01c	0.31±0.02	<0.001
Number of cattle	(Mean±SE)	5.25±0.40b	8.22±0.33a	5.25±0.31b	3.92±0.29c	5.66±0.21	<0.001
Number of oxen	(Mean±SE)	2.10±0.15b	2.65±0.13a	2.10±0.12b	1.72±0.10bc	2.14±0.07	<0.001

Source: Own survey result, 2016/17. Means with different superscript letter in the same row differ significantly (P ≤ 0.05).

producers, 1.2% were illiterate, 12.5% could read and write, and 36.2% had attended primary and secondary education (grades 1-10), while 50.0% had graduated (grades 10+ or 12+). In addition, Addis (2007) reported a positive and significant relationship between education and technology adoption.

Furthermore, farmers' experience plays a pivotal role in the adoption of agricultural technologies. Experience is expected to enhance farmers' engagement in seed production. A more experienced grower tends to have reduced uncertainty regarding the technology's performance (Chilot *et al.*, 1996). Farmers with extensive experience consistently demonstrated comprehensive knowledge and the ability to assess the benefits of agricultural technology. Specifically, among respondents who cultivated garlic, 47.5% in Basona Werana and 45.0% in Angolelana Tera districts had more than 5 years of farming experience. In contrast, 80.0% of farmers in Mojana Wedera and 85.0% in Tarmaber districts had <5 years of farming experience.

Farming was reported as the main occupation of the household in the study area. Land, being the most crucial asset, holds immense significance for households reliant on agriculture. Access to land is a fundamental prerequisite for farming, and ownership and control over land are often synonymous with wealth, status, and influence in many regions. Farmers in the study areas utilized both their personal land and hired or shared land for cultivating various crops. The average total farm size, owned and rented per household, was 1.75 and 0.91, respectively, in Angolelana Tera, significantly surpassing other districts. In addition, the three districts Basona Werana, Angolelana Tera, and Mojana Wedera had similar shared in land (Table 1). Notably, the average size of garlic land in Angolelana Tera and Mojana Wedera districts significantly exceeded that of Basona Werana and Tarmaber districts. Farmers with larger farm size had more chance to use improved seeds and allocate land to seed production for sale as compared to farmers with smaller landholdings (Gezahegn, 2008). Crop production in the study area was subsistence; and most of the farmers used oxen for land preparation. Respondents in Angolelana Tera district had the highest number of cattle and oxen as compared to the other districts (Table 1). As the number of oxen owned by farmers' increased, adoption of improved seed is expected to increase. This implies that those who have oxen for ploughing the land are likely to be involved in garlic production.

Labor and financial sources for garlic production

In Angolelana Tera district, most farmers relied on a combination of family labor, hired labor, and self-help associations for their agricultural activities (Table 2). In contrast, in Basona Werana, family labor and labor exchange played a more significant role. In the Mojana Wedera district, farmers predominantly utilized family labor, labor exchange, and self-help associations. Meanwhile, in Tarmaber, family labor remained the primary source of workforce.

One possible explanation for this pattern could be that the sample respondents heavily depend on their productive family labor or the economically active labor force within their households. Similar finding by Bekele (2010) showed that family members were the major source of farm labor in Gobu-Sayo, Sibu-Sire, and Guto-Gida districts in Eastern Wellega.

Across all districts, the majority of respondents did not receive credit (Table 2). Specifically, 13.1% of respondents in the zone received credit for purchasing seeds, while the remaining 86.9% did not take credit for purchasing seeds. Credit played a crucial role for economically disadvantaged farmers, enabling them to access the specific agricultural inputs they needed and adopt innovative technologies. Previous studies also support the idea that credit significantly influences the adoption and application of new farming techniques (Yishak, 2005). The reasons behind this disparity include some farmers being able to purchase seeds outright with available cash, while others hesitated due to the complexities involved in obtaining credit or concerns about interest rates. According to the focus group discussion, the main source of credit for buying seeds was Amhara credit and saving institute (ACSI). Most farmers preferred credit source from ACSI because the process to receive the credit was relatively short and they considered that ACSI was their own institution.

Agronomic packages for garlic production

Garlic cultivation practices vary across districts, with ploughing frequency being a notable difference. Most of the respondents in Basona Werana (60%), Mojana Wedera (60%), and Tarmaber (70%) districts plough their land three times for garlic production. However, in Angolelana Tera district, a substantial 87.5% of respondents plough their fields four times (Table 3).

Hand weeding is a common practice among all farmers, but the frequency of weeding varies. In Basona Werana, 50% of respondents weed their garlic fields three times, while the majority (85%) in Tarmaber district follow the same practice. Conversely, the remaining 50% of Basona Werana respondents and the majority in Angolelana Tera (50%) and Mojana Wedera (47.5%) districts weed their fields four times (Table 3). Effective weed control is crucial for successful garlic production. Weeds can significantly impact yields, even during the early growth stages of the crop. In fact, weeds can reduce garlic yields by half and compromise crop quality (Bachmann, 2001). In addition, disease and insect pressures affect garlic production. In Angolelana Tera (87.5%) and Tarmaber (97.5%) districts, respondents faced white rot and rust diseases, along with insect pests like thrips and aphids. Irrigation was widely practiced across all districts. All respondents in Angolelana Tera district utilize irrigation, while in Tarmaber, 57.5% of respondents rely on this water source (Table 3). Notably, the increased use of irrigation in Angolelana Tera district is attributed to an expanded river-based irrigation system, whereas Tarmaber district primarily relies on spring water.

Farmers actively seek information from multiple sources, with the formal Bureau of Agriculture (BoA) being the primary organization providing agronomic training across all districts. Mass media (radio) emerges as the second most important informal source of information for agronomic practices in all districts. However, research centers and universities do not contribute to farmer training in any of the districts (Table 4). Interestingly, a significantly higher number of respondents in Angolelana Tera and Basona Werana districts rely on media as an information source compared to Mojana Wedera and Tarmaber districts. Non-governmental organizations play a minor role as information sources across all districts (Table 4). During group discussions and key informant interviews, it became evident that agricultural extension agents play a crucial role in training farmers on specific agronomic practices, particularly those relevant to garlic production.

Constraints in garlic production

Farmers prioritized several constraints, and across Angolelana Tera**,** Mojana Wedera, and Tarmaber districts, disease, and insect occurrence emerged as the top two ranked limitations. Meanwhile, in Basona Werena district, the primary constraints were disease and the absence of storage structures and facilities (Table 5). During group discussions, farmers highlighted that the key challenges in garlic production included diseases (such as white rot and rust), insects (such as aphids and thrips), and the lack of storage infrastructure. This aligns with findings from Firew (2008)**,** who reported that production-related issues (insect and disease)**,** followed by post-

Table 2: Percentage distribution of farmers' by source of labor and credit service for garlic production

Source of labor and credit service	Districts					p-value
	Basona Werana (n=40)	Angolelana Tera (n=40)	Mojana Wedera (n=40)	Tarmaber (n=40)	Overall (n=160)	
Family labor	95	100	97.5	100	98.1	0.291
Hired labor	37.5b	60.0a	10.0c	12.5c	30	<0.001
Labor exchange	77.5a	30.0c	60.0ab	52.5b	55	<0.001
Self-help associations	10.0b	35.0a	40.0a	15.0b	25	0.003
Received credit (%)	7.5	12.5	22.5	10	13.1	0.208

Source: Own survey result, 2016/17.
only positive responses were reported. Means with different superscript letter in the same row differ significantly (P ≤ 0.05).

Table 3: Agronomic practices used for garlic production by sample farmers

Agronomic packages	Districts					p-value
	Basona Werana (n=40)	Angolelana Tera (n=40)	Mojana Wedera (n=40)	Tarmaber (n=40)	Overall (n=160)	
Disease and insect pests occurrence	47.5c	87.5ab	70.0b	97.5a	75.6	< 0.001
Irrigation used	92.5ab	100.0a	87.5b	57.5c	84.4	< 0.001
Frequency of weeding						
3 times	50.0b	47.5b	32.5b	85.0a	53.8	
4 times	50.0a	50.0a	47.5a	12.5b	40	
5 times	0.0b	2.5b	20.0a	2.5b	6.2	< 0.001
Frequency of ploughing						
2 times	0.0b	0.0b	32.5a	17.5a	12.5	
3 times	60.0a	12.5b	60.0a	70.0a	50.6	
4 times	40.0b	87.5a	7.5c	12.5c	36.9	< 0.001

Source: Own survey result, 2016/17. Means with different superscript letter in the same row differ significantly (P ≤ 0.05).

Table 4: Source of training on garlic agronomy practices

Source of training	Districts					p-value
	Basona Werana (n=40)	Angolelana Tera (n=40)	Mojana Wedera (n=40)	Tarmaber (n=40)	Overall (n=160)	
Office of agriculture	92.5	77.5	87.5	87.5	86.2	0.261
Research	0	0	0	0	0	
University	0	0	0	0	0	
Media (television or radio)	60.0a	70.0a	25.0b	32.5b	46.9	< 0.001
Non-governmental organization	0b	0b	10.0a	2.5ab	3.1	0.031

Source: Own survey result, 2016/17. Means with different superscript letter in the same row differ significantly (P ≤ 0.05).

harvest problems, were the major constraints in sorghum seed production in eastern Ethiopia.

Seed sources

Informal sectors served as the primary source of garlic seed for 100% of the farmers across the districts from 2013/14 to 2015/16. During the 2013/14 crop season, all farmers in Basona Werana (100%) obtained seed from the market, while in Angolelana Tera, the majority of farmers (37.5% and 20%) used seed from their own stock and purchased it from farmers (Table 6).

In the 2014/15 crop season, most farmers in Basona Werana (100%) continued to rely on market-purchased seed. In Angolelana Tera, 42.5% of farmers and in Mojana Wedera, 25.0% of farmers obtained seed from farmers. Meanwhile, in Mojana Wedera (52.5%) and Tarmaber (60.0%) districts, the majority used seed from their own stock. During the 2015/16 crop season, in both Basona Werana and Angolelana Tera districts, 100% of farmers obtained seed from the market. In Mojana Wedera, 80% of farmers and in Tarmaber, 70% of farmers used seed from their own stock (Table 6).

Interestingly, the formal sector, including the extension service of the Regional Agricultural Bureau or the Ethiopian Seed Enterprise (a public seed production and marketing organization), or any other formal seed sector entities such as universities and research centers, did not serve as the source of garlic seed for farmers. Instead, the informal sector played a crucial role. This aligns with findings from Zewdie's study (2004), which revealed that the informal sector was an initial source of modern wheat varieties for 57.8% of the farmers where seed was obtained from neighbors/other farmers (35.5%), relatives (6.9%) or local trading (15.4%). Similarly, Regassa *et al.* (1998) observed that local markets and other farmers were the primary initial sources of seed for wheat in eastern Ethiopia.

Contractual seed production

Enhancing farmer-based seed production plays a pivotal role in advancing the seed sector within the country, as emphasized by Zewdie and van Gastel (2008). In the study area, there is currently no established system for contractual garlic seed production. However, among the total sample households, approximately 86.2% of farmers expressed interest in participating in contractual seed production (CSP) (Table 6).

During focus group discussions, it became evident that many non-participant farmers were keen on engaging in CSP. Their primary concern, however, revolved around varietal stability, particularly in light of major diseases affecting garlic. If solutions to these challenges are found, more farmers are likely to embrace CSP. The rationale behind their interest lies in the anticipation of quality seed, improved income, increased yield, and enhanced management practices. In addition, key informants highlighted that farmers participating in barley CSP across all districts experienced better income and greater seed security, which could serve as an encouraging precedent for garlic producers to participate in CSP initiatives.

Table 5: Garlic production constraints by districts

Production constraints	Districts							
	Basona Werana (n=40)		Angolelana Tera (n=40)		Mojana Wedera (n=40)		Tarmaber (n=40)	
	HHs	Index	HHs	Index	HHs	Index	HHs	Index
Diseases	22.00	0.28	29.67	0.37	33.00	0.41	39.00	0.49
Insects	10.00	0.13	13.67	0.17	21.67	0.27	18.00	0.23
Fertilizer shortage	1.67	0.02	5.67	0.07	6.33	0.08	0.00	0.00
PHL (spr., wt. loss and rot.)	1.33	0.02	9.00	0.11	4.00	0.05	8.00	0.10
Moisture stress	17.00	0.21	5.67	0.07	11.00	0.14	1.67	0.02
Abs. of stor. str. and fac.	21.00	0.26	12.67	0.16	1.33	0.02	6.00	0.08
Poor extension system	7.00	0.09	3.67	0.05	2.67	0.03	7.33	0.09

HHs: Number of households ranking variables (i.e., ranks 1, 2, or 3); PHL (spr., wt. loss &rot.) = post-harvest losses (sprouting, weight loss and rotting) and Abs.of stor. str. and fac.: Absence of storage structures and facilities

Table 6: Seed sources of the farmers for initial, 2013/14, 2014/15, and 2015/16 cropping seasons

Seed sources	Districts					p-value
	Basona Werana (n=40)	Angolelana Tera (n=40)	Mojana Wedera (n=40)	Tarmaber (n=40)	Overall (n=160)	
Initial						
Farmers	2.5	0	5	2.5	2.5	0.562
Family	2.5	0	7.5	0	2.5	0.104
Exchange	0	0	2.5	0	0.6	0.389
Market	100.0a	100a	85b	97.5a	95.6	0.002
Seed source (2013/14)						
Own stock	0c	37.5a	27.5ab	12.5b	19.4	<0.001
Farmers	2.5b	20a	12.5ab	5b	10	0.04
Market	100a	35c	57.5b	52.5bc	61.2	<0.001
Seed source (2014/15)						
Own stock	2.5b	12.5b	52.5a	60a	31.9	<0.001
Farmers	0b	42.5a	25a	5b	18.1	<0.001
Market	100a	47.5b	22.5c	35bc	51.2	<0.001
Seed source (2015/16)						
Own stock	2.5b	0b	80a	70a	38.1	<0.001
Farmers	0	2.5	5	5	3.1	0.518
Market	100a	100a	20b	30b	62.5	<0.001
Contractual seed production	90	92.5	82.5	80	86.2	0.31

Source: Own survey result, 2016/17. Means with different superscript letter in the same row differ significantly (P ≤ 0.05)

Problems in use of garlic seeds

Disease, germination problems, and higher prices emerged as the top three constraints in using garlic seeds as planting material across the districts. Specifically, the disease was ranked as the most critical constraint in the use of garlic seed in Angolelana Tera, Mojana Wedera, and Tarmaber districts, while germination problems took precedence in Basona Werena district (Table 7). In alignment with this, Getachew and Asfaw (2000) highlighted that the major challenges faced in producing and supplying quality garlic seed were insufficient disease control and poor sprouting when using seeds soon after harvest due to dormancy, resulting in poor crop emergence and vigor. In addition, Getachew *et al.* (2004) emphasized that garlic cloves require over 12 weeks of storage at ambient temperature and relative humidity for uniform sprouting, maturity, and optimal bulb yield.

Farmers' selection criteria for adopting garlic varieties

Farmers identified various technological and socioeconomic factors influencing the cultivation of modern garlic on their farms. Data were selectively recorded based on the characteristics perceived as significant by farmers. Among the identified varietal traits, bulb yield, bulb size, food quality, marketability, early maturity, uniform maturity, fast germination rate, insect pest resistance, disease resistance, drought resistance, and poor fertility tolerance emerged as crucial factors for adopting improved garlic varieties (Table 8). Farmers were encouraged to assess the specific characteristics of the garlic varieties they grew during the season and provide comprehensive information, ranking them according to their selection criteria.

Inquiring about selection criteria, farmers were asked to prioritize the characteristics for adopting improved garlic varieties. Bulb yield was ranked as the most critical attribute in selecting garlic varieties. Bulb size followed closely as the next criterion. The top five characteristics defining good-quality seed were bulb yield, bulb size, fast germination rate, disease tolerance, and early maturity, ranked 1st, 2nd, 3rd, 4th, and 5th, respectively (Table 8). Similarly, in eastern Ethiopia, yield and seed size were also among the top five selection criteria for beans (Teshale *et al.*, 2005).

Group discussions were conducted to get detailed information regarding selection criteria. According to farmers' perceptions, varietal characteristics such as higher yield, large bulb size, fast germination rate, disease tolerance, and early maturity were deemed essential for adopting improved garlic varieties. Key informants, including NGOs, agricultural experts, and research center professionals, confirmed that better yield, large bulb size, fast germination rate, disease tolerance, and early maturity were effective attributes for adopting improved garlic varieties in the study area.

Household seed security

In all study sites, all farmers faced seed insecurity. The primary underlying reasons for this insecurity included insufficient seed production, use of poor-quality seed, disease, and selling all-out to the market or consuming seed stocks due to post-harvest challenges. Production-related problems (insect and disease), followed by post-harvest problems, consumption, and natural calamities (drought) were the major reasons affecting seed security of farmers in eastern Ethiopia in sorghum (Firew, 2008). Respondents consistently experienced seed insecurity year after year. To mitigate this, farmers proposed several strategies, including adopting better-adapted and high-performing seed varieties, implementing effective pest management, increasing yield, and providing seed aid. Group discussions and interviews with key informants were conducted to assess household seed security. The findings confirmed that the most critical factors contributing to seed insecurity were lack of access to improved varieties and high-quality seed, inability of farmers' production to meet family food needs, selling produce to the market, and insufficient production due to diseases and abiotic factors. Consequently, farmers recommended the timely provision of improved and disease-resistant seed varieties, along with raising

Table 7: Problems in use of garlic seeds by districts

Problems	Districts							
	Basona Werana (n=40)		Angolelana Tera (n=40)		Mojana Wedera (n=40)		Tarmaber (n=40)	
	HHs	Index	HHs	Index	HHs	Index	HHs	Index
Disease	14.00	0.18	33.67	0.42	24.00	0.30	32.00	0.40
Germination	25.33	0.31	16.67	0.21	21.00	0.26	22.33	0.28
Mixture of seeds	2.33	0.03	2.67	0.03	3.33	0.04	2.00	0.03
Higher price	23.33	0.29	22.00	0.28	18.00	0.23	13.33	0.17
Scarcity	11.00	0.14	4.67	0.06	11.00	0.14	6.67	0.08
Yielding potential	4.67	0.06	0.33	0.00	2.67	0.03	3.67	0.05

HHs: Number of households ranking variables (i.e., ranks 1, 2 or 3)

Table 8: Farmers' selection criteria to adopt varieties

Farmers' selection criteria	Districts					Index	p-value
	Basona Werana (n=40)	Angolelana Tera (n=40)	Mojana Wedera (n=40)	Tarmaber (n=40)	Overall (n=160)		
Higher bulb yield	92.5	95	82.5	90	90	0.125 (1st)	0.274
Large bulb size	82.5	85	82.5	90	85	0.118 (2nd)	0.759
Good food quality	42.5	47.5	32.5	35	39.4	0.055	0.497
Marketability	55	57.5	62.5	65	60	0.083	0.791
Early maturity	70	67.5	62.5	67.5	66.9	0.093 (5th)	0.911
Uniform maturity	72.5	60	55	65	63.1	0.088	0.412
Fast germination rate	87.5	85	80	82.5	83.8	0.117 (3rd)	0.821
Pest tolerance	47.5	37.5	32.5	32.5	37.5	0.052	0.465
Disease tolerance	87.5a	87.5a	80a	50b	76.2	0.106 (4th)	<0.001
Frost tolerance	62.5	62.5	55	62.5	60.6	0.084	0.872
Poor fertility tolerance	62.5	57.5	50	55	56.2	0.078	0.724

Source: Own survey result, 2016/17. Means with different superscript letter in the same row differ significantly ($P \leq 0.05$).

awareness through training programs. Some key informants also supported the need to strengthen local seed supply systems as a means to reduce seed insecurity.

Harvesting stages and methods

Yellowing and drying of leaves served as the primary indicator for harvesting across all districts. In Basona Werana (52.5%) and Angolelana Tera (65%) districts, large bulb size was also a significant criterion for harvesting. However, in Mojana Wedera (25%) and Tarmaber (30%) districts, fewer respondents relied on this criterion (Table 9). In agreement with this, Kamenetsky (2007) reported that garlic is ready for harvest when its plant tops have dried and fallen, and the stems (necks) have started to soften and partially dry. Garlic bulbs typically mature 4-6 months after planting (Purseglove, 1975; Ib Libner, 1989), or 3-4 months after planting (Rice *et al.*, 1990), indicated by the drying and falling of the tops or the softening of the main stem above the bulb, along with 75% yellowing of the leaves (Dickerson, 1999). Similarly, Brewster (1994) noted that onions intended for dry bulbs are ready for harvest when the bulbs reach maturity and 50-80% of the tops fall over.

The majority of respondents (92.5%) employed the hoe-digging method of harvesting while a few proportion used hand lifting (11.2%) and oxen ploughing (2.5%) across districts (Table 9). Consistent with this, Brewster (1994) mentioned that onions can be manually harvested by pulling them up or digging them out using hand instruments, or through mechanical harvesting using machines.

Curing

Approximately 80.0% of participant farmers in Mojana Wedera and 85.0% in Tarmaber districts cured their produce before storage, percentages higher than those in Basona Werana and Angolella districts (40.0% and 57.5%, respectively). Notably, in Mojana Wedera district, 50.0% of respondents used the piling method for storage, while none in Angolelana Tera and 20.0% in Basona Werana, and 22.5% in Tarmaber districts practiced piling.

Moreover, the majority of farmers in Angolelana Tera (57.5%) and Tarmaber (62.5%) districts opted for windrowing, surpassing the proportions in Basona Werana (20.0%) and Mojana Wedera (30.0%) districts (Table 10). When weather conditions permit, bulbs are cured in windrows either in the field or open sheds. Alternatively, forced heated air is used to rapidly dry the neck and outer scales (Maw *et al.*, 1997). Traditional field curing of onions involves "windrowing," where detached bulbs, shaded by their tops, rest on their slices (Thompson, 1996). Interestingly, the thick neck with succulent skin of non-cured topped bulbs led to maximum physiological weight loss, skin shrinkage, and earlier sprouting – possibly due to higher respiration. In agreement with this, Sidhu and Chadha (1986) observed that physiological loss in weight was higher in non-cured bulbs during storage.

In Basona Werana district, the majority of respondents cured their produce for up to 7 days, while in Angolelana Tera district, most respondents extended the curing period to 10 days. Meanwhile, in Mojana Wedera, approximately 40% of respondents cured their produce for 8-10 days. In contrast, respondents from Tarmaber indicated that they cure their produce for more than 14 days (Table 10). Following harvest, it is recommended to cure or dry garlic bulbs for 8-10 days (Tindall, 1983) before marketing or storage to prevent deterioration. Similarly, for onion storage, drying times vary from 3 days (Swift, 1997) to 21 days (Mondal and Pramanik, 1992), depending on the local climatic conditions. In addition, Maw *et al.* (1997) suggested that onion bulbs can be field-cured at temperatures of 24-32°C for 5 to 10 days.

Majority of the respondents in Basona Werana district predominantly prepare their produce as non-cured topped whereas in Angolelana Tera

Table 9: Harvesting stages and methods for garlic production

Harvesting stages and methods	Districts					p-value
	Basona Werana (n=40)	Angolelana Tera (n=40)	Mojana Wedera (n=40)	Tarmaber (n=40)	Overall (n=160)	
Harvesting stages						
Large bulb size	52.5a	65.0a	25.0b	30.0b	43.1	0.001
Yellow and dried leaves	97.5	97.5	92.5	95	95.6	0.650
Harvesting methods						
Hoe digging	95	90	92.5	92.5	92.5	0.868
Hand lifting	5	17.5	15	7.5	11.2	0.235
Oxen ploughing	5	2.5	2.5	0	2.5	0.562

Source: Own survey result, 2016/17. Means with different superscript letter in the same row differ significantly (P ≤ 0.05).

Table 10: Farmers' practices of curing garlic in North Shewa

Curing treatments	Districts					p-value
	Basona Werana (n=40)	Angolelana Tera (n=40)	Mojana Wedera (n=40)	Tarmaber (n=40)	Overall (n=160)	
Is there curing treatment?	40b	57.5b	80a	85a	65.6	<0.001
Curing methods						
Piled in field or storage	20.0b	0.0c	50.0a	22.5b	23.1	<0.001
Windrowing	20.0b	57.5a	30.0b	62.5a	42.5	<0.001
Curing period (day)						
0	60.0a	42.5a	20.0b	15.0b	34.4	
7	37.5a	22.5ab	17.5b	10.0b	21.9	
8–10	0.0b	32.5a	40.0a	25.0a	24.4	
14	2.5b	2.5b	5.0ab	17.5a	6.9	
>14	0.0b	0.0b	17.5a	32.5a	12.5	<0.001
Produce preparation						
Cured – Topped	27.5b	50.0a	60.0a	47.5ab	46.2	0.03
Cured – Non-topped	12.5b	7.5b	22.5b	75.0a	29.4	<0.001
Non-cured – Topped	60.0a	32.5b	20.0b	15.0b	31.9	<0.001

Source: Own survey result, 2016/17. Means with different superscript letter in the same row differ significantly (P ≤ 0.05).

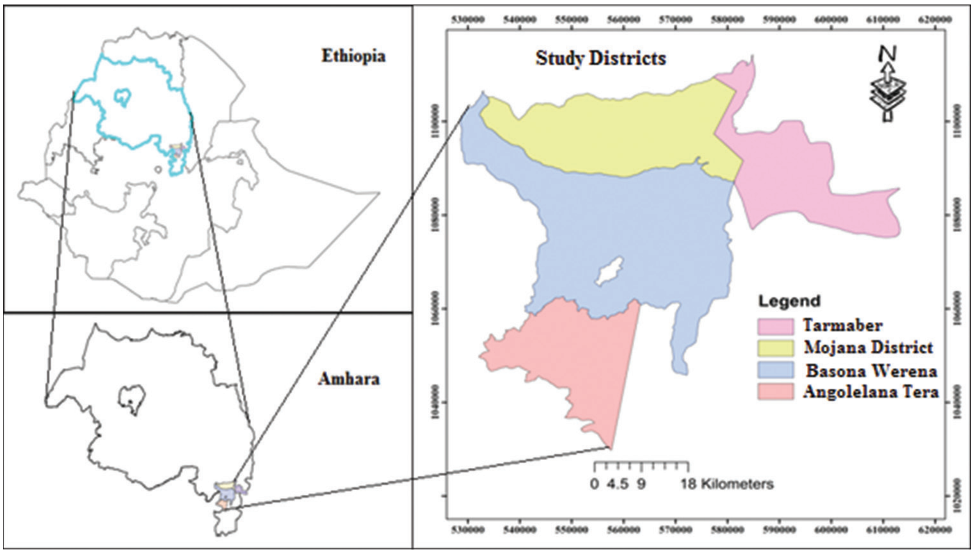

Fig. 1: Location map of the study districts

Table 11: Farmers' bulb storage method and marketing

Storage methods and marketing	Districts					p-value
	Basona Werana (n=40)	Angolelana Tera (n=40)	Mojana Wedera (n=40)	Tarmaber (n=40)	Overall (n=160)	
Storage methods						
Storage on floor	60.0a	50.0a	47.5a	57.5a	53.8	0.635
Storage in sack	5.0b	10.0b	40.0a	5.0b	15	<0.001
Storage on shelf	0.0c	30.0a	12.5ab	10.0b	13.1	0.001
Storage by hanging on	7.5b	7.5b	12.5b	37.5a	16.2	<0.001
Selling the produce						
Taking to the nearby towns market and selling to consumers	40.0a	15.0b	47.5a	35.0a	34.4	0.016
Directly to distributors on the market of nearby towns	60.0b	92.5a	55.0b	65.0b	68.1	<0.001

Source: Own survey result, 2016/17. Means with different superscript letter in the same row differ significantly ($P \leq 0.05$).

and Mojana Wedera districts, most respondents prepare the produce as cured topped. Conversely, in Tarmaber district, majority of the respondents prepare their produce as cured topped and cured non-topped.

Garlic storage and marketing

Majority of the respondents stored their produce on floor across the districts. Besides floor storage, most respondents in Angolelana Tera (30.0%), Mojana Wedera (40.0%), and Tarmaber (37.5%) districts stored their produce on shelves, in sacks and by hanging on, respectively (Table 11). Furthermore, in Angolelana Tera district, 92.5% of respondents sold their produce directly to distributors in nearby towns, while a smaller proportion (15.0%) transported it to nearby town markets and sold to consumers. In contrast, in Basona Werana, Mojana Wedera, and Tarmaber districts, a higher number of respondents directly sold their produce to consumers in nearby town markets compared to Angolelana Tera district (Table 11).

The limited availability of storage facilities compelled producers to sell their entire harvest immediately after harvest, often resulting in significantly lower prices than under normal market conditions. This challenge aligns with findings from other researchers who reported that the absence of storage facilities posed major constraints to horticultural crop production and marketing in Ethiopia (Fekadu and Dandena, 2006; Bezabih and Hadera, 2007) and India (Kiresur and Ganeshkumar, 1998). Households emphasized that inadequate knowledge and extension services related to post-harvest handling and storage were significant bottlenecks affecting the profitability of garlic production and marketing in the area. Besides, during focus group discussions, participants stressed the need for knowledge and extension services on pre-harvest management practices for enhanced post-harvest quality and storability of garlic bulbs.

Farmers strongly recommended providing training on pre-harvest management to enhance garlic productivity in the districts. Interestingly, a similar finding was reported in India by Waman and Patil (2000). The lack of access to credit significantly affects the establishment of storage structures and facilities, as well as the assurance of regular cash flows. Results consistent with the findings of this study were reported in India (Choudhury, 2006). Besides, the poor storage potential of the existing garlic variety emerged as a barrier to implementing effective post-harvest handling practices, as underlined during individual interviews and focus group discussions.

CONCLUSION

The survey results indicated that the market serves as the primary source of garlic seed, while only a few farmers save their own seed. This suggests that farmers predominantly rely on local seeds, and access to extension services for improved seed varieties is quite limited. However, efforts are underway by the Ministry of Agriculture and Natural Resources, along with other organizations, to develop local seed businesses for various crops through farmers' cooperatives. Insights from other crops underscore the need to initiate, strengthen, and scale up local seed businesses specifically for garlic, thereby enhancing the seed supply system. Notably, having small-scale seed enterprises at the village level provides an effective link that integrates variety selection, seed multiplication, distribution, and utilization with all stages involving active participation by smallholders. Despite this, the formal seed system's role in garlic production remains absent, while the informal seed system prevails. To address these challenges and establish a sustainable seed system in North Shewa, integrating both formal and informal seed systems is essential. In addition, introducing a post-harvest management system that ensures bulb storability across production seasons and helps growers mitigate price fluctuations is crucial.

DATA AVAILABILITY

Primary data were used to support this study.

DISCLOSURE

The authors confirm that the content of the manuscript has not been published or submitted for publication elsewhere.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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AUTHORS' CONTRIBUTIONS

Bizuayehu Desta is the first author of the research article, whereas the co-authors have contributed equally for the literature collection, manuscript documentation, and its revision. All authors read and approved the final manuscript.

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