SOIL & CROP SCIENCES | RESEARCH ARTICLE

Revealing determinants that affects garlic production in Ethiopia using PRISMA methodology

Gebre Garmame Galdgaye

Abstract: Today, garlic productivity in Ethiopia is below its potential which is ranked 15 in the world. This is due to numerous determinants that affect garlic production. Therefore, the study’s main objective was to reveal and sum up determinants affecting garlic production in Ethiopia using PRISMA Method. Preferred reporting items for systematic review and meta-analysis checklist s1 table were employed. Universally accredited and indexed high-quality databases and university libraries; specifically, Scopus, PubMed, Science Direct, University of Toronto Library, and Google Scholar were used for retrieving published data (2000–2022). The titles “Garlic” and Ethiopia” were used to summarize results. The present study indicated that a total of 12,000 publications from Google scholar, and 51 publications from the University of Toronto library search engine published on the web of science and Scopus were used. A total of 51 publications were chosen as being the most suitable for this paper. Among the 51 publications, 86%, 6%, 6%, and 2% were articles, Newsletter articles, Text resources, and conference proceedings, respectively. Accordingly, a study revealed that the low production of this crop is due to information obtained via a systematic review discussed and categorized as institutional determinants (15.69%), farmers' hypotheses, and research questions, and written a full original research article.

ABOUT THE AUTHOR
Gebre Garmame Galdgaye is a senior lecturer and researcher at Bule Hora University. He has been teaching horticulture, plant sciences, and environmental sciences students. He has conducted different research activities related to horticulture agronomy, plant physiology, food security, and variety adaptation. Finally, he has an interest in teaching and conducting research related to crop-climate, horticultural agronomy, and post-harvest management. He is an independent researcher who has been working with new research designs and methodologies like PRISMA. In this paper, he has independently designed a systematic review, which consists of objectives, hypotheses, and research questions, and written a full original research article.

PUBLIC INTEREST STATEMENT
Garlic is a member of the family Alliaceae, genus Allium, and originated in India, Afghanistan, West China, and Russia, which is generally known as Central Asia. It is mostly used for spicing food as a spice and in modern medicine to treat and cure different diseases. For producing this type of important crop in Ethiopia, there is broad opportunity and potential. However, it has been producing below its potential.

The very low production of this crop is due to several abiotic and biotic determinants. Therefore, the main objective of this paper was to reveal determinants that affect garlic production in Ethiopia using the preferred reporting items for systematic review and meta-analysis (PRISMA) method. The study revealed that garlic production in Ethiopia was determined by institutional, farmer characteristics, production and management; and post-harvest technology determinants. Therefore, these determinants should be adjusted based on appropriate garlic production practices.
characteristics (9.8%), production and management practice (68.63%), and post-harvest (5.88%). Institutional; production and management practices are of the major determinants negatively affecting garlic production in Ethiopia. Moreover, research limitations also were revealed. The recommendation of this paper is therefore not general, specifically, each factor has been recommended.

Subjects: Agriculture; Horticulture; Botany

Keywords: Ethiopia; Factors; Garlic Production; PRISMA

1. Introduction

Garlic (Allium sativum L.) is the second most commonly produced and consumed horticultural crop of the cultivated Alliums next to the onion in the world (Rubatzky & Yamaguchi, 1997; Singh & Chand, 2003). According to reference (James, 2008) garlic is a member of the family Alliaceous, genus Allium and originated in India, Afghanistan, West China, and Russia which is generally known as Central Asia. It is distributed and spread to other countries of the world through trade and colonization (Panthee et al., 2006; Tindal, 1986).

It is mostly used to spicing food as a spice and in modern medicine to treat and cure different diseases (Labu & Rahman, 2019). Garlic has been used as a paramount medicine started from ancient Egyptians which is stated in the medical text Codex Ebers (ca.1550 BC). Mostly it is a remedy for different ailments such as tumors, headache, heart problems, worms, and bites (Tattelman, 2005; Thomson, 2007). According to reference (Bongiorno et al., 2008) garlic has antibacterial, antifungals, anti-viral, and antioxidant capacities. Moreover, anti-cancer and anti-atherosclerotic properties have also been observed (Bongiorno et al., 2008). Currently, intensive review article revealed that the major biologically active ingredient of garlic (allicin) with its derivatives have been used therapeutic use and potential for drug discovery worldwide (Azene, 2021).

Garlic grows very-well at sub-tropical to temperate or high lands (1500–3456 msl), well-drained sandy, silty-clay soils, pH of 7, and excellent storage condition (Alemu et al., 2016, Table 1-13). The significant importance of garlic has been known as a cultivated spice and medicinal plant for over 5000 years (Bizayahu et al., 2021). Therefore, Garlic have been a big demanded crop both locally and internationally (Alemayehu & Abate, 2021). Consequently, garlic is one among the most paramount economic crops of low income smallholder producers of highland area of Ethiopia (Alemayehu & Abate, 2021; Diriba, 2016). The highest net returns of Ethiopian Birr 518,409 and 626,814 per hectare had obtained in 2017 and 2018, respectively (Alemayehu & Abate, 2021). Thus, most of Ethiopian smallholder farmers around highland area produce garlic partially for home self-consumption and mainly for marketing as an income generation (Diriba, 2016).

Ethiopian agro-ecology has been ample opportunity and potential for garlic production. According to central statistical agency (2017), garlic production declined from coverage hectare of 16,411.19, during 2013/14 to production coverage hectare of 15,381 during 2016/17 having a total production of bulb yield (159,093.58 and 138,664.3 tons) with the average garlic productivity of 9.7 and 9.02 t ha–1, respectively, while current garlic productivity in Ethiopia is below potential (CSA (Central Statistical Agency), 2018; FAO, 2015; FAOSTAT (Food and Agriculture Organization of the United Nations Statistics), 2011; FAOSTAT (Food and Agriculture Organization Statistics), 2018; (AW Worku & Mehari, 2018),Shege et al., 2021). Internationally, Ethiopia has ranked 15 (FAOSTAT (Food and Agriculture Organization Statistics), 2018). While, China is the first ranked country accounting for over 78% of world total production (22.27 million tons) (Bizayahu, et al., 2021). Following china, other ranked counties were India, Bangladesh, Republic of Korea, Egypt, Spain, USA, Uzbekistan, Russia, and Myanmar, respectively (FAOSTAT (Food and Agriculture Organization Statistics), 2018). Worldwide, the production of garlic during 2018 was 28.49 million
Table 1. Institutional determinants and farmers characteristics that affects garlic production in Ethiopia

| Factor                                      | Extent\textsuperscript{12} of the factor problem | Specific region\textsuperscript{13} | Specific District\textsuperscript{15} or kebele\textsuperscript{16} | Citation                                                                 |
|---------------------------------------------|-----------------------------------------------|-------------------------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------|
| Shortage of finance service for input like improved variety seed, chemical, pesticides and irrigation facilities purchase Lack of credit services | Major (lack of credit services (70.6%)). | Amhara, Southwest Ethiopia, SNNP, Tigray Oromia                      | Yilmana Densa district AdetZuria Gashaye and Ambesit kebele, Bench-Sekko, Kaffa, Sheka, and West-Omo zones, west shewa zone, gurage, hadiya, yemi special district\textsuperscript{17} Arsi Zone, Digelu-Tijo, Lemu-Bilibilo, Hetosa, Tiyo and Ziway-Dugda Districts \textsuperscript{18} | (Shege et al., 2021, Benyam et al., 2021, Bezabih et al., 2015, Diriba et al., 2020, Lema et al., 2017, G et al., 2017, Shege, 2015, Hanibal et al., 2010) |
| Low supply of improved seed varieties low supply of fertilizers Poor extension service | Major (improved seed varieties (94.5%), low supply of fertilizers (95%)| Medium (Poor extension service (57.3%)) | Bench-Sekko, Kaffa, Sheka, and West-Omo zones Kaffa, Sheka, and West-Omo zones, west shewa zone, gurage, hadiya, yemi special district Arsi Zone, Digelu-Tijo, Lemu-Bilibilo, Hetosa, Tiyo and Ziway-Dugda Districts | (Benyam et al., 2021, Bezabih et al., 2015, Diriba et al., 2020, Lema et al., 2017, G et al., 2017) |
| Poor market linkage Low institutional support and market information’s | Major (lack of market linkage (62.5%)) | Major | Southwest Ethiopia SNNP and Oromia Tigray | west shewa zone, gurage, hadiya, yemi special district Kaffa, Sheka, and West-Omo zones, west shewa zone, gurage, hadiya, yemi special district Arsi Zone, Digelu-Tijo, Lemu-Bilibilo, Hetosa, Tiyo and Ziway-Dugda Districts | [Shege, 2015, Shege et al., 2021, Shibabaw et al., 2017, Siyourm & Yesuf, 2013] |

tons from 1,546,741 hectares of land (FAOSTAT (Food and Agriculture Organization Statistics), 2018). Among this, only 124,801 tons from 12,429 hectares of land was the total production of Ethiopian with a mean productivity of 10.04 tons/ha (FAOSTAT (Food and Agriculture Organization Statistics), 2018). This indicates Ethiopian garlic production is very low when compared to world average 18.4 tons/ha (FAOSTAT (Food and Agriculture Organization Statistics), 2018).

The very low production of this crop is due to several abiotic and biotic factors including limitation of irrigable land (Shege et al., 2021), unavailability of improved and high yielder varieties, cultivar and germ plasm (Atinafu et al., 2021; Ayalew et al., 2015; Bewuketu et al., 2000; Dessie & Mulat, 2019; Fikrte et al., 2017; J Mohammed et al., 2021; Motuma et al., 2020; Mulu & Negasi, 2021; Shege et al., 2021; HS Tabor et al., 2021; Tadesse, 2009; Tadesse, 2015; Tesfaye & Merah, 2021; Tewodros et al., 2014; Yeshiwas et al., 2018), good agricultural practices and use of organic and inorganic fertilizer type or rate or soil fertility condition (Abraha et al., 2015; Adem et al., 2014; Asegnehu et al., 2013; Alemayehu & Abate, 2021; Amare & Mamo, 2020; Assefa & Abrha, 2015;
Bewuket, 2021; Diriba, 2016; Fikru & Fikreyohannes, 2018; Gashaw & Gashaw, 2021; Habtamu et al., 2014; Habtu et al., 2019; Ketema & Bauer, 2011; Merga, 2019; Mululem & Yebo, 2015; Shbabaw et al., 2017; Tadesse, 2015; Taffesse et al., 2012; Tomene et al., 2017), disease (Abraha et al., 2015; Abraham et al., 2019; Adem et al., 2014; Agegnehu et al., 2013; Amare & Mamo, 2020; Assefa & Abro, 2015; Bewuket, 2021; Dejene M. Worku & Dejene, 2012; Fikru & Fikreyohannes, 2018; Gashaw & Gashaw, 2021; Habtu et al., 2019; Kassaw & Ayalew, 2021; Mengesha, 2015; Merga, 2019; Shege et al., 2021; Siyoum & Yesuf, 2013; Taffesse et al., 2012; Tamire et al., 2007; Workat et al., 2018; Zewide et al., 2007), spacing or plant population (Getachew & Asfaw, 2010; Mengesha, 2015; Merga, 2019; A Mohammed et al., 2014; Mulu & Negasi, 2021; Taffesse et al., 2012; Tewodros et al., 2014), propagation method like clove size (Bizuyehu, et al., 2021; Lencha & Buke, 2017; Nasir, 2018; Semira & Tefera, 2017), climate change or agro-ecology (Atinafu et al., 2021; Merga, 2019; Shege et al., 2021; Taffesse et al., 2012; Tesfahunegn & Gebru, 2019), shortage of irrigation water and inappropriate irrigation system (Ashebir et al., 2021; Eliyas et al., 2022; Mandefro & Shoeb, 2015). Post-harvest factors like harvesting, curing, storage site, storage season, storage method and duration (Bizuyehu, Kebede, et al., 2021; Diriba et al., 2000; G Tabor et al., 2004) also indicated. Furthermore, inadequate research, dissemination and extension, and government institutional constraints in production as well as in market value chain development contributed for low garlic yield in Ethiopia (Abate & Habteyesus, 2022; Gebrehiwot et al., 2018; Merga, 2019; Shege et al., 2021; Taffesse et al., 2012; AW Worku & Mehari, 2018; Yaye et al., 2017). There are also limitations of researches focused on sun duration and other factors not included in the current study which should be focused by the researches in the country.

However, these factors have been factors that affect the production of garlic across part of the country. Indeed, a several detail of factors influences garlic production has been studied across the country, however, there are some more poorly conducted studies which have not been published and not used in this paper yet.

I collected and extracted the published literature (from high quality indexed journals like web of science, Scopus, ScienceDirect, PubMed and Google scholar databases) on garlic production factors. Therefore, the general objective of this paper is to better reveal the determinants that affecting garlic production in Ethiopia. Specifically, the first one is to systematically review entire government institution determinants and farmers characteristics affecting garlic production; second, to reveal production and management practices determinant that affects garlic production. Then finally, to gather and show the post-harvest practices that affects garlic yield/production. This findings could help to sum up to date evidences concerning factors affecting garlic production in Ethiopia and to exploit different existing production influences with in a single paper to fill gaps and improve future research prospect by indicating pillars where more scientific focal point might be sighted.

1.1. Hypothesis

- H0: A government institution, farmer’s characteristics, production and management practices; and post-harvest technology have not determined garlic production in Ethiopia.

- H1: A government institution, farmer’s characteristics, production and management practices; and post-harvest technology have determined garlic production in Ethiopia.

1.2. Research questions

(1) What are the government institutions determinants that affects garlic production in Ethiopia?

(2) What are the farmer’s characteristics that determines garlic production in Ethiopia?
(3) What are the production and management determinants that affects garlic production in Ethiopia?

(4) What are the post-harvest determinants that affects garlic production in Ethiopia?

2. Methodology

2.0.1. Study design

This study was designed and done according to the provided guidelines by Mother D. et al. (Moher et al., 2009) of PRISMA meaning preferred reporting items for systematic review and meta-analysis. As indicated by reference (Moher et al., 2009), it is not as an essay or term paper or normal literature review, but it is a review of a clearly prepared questions that utilizes systematic and explicit tools to identify, choose, and deeply appraise appropriate research, and to gather and analyze data from the articles that are included in the systematic review. It may or may not include statistical method to analyze and condense the findings of the included articles/research report (Moher et al., 2009). Furthermore see the official website interpreting the methodology (www.prisma-statement.org). Other detail protocol for conducting this study was not used. The Preferred Reporting Items for Systematic Review and Meta-Analysis check list S1 Table is submitted in the supporting information section.

2.0.2. Searching strategy

Universally accredited and indexed high quality databases and university library; specifically, Scopus, PubMed, Science Direct, University of Toronto library and Google Scholar were used for retrieving published data (2000-2022). The searching strategy was to retrieve and download high quality published original research and review articles revealing government institution, farmer’s characteristics, production and management practices; and post-harvest determinants affecting garlic production. The detail keywords including “Garlic”, “Clove size”, “Clove weight”, “Spacing”, “Watering”, “Irrigation”, “variety”, “Ethiopia”, and “Fertilizer” were used.

2.0.3. Exclusion/inclusion criteria

Published Original research and review articles reporting factors that affect garlic production were included in this paper. Specifically, studies indicating limitation of irrigable land problem, improved and high yielder varieties, cultivar and germ plasm, agricultural practices and organic and inorganic fertilizer type and rate, mulching, location, disease, spacing or plant population, propagation method like clove size and weight, and irrigation were included. Moreover, lack of research, dissemination and extension, and entire government institutional (concerns garlic development) constraints in production of garlic were consisted. Post-harvest factors like harvesting time, curing, storage method, storage site, storage season and storage conditions were also included. However, articles written with out of English languages were excluded. Generally, the following reasons were as follow;

Reason 1, the articles (record) must contain both garlic and Ethiopia that has been published data from 2000–2022.

Reason 2, the article (record) must be from universally high indexed journal or database, and

Reason 3, the article (record) must discuss about factors that affect garlic production in Ethiopia.

2.0.4. Selection of study

In PRISMA, commonly known method called Endnote (San Francisco, Thomson Reuters, CA, and United State of America) was employed to assemble materials (compile) the articles. First, the author assessed titles and executive summary (abstracts) of the retrieved articles for inclusion criteria. Next, the appropriate, and relevant full published studies (articles) were assessed and reviewed. Information such as factors used, treatments levels, the name of the specific areas in
which the trial (experimental) work was conducted were also taken in to account during the selection process.

2.0.5. Method of data analysis
Non-parametric, descriptive quantitative statistic were used to summarize the articles. Quantitative, and qualitative data were employed due to their suitability for PRISMA. Software including “Microsoft Excel” was used.

3. Result
Country wide (Ethiopia), scholars revealed that garlic is a major spicing component of almost all dishes. Moreover, it is a paramount economic cash crop which could treat various human, plant and animal diseases. However, Production of garlic is affected by biotic (living things) and abiotic (non-living things) stresses. These could categorized as government research and economic institutional determinants, farmers characteristics, production and management practices including variety development and adoption, location, inappropriate propagation (clove size and weight), planting density, mulching, irrigation schedule or shortage of rainfall, and using appropriate, and type of irrigation, diseases management, and postharvest technology factors (Figure 1).

This paper was designed to reveal those factors affecting garlic production in Ethiopia. A total of 12,000 publications from Google scholar and 51 publications from the University of Toronto library search engine which is published on the web of science and Scopus were searched (Figure 2). After take-off irrelevant and duplicated articles, a total of 51 publications were carefully chosen as being most suitable for this paper. Among the 51 publications, 44, 3, 3, and 1 were articles, Newsletter articles, Text resources, and conference proceedings, respectively (Figure 3).

**Figure 1. Search Conceptual framework –determinants affecting garlic production in Ethiopia. Source: own organized.**

**Institutional factors**
- Finance and credit access
- Research participation
- Dissimination and extention of research research output

**Farmers Characteristics**
- Farmers experiance
- Knowledge to wards using garlic production technology package
- skill of farmer

**Agronomic practices/ Factors**
- Variety selection and adoption
- Propagation(clove size and weight),
- Planting density/spacing
- mulching
- Irrigation
- Fertilization
- Diseases and Insect Pests Management

**Garlic production/yield in Ethiopia**

**Post-harvest techology**
- Harvesting
- curing
- storage site
- storage season
- Storage duration
4. Determinants affecting garlic production in Ethiopia

A total of 51 original research articles were included, consisted 8(15.69%) articles discussing government institutional determinants, 5(9.8%) farmers' characteristic, 35(68.63%) production and management practice including variety, clove size, clove weight, spacing, irrigation, disease management, and 3(5.88%) postharvest factors [Figure 3, Table 1-13]. The present systematic study also indicated that there were around 23(45.1%) articles revealing about two or more two factors that affect garlic yield [Table 1-4, 13].

The result of this review indicates that most 35(68.63%) of the study focused on production and management practices factors including variety, clove size, clove weight, spacing, mulching, irrigation, diseases, and insects management [Figure 3, Table 3-5]. Next to this, 23(45.1%) articles revealing about two or more determinants that affect garlic production (findings deals about two or more subjects under one experimental setup like variety and fertilizer; location, spacing, and variety … etc) [Table 1-4, 13]. There were very low studies focused on post-harvest factors (5.9%) and farmers' characteristics (9.8%), respectively [Figure 3, Table 2 and 13].

4.1. Institutional determinants, and farmers' characteristics

Among institutional factors shortage of finance service for input like improved variety seed, chemical, pesticides, and irrigation facilities purchase were indicated [Table 1]. Moreover, Low supply of improved seed varieties, and fertilizers including poor extension service, poor market linkage, Low entire institutional support(institutional procurement of production inputs, extension services, financing institutions, market institutions) and market information's(supply, demand, price, market absorption) were observed as a major problem by different survey scholars [Table 1].

Poor knowledge and skill gap of farmer (57.14%) were highly studied farmer among farmer's characteristics, while low attitude of farmers towards improved technology like low usage of improved seed varieties, low supply, and use of fertilizers (14.29%) were the lowest studied problem in Ethiopian context [Table 2]. Furthermore, this systematic review indicated that poor knowledge and skill gap of farmer, and low attitude of farmers towards improved technology like low usage of improved seed varieties, low supply, and use of fertilizers were observed as a major problem which affects garlic production in Ethiopia. Whereas farmers experience (28.57%) was medium problem to wards reduction of garlic production [Table 2].
4.2. Production and management practices
Variety/germ plasma/accession/cultivar were found to be the most frequently used, being the part used in 31% of the studies production and management factors, followed by fertilization especially nitrogen and phosphorous fertilization (19%), diseases (11%), location (8.6%), spacing (8.6%), mulching (8.6%), irrigation (8.6%). While the lowest researched production and management practices of garlic was about planting material like size, weight of clove, time of dormancy, and other vegetative or seed propagation or generally how to multiply seedlings of garlic either sexually or asexually (5.01%). Report of this systematic review revealed that research on garlic propagation in Ethiopia is very low [Table 1-12].

4.3. Post-harvest factors
Country wide, research on garlic harvesting, curing, storage method, storage sites, storage season storage was found to be the least researched areas, being the part used in 5.9% of the studies [Figure 3, Table 13]. Report of this systematic review revealed that garlic post-harvest research was narrowed. Harvesting time, sorting, curing, storage method, site, duration and season, and transportation of garlic bulbs are the determinants that contributes great value in increasing product
value and price stabilization. While as the base the researchers and research output users may use this review for further research work.

### 4.4. Publication-region wise

Most of the study was conducted at Oromia (35.94%), Amahara (25%), and Tigray (20.31%), SNNNPR (17.19%), respectively [Table 1-13]. Only one study reported 1.6% from Dire Dawo. While even a single study was not reported from other parts of the country. The output of the study revealed that most of the studies/researches were focused on Oromia, Amahara and Tigray due to most of the production potential area of the country was Oromia, Amahara and Tigray. Besides, most of the researchers choose the areas to conduct garlic production trials. Furthermore, international projects focus these areas and research at these areas were accessible as compared with other areas. However, other part of the country like Afar and Somali has not been researched for garlic production due to the areas are not suitable for garlic production. Even though the environment is not suitable, other technological options should be researched and funded to increase the productivity of garlic in the country. This indicates there were research gaps in the country.

### 4.5. Publications-year wise

From 2000 up to the 2022 year data was used for this systematic review. Consequently, the work indicated that a higher number of published articles were recorded from the 2021 year data, while no published articles were recorded in the year 2000–2003, 2005–2006, and 2008–2011 [Figure 4]. Specifically, from 2004, 2012–2014 yearly only a single published article was observed. Generally, during 2011–2022, (Figure 4) indicated that there was up down increase in research article publication. This might be due to the fluctuation of topic selection interest by graduate and postgraduate students on the garlic crop and publication of their findings; the interest of researchers who has been working in Ethiopian research institutions to publicizes the output, and international garlic related projects engaged in Ethiopia garlic research and publication.
Table 3. Production and management determinant (variety) affecting yield production of garlic in Ethiopia

| Factor                     | Study altitude (m.a.s.l) | Studied Variety/ cultivars /germplasm | Recommended variety | Specific region                        | Specific Zone, District or kebele                                                                 | Citation                                      |
|----------------------------|--------------------------|---------------------------------------|---------------------|----------------------------------------|------------------------------------------------------------------------------------------------|-----------------------------------------------|
| **Agronomic practices/ factors** |                          |                                       |                     |                                        |                                                                                                 |                                               |
| Variety                    | 1200-2938                | Chefe, Kuniftu, Tsedey 92, Holeta, Chelenko I (S. C.), and Local | Tsedey 92           | Oromia                                 | Gursum, and Kombolcha districts on farmers’ farm, Eastern Hararghe zone                           | [Mohammed et al., 2021]                       |
|                            | 1960                     | Tsedey 92, and local                  | Tsedey 92           | SNNPR                                  | Beresa watershed, Mesqanworeda, Guraghe Zone of the                                              | [Abreham et al., 2017]                       |
| Not-mentioned              |                          | Adiszemene local, Holleta, Tsedey 92, Kuniftu, and Chefe | Adiszemene local   | Amhara                                 | South Gondar zone, Angot, and Ginaza Woreta                                                      | [Dessie & Mulat, 2019]                       |
|                            | 2027-2632                | Briki-Gc-1/16, Kuniftu(S. C), briki-Gc-2/16, Bora-Gc-16, Bisheftu, Nech (S.C), Tseday(S. C), Bora-2/16, Bora-3/16, and Bora-1/16 | Bora-1/16 and Bora-2/16 | Tigray                                 | Ahferam, Hagere, selam, Hatsebo, and Ofla                                                        | [Fasikaw, 2020]                              |
|                            | 1500-3200                | BishoftuNech, Tseaday 92, Kuniftu, MM-98 and local | Local               | Amhara                                 | Dabati district North Gonder                                                                       | [Ayalew et al., 2015]                        |
|                            | 1864                     | Bishofu Netch, Tsedey 92, and local   | Tsedey 92           | Tigray                                 | Aksum University Selekleka research and demonstration center, located at Medebay Zana district, Northwestern Zone | [Mulu & Negasi, 2021]                        |
5. Discussions

5.1. Institutional determinants affecting garlic production

Several scholars revealed that institutional factors could affect garlic production. In this systematic review, about 15.69% institutional determinants. According to these articles institutional determinants are discussed as follow. Among them a study conducted in the Amhara region, Yilmana Densa district by shege (Shege, 2015) indicated that no companies are producing improved planting material. As a result, farmers have been using only local garlic varieties either purchased from 29 local markets (in his sample 66.7 %) or used their own saved seed (30%) for garlic production. Similarly, lack of access to pest and disease-resistant varieties, lack of a functional seed Seed¹ is any planting material used for propagation certification/regulatory system which ultimately results in the use of uncertified poor quality seeds by farmers are indicated as a major institutional factor in SNNPR² and Oromia, specifically Kaffa, Sheka, and West-Omo zones, West shewa zone, Gurage, Hadiya, Yemi special district (Shege et al., 2021, Table 1). Reference (Diriba et al., 2020) also indicates that horticultural crops including garlic producing farmers in Arsi oromo areas had no access to any of the modern inputs from NGO,³ research and university institutions except improved seed from NGO. Their study revealed that 20.6%, 38.8%, 43.1%, and 44.4% of the sample identified limited access to transport, limited supply of credit, high cost of credit/interest, and huge bureaucracy are the causes of limited access to finance access, respectively for more production. Moreover, a study conducted at SNNPR and Oromia, shows that the lack of private seed company engaged in the seed supply and distribution channel, and lack of institutional coordination in the seed supply system at some districts such as Guder and Ambo has been also eliminated as constraints for the production of vegetable crops including garlic (Shege, 2015, Shege et al., 2021, Table 1). In the Kaffa, West-Omo, Sheka, and Bench-Sheko zones of southwest Ethiopia, during the 2015/16 and 2018/19 production periods, no supply of inputs such as improved varieties and fertilizer had been delivered to the farmers which negatively influenced the productivity of crops including garlic (Shege, 2015, Table 1). The government planned to engage in small-scale irrigation. However, there is inadequate irrigation water in some other potential mid to highlands of Ethiopia, resulting in conflict between farmers in irrigation water use. Limited organized market information, linkages, lack, and unapplied government policy and initiatives to overwhelm the issue are major institutional factors (20, Shege et al., 2021, Shibabaw et al., 2017, Singh & Chand, 2003, Siyoum & Yesuf, 2013, and G Tabor et al., 2004). In 1986, garlic research was started at Debre Zeit (Bishoftu) and 5 varieties have been released so far (Getachew et al., 2021). Currently, several organizations collaborate in backstopping, fundraising, technology dissemination, and offering feedback to the vegetable research (Getachew et al., 2021). However, the collaboration
among organizations engaged in the vegetable sub-sector including EHDA\textsuperscript{4} and EHPEA,\textsuperscript{5} while they are not strong as expected [HS Tabor et al., 2021, Table 1].

5.2. Farmer’s characteristics affecting garlic production

Although in this systematic review, about 9.8% articles has been discussing farmers characteristic. Accordingly, farmers characteristic are discussed as follow. A study conducted in the Amhara region by Shege et al. (Shege et al., 2021) shows that most farmers are with less than 5 years of experience in the participation of garlic production. Farmers with less experience produce less garlic production and the vice versa which indicates garlic production directly proportionated with years of experience in garlic production. The use of poor agricultural practices (traditional technologies) is distributed and practiced in this sector. The current work shows that the use of improved variety and fertilizer by farmers have been very weak and negatively viewed in some part of the country particularly, Arsi, West-Omo zone, Sheka, Bench-Sheko, Kaffa, West shewa zone, Gurage, Hadiya and Yemi special district [Shege, 2015, 2021, Shibabaw et al., 2017, Table 2]. Due to the farmer’s background in traditional agricultural production, they are still farming with poor agricultural practices and are not familiar with good agricultural practices (modern farming) yet. The farmer’s education level is less and influences the ability, skill, and perception of farmers to adopt good agricultural practices (new technologies) to boost production. In the study reported by reference (Benyam et al., 2021) about 100%, 97%, 63%, and 60% of the sample in West-Omo zone, Bench- Sheko, Sheka, and Kaffa respectively, indicated that lack of knowledge and skill showed a statistical difference on crop production including garlic production. As revealed by reference (Benyam et al., 2021), except for maize variety, all farmers has been used local seed variety and no application of fertilizer in sheka zone, south-west Ethiopia. From 2015/16 to 2018/ 19, the average land coverage was 48,135.7 ha, while the average improved variety usage for this entire land was only 1,335.5 qt. Consequently, it has been revealed that improved seed variety usage behavior of the West-Omo zone is weak and needs further intervention and training. Moreover, it could indicate that there is a lack of skill, knowledge, poor knowledge dissemination and extension service, and accessibility (Benyam et al., 2021).

5.3. Production and management practices

In Ethiopia, vegetative (clove) means of propagation is common. Farmers has been using local cultivar, improved variety, hybrids, imported varieties in local and modern commercial production system based on accessibility. Any appropriate production and management practices, including propagation method/planting material, plant population density/spacing, mulching, fertilizing, and watering/irrigating, disease, and insect control vary across different environments and varieties. Improved and high yielding variety with wide agroecology adaptability is the main target of breeders for which genotype by environment combination evaluation is paramount important for variety selection, cultivar, and germplasm recommendation leading to identifying potential production in several areas of the country [Bizuyehu, Kebede, et al., 2021, Bongiorno et al., 2008, Debebe, 2022, Debebe et al., 2017, Dessie, 2020, Dessie & Mulat, 2019, Diriba et al., 2020, Diriba et al., 0000, Diriba et al., 2015, FAO, 2015, Mohammed et al., 2014, HS Tabor et al., 2021, Tadesse, 2015, Tamire et al., 2007, Tattelman, 2005, Table 3-12].

Worldwide, garlic is grown in all temperate to subtropical as well as in hilly low land areas (tropical) (Pandey, 2012). However, In Ethiopia, garlic is produced mostly in the sub-tropical (midland) and temperate (highlands) of the country (Dessie & Mulat, 2019; Fasikaw et al., 2020; J Mohammed et al., 2021). As indicated under [Table 6] Angot followed by Ginaza had recommended for high garlic yield production due to overall higher yield obtained from Angot and Ginaza, respectively. It is not surprising that the yield of cultivars at location Angot had statistically higher as compared to the two locations revealing variations in agro-ecology conditions for the production of garlic (Dessie & Mulat, 2019). Similarly, Fasikaw Belay et al. [Taffesse et al., 2012, Table 6] experimented with different locations including, Hagere Selam, Ofa, Hatsebo, Aherom, Hagere Selam, Ofa, Hatsebo, Aherom with an altitude 2632, 2133, 2107, 2027, 2632, 2133, 2100, 2027, respectively. Among these locations, Ofa and Aherom with an altitude of 2107 and 2027
respectively had produced higher garlic yields than other locations [Taffesse et al., 2012, Table 6]. However, a study at Gursum and Kombolcha reported statistically similar garlic yields which might be due to close environmental factors [Bizuayehu, Kebede, et al., 2021, Table 6]. The variation of yield across locations is mainly attributed to the suitability of edaphic and environmental conditions for the revelation of the genetic code of different genotypes, accessions, varieties, and cultivars. Moreover, this emphasizes the effect of varied environmental (climate) factors on the yield of garlic.

Several study revealed that different varieties response differently across areas [Bizuayehu, Kebede, et al., 2021, Bizuayehu, et al., 2021, Bongiorno et al., 2008, Debebe, 2022, Debebe et al., 2017, Dessie & Mulat, 2019, Diriba et al., 2020, Diriba et al., 0000, FAO, 2015, Tadesse, 2015, Taffesse et al., 2012, Tamene et al., 2017, Tamire et al., 2007, Tattelman, 2005, Table 3–5]. For an instance, an evidence to the GGE⁶ and AMMI⁷ biplot models, G9 (Bora-1/16) and G7 had observed as high yielder and stable genotypes. Thus, these genotypes had released for the study area and others with the same agro-ecologies to boost the production of garlic [Bongiorno et al., 2008, Table 3]. According to reference (J Mohammed et al., 2021) an experiment had also conducted during the rainy season for 2 consecutive years (2019 and 2020) at Gursum and Kombolcha districts on farmers’ farms, Eastern Hararghe zone, Oromia region state, Ethiopia with an altitude of 1200–2460 m.a.s.l.⁸ Consequently, Tseday 92 had produced 13.3% and 54.3% yields more than the local and Chelenko I, respectively. At that agro-climate, therefore, Tseday 92 had recommended having sustainable garlic production. During 2010/2011, in Beresa watershed, Mesqanworeda, Guragie Zone of the SNNPR, Ethiopia, with an altitude of 1960 m.a.s.l., two varieties namely Tseday 92 and local had tested at farmers’ fields by using supplementary irrigation [Tamire et al., 2007, Table 3]. Accordingly, Abream Mulatu et al. [Tamire et al., 2007, Table 3] reported that Tseday 92 variety had a superior yield over the local one. However, the study conducted at three locations of the south Gondar zone of Amhara Region in Ethiopia revealed that Tseday 92 (40.88 q/ha) statistically recorded as ranked 3rd next to Holleta (42.74 q/ha) and Cultivars Adizemene local (55.44 q/ha), respectively in descending order (Dessie & Mulat, 2019). Similarly, Ayalew et al. [Bongiorno et al., 2008, Table 3] study conducted at Dabat district of north Gondar with altitude ranges from 1500 to 3200 masl revealed that the lowest fresh bulb weight (5.57 t/ha—1 and 16.70 g per plant) had recorded from the Tseday 92. While the local variety had yielded high (16.56 t/ha—1 and 49.72 g per plant) followed by Kuriftu (35.36 g per plant and 11.78 t/ha—1). The varied yield from different studies indicates the genetic variation of the genotypes, and the alteration of altitude and other environmental factors of the areas.

An appropriate planting method is paramount important in garlic production. It affects garlic growth and development thereby yield. Most farmers use cloves varying in weights/sizes, which might affect plant stand, vegetative growth, bulb yield, and even its quality (Semira & Tefera, 2017; Shege et al., 2021). Garlic clove size used for propagation significantly affects the marketable bulb of garlic. According to the report by (Semira & Tefera, 2017) consistent increased marketable bulb size had revealed in response to an increased weight of garlic cloves. Therefore, the largest-width cloves (with the thickest) had produced from the plot where the largest weigh cloves were planted. Contrarily, plots planted with small-weight garlic cloves produced small-sized garlic cloves [Moher et al., 2009, Table 6]. The highest bulb diameter and bulb length had recorded from medium-weight garlic cloves (1.5–2 g) planting material. Large-sized garlic cloves (2–3 g) weight garlic cloves significantly varied when compared with small-weight garlic cloves (1–1.5 g) cloves in bulb yield. Several scholars indicated that smaller-weight garlic cloves negatively affected its yield [Amare & Mamo, 2020, Bewuketu et al., 0000, Moher et al., 2009, Motuma et al., 2020, Tesfaye & Meroh, 2021, Table 6]. This reveals the failure of the small weight garlic seed cloves in the development of higher bulb size due to low storage food when compared with large weight garlic cloves. While, in the large weight garlic cloves, there might be the presence of a higher quantity of contained food which boosted cell division, cell elongation, and growth resulting in larger bulb yield than the medium and smaller sized (Nasir, 2018). Similarly, Bizuayehu Desta et al. [Amare & Mamo, 2020, Table 6] the longest bulb length (4.03 cm) had recorded by using 3–3.5 g weighted
| Factor                      | Study altitude (m.a.s.l) | Studied Variety/germplasm                         | Recommended variety | Specific region | Specific Zone, District or kebele | Citation                                                                 |
|-----------------------------|--------------------------|--------------------------------------------------|---------------------|----------------|----------------------------------|--------------------------------------------------------------------------|
| **Agronomic practices/factors** |                          |                                                   |                     |                |                                  |                                                                          |
| Cultivars/variety           | 2376                     | DZARC/EIAR, DZARC/EIAR, Around Bora, Around Bora, Bora, Bora, Borki and Brik | Around Bora and Bora | Tigray         |                                  | (Harnet & Yibrah, 2015)                                                  |
| Accession/germplasm         | 2509                     | Sekela - Lijma, Awebel - Dehuma, Dejen - Borbor, Bore - Kebba, Sinan - Debre Zeit, Sekela - Yedem Mariyam, Banja - Satma, Dejen - Giyeb, Sekela-Membeta, Banja - Satma, Awebel - Yazerig Giorgis, Dembecha - Senseb, Gebriel, Dejen - Giyeb, Dejen - Jevu, Kuriftu (S.C), and Bishaftu (S.C) | Banja - Satma, Awebel - Yazerig Giorgis, Dembecha - Senseb, Gebriel, Dejen - Giyeb | Amahara                      |                                  | (Yeshiwas et al., 2018)                                                  |
| Cultivars/variety           | 2710                     | Rie (Local), G-99-2, Bishetfu netch (W-014), G-161-2, and Tseday 92 (G-493) | Tseday 92 followed by Bishetfu netch (W-014) | Tigray         |                                  | (Tadesse, 2009)                                                          |
| Factor                     | Study altitude (m.a.s.l) | Studied Variety/ cultivar /germplasm | Recommended variety | Specific region        | Specific Zone, District or kebele                                      | Citation                                      |
|----------------------------|--------------------------|--------------------------------------|---------------------|------------------------|------------------------------------------------------------------------|-----------------------------------------------|
| Cultivar/Variety           | 2444                     | Bishoftu Nech, Tsedey 92, Kunfu, Felegdaero, Bora-1, Bora-2, and local garlic cultivar (Guahgot) | cultivar Bora 1     | Tigray                 | Gantaofeshum district Eastern Zone of Tigray                           | (Todesse, 2015)                              |
| Accessions                 | Not described            | 81 germplasm accessions              | GOG-065/18 (7327.55 kg/ha) | Oromia                | DZARC, and Chefe Donsa research sub-station                            | (Atinafu et al., 2021)                        |
| Accessions                 | 3,150                    | Twenty-eight garlic accessions       | G16 and G1          | SNNP                   | Ez-o Otte kebele, Chencha district, Gamo zone highlands               | (Tesfaye & Merah, 2021)                      |
| Germplasm/accession        | Greenhouse condition     | 115 garlic germplasm/ accession      | Further study       | Not-Mentioned          | Not mentioned                                                          | (Kalkidan et al., 2021)                      |
| Accession                  | 1990                     | 49 garlic Accessions                 | Further study       | Oromia                 | Debre Zeit                                                            | (Tesfaye et al., 2021)                       |
| Factor                          | Study altitude (m.a.s.l) | Study area | Recommended location | Specific region | Specific Zone, District or kebele | Citation                                                                 |
|--------------------------------|--------------------------|------------|-----------------------|-----------------|----------------------------------|---------------------------------------------------------------------------|
| **Location**                   | 1200 to 2460             | Kombolcha  | No statistical difference among the location | Oromia          | farmers' farm, Eastern Hararghe zone | (J Mohammed et al., 2021)                                                  |
|                                | 1200 to 2938             | Gursum     |                       |                 |                                  |                                                                           |
|                                | Not-described            | Angot, Ginaza, Woreta | Angot              | Amhara          | South Gondar zone                | (Dessie & Mulat, 2019)                                                    |
|                                | 2632                     | Hagere Selam | Ofia and Ahferom      | Tigray          | Hagere Selam Ofia Hatsebo Ahferom Hagere SelamOfia HatseboAhferom | (Fasikaw et al., 2020)                                                   |
|                                | 2133                     | Ofia       |                       |                 |                                  |                                                                           |
|                                | 2107                     | Hatsebo    |                       |                 |                                  |                                                                           |
|                                | 2632                     | Hagere Selam | Ofia                 |                 |                                  |                                                                           |
|                                | 2133                     | Ofia       |                       |                 |                                  |                                                                           |
|                                | 2107                     | Hatsebo    |                       |                 |                                  |                                                                           |
|                                | 2027                     | Ahferom    |                       |                 |                                  |                                                                           |
| **Propagation** (clove size)   | 2840                     | Clove size used | Recommended clove size | Specific region | Specific Zone, District or kebele | Citation                                                                 |
|                                | 1–1.49 g, 1.5–1.99 g, 2–2.50 g, 2.51–2.99 g, and 3–3.5 g | Ofia       | 3–3.5 g              | Amahara          | Demonstration and research site of Debre Berhan University | (Bizuayehu, Netsanet, et al., 2021)                                        |
|                                | Not mentioned            | large (3.60–4.5 g), medium (2.6–3.5 g) & small (1.5–2.5 g) | Kuriftu         | Medium clove weights (2.6–3.5 g) | Oromia                          | Madawalabu University                                                     | (Semira & Tefera, 2017)                                                    |
Table 7. Production and management determinants (spacing, and mulching) affecting yield production of garlic in Ethiopia

| Factor | Study altitude (m.a.s.l) | Spacing (cm) tested | Variety used | Recommended spacing in cm | Specific region | Specific Zone, District or kebele | Citation |
|--------|--------------------------|---------------------|--------------|---------------------------|----------------|----------------------------------|----------|
| Agronomic factors | | | | | | | |
| Spacing | 1864 | 5, 7.5, 10, and 12.5 | Bishaful Netch, Tsdey92, and local | 5 for Bishaful Netch, And Tsdey92 | Tigray | Aksum University Selekeka research and demonstration center, Medebay Zana district, Northwestern Zone | (Mulu & Negasi, 2021) |
| | 1980 | 10, 15, and 20 | local variety (Chiro) | 10 | Oromia | Raware, Eastern Ethiopia | (Mengesha, 2015) |
| | 2600 | 0x40, 5x40, 10x40, 15x40 and 20x40 | Local variety | 20x40 for leaf number | Amhara | South Wollo Zone, at the experimental site of Wollo University, | (Seid et al., 2014) |
| Mulching | Study altitude (m.a.s.l) | Type of mulching | Variety used | Recommended mulching | Specific region | Specific Zone, District or kebele | Citation |
| Mulching (review) | | | | | | | |
| | 1854 | Wheat straw mulch at 4 tons/ha and no mulch. | Not indicated | Wheatstraw mulch at 4 tons/ha | SNNPR | Wolaita Soddo ATVET College, Wolaita Zone | (Mandefro & Shoeb, 2015) |
| | 2750 | black polyethylene mulch, grass mulch, no mulch/ control | Local garlic cultivar | black polyethylene mulch, followed by the grass mulch | Oromia | Fiche, Addis Ababa University, Selale campus demonstration farm. | (Weidemariam et al., 2017) |
| | Any | Any | Any | Mulching | Any | Any | (Yimer, 2020) |
Table 8. Production and management determinant (watering/irrigation) affecting yield production of garlic in Ethiopia

| Factor                  | Study altitude (m.a.s.l) | Irrigation type                                      | Variety used | Recommended irrigation                              | Specific region                      | Specific Zone, District or kebele | Citation                                      |
|-------------------------|--------------------------|------------------------------------------------------|--------------|-----------------------------------------------------|--------------------------------------|-----------------------------------|----------------------------------|
| Agronomic factors       |                          |                                                      |              |                                                      |                                      |                                   |                                   |
| Irrigation/ watering    | 1854                     | 100%, 80% and 60% of ETC (Crop evapotranspiration) | Not indicated | 100%, and 80% of ETC (Crop evapotranspiration)      | SNNPR                                | Wolaita Soddo ATVET College, Wolaita Zone | (Mandefro & Shoeb, 2015)          |
|                         | 2720-3456                | Trickle irrigation & Gravity irrigation method       | Not indicated | Trickle irrigation method                           | Amahara                              | The Wonka Kebelle                  | (Dessie, 2020)                   |
|                         | 1610-1908                | Soil moisture depletion levels (ASMDL) of Irrigation at 60%, 80%, 100%, 120%, and 140% | Tsedey       | Managing the soil moisture content above the allowable depletion level of 60% and 80% | Oromia                               | Debre Zeit Agricultural Research Center, located in Oromia region, East Shoa zone | (Ashebir et al., 2021)          |
garlic cloves planting material. While the shortest bulb length (3.45 cm) had recorded from 1–1.49 g weighted garlic cloves planting material. Consequently, it is shown that the longest bulb length recorded is due to large-sized garlic cloves planting material might be regarded quality as belongs to the higher presence of stored nutrients that resulted in high leaf area index, seems high storage of photoassimilates and translocation to bulb yield.

Plant population/spacing is one of the production and management practices affecting the yield of a plant. Consequently, inappropriate spacing significantly reduces the yield and yield components of garlic. According to the reference (Shege et al., 2021), the assessment report indicated that farmers had planted cloves in a double-row arrangement with 34.8 cm between double-rows, 26.8 cm between rows, and 11.8 cm between plants, which is not in line with the recommendation by researchers. In 2007, EIAR, cited in (Shege et al., 2021) recommended that planting space is 30, 15, and 10 cm between double rows, rows, and plants for improved garlic clove varieties, respectively. However, spacing can be varied from location to location, season to season, and variety to variety since it affects the yield of garlic. In different areas, scholars recommended different spacing between plants (intra row spacing) which significantly affect bulb yield and yield components. Mengesha, and Tesfaye [Kalkidan et al., 2021, Table 7] indicated that the high garlic yield (7.87 t/ha) had been recorded from 10 cm spacing between plants (intra row) while the low garlic yield (4.85 t/ha) had observed from 20 spacing (intra row). The study conducted at Aksum University, Selekleka research and demonstration center, Tigray, elucidated that the highest garlic bulb yield had recorded from the combinations of 5 cm spacing (intra-row) with Tsedey 92 and Bishoftu Netch improved varieties due to the absence of statistical difference with the yield recorded from combinations of same intra-row spacing (5 cm) [Dessie & Mulat, 2019, Table 7]. This reveals to utilize effectively a given land through a dense population. Wide spacing between plants has been employed by the producers/farmers resulting in a low bulb yield of garlic. Thus, having appropriate garlic plant density or spacing as recommended by researchers is paramount important to enhancing the production of garlic.

Mulching is one of the good agricultural practices which involves placing inorganic or organic materials on the soil plants to provide a suitable environmental condition for the growth and development of a plant. It reduces soil moisture loss by preventing evaporation, breaking winds, and regulating the temperature of the soil which regulates the effect of encouraging root growth and there determines the yield of the garlic. Black polyethylene (plastic) and different plant straws are mostly used in Ethiopian vegetable farms or fruit nurseries. Bark chunks, pine needles, and wood chips are suitable mulching materials. A review by Ousman (Yimer, 2020) indicated that fine mulches, such as wood shavings, buckwheat hulls, bark granules, and cocoa shells are attractively used in beds.Figuratively, a study conducted by [Pandey, 2012, Table 7] showed that wheat straw mulch had positively influenced the total yield of garlic (68.6 qt/ha) which had a real (p < 0.05) difference than without mulch total yield (62.8 qt/ha) plots. This revealed that the increased yield is due to wheat straw mulch effectively conserving soil moisture and retrieving other functions of mulching. Weldemariam Seifu et al. [Tesfaye et al., 2021, Table 7] also reported that black polyethylene and grass mulch boosts garlic leaf number by 5.466 and 4.166 respectively when compared with no mulching. In Ethiopia, there are limitations in the published research conducted on mulching materials and mulching-related works. Further research and publication therefore kindly be suggested.

Regularly, watering garlic throughout the growth is required for its maximum potential production. Irrigation/watering are paramount since garlic root depth is shallow. Insufficient watering or lack of irrigation (rainfall) when garlic reaches the bulbing stage, will result in few bulbs which cause early maturation. Water stress during plant growth and development deducts potential yield. A study by Dessie Gieta (Dessie, 2020) reported that the level of soil moisture affects not only the yield of garlic but also its bulb quality which is kindly affected by irrigation system/method [Table 8]. The trickle irrigation system/method is advantageous over the gravity irrigation method since the trickle system uses water efficiently and also high yield production. Reference [Thomson,
| Factor                        | Study altitude (m.a.s.l) | Fertilizer levels kg ha⁻¹ | Variety used       | Recommended fertilizer level (kg/ha) | Specific region     | Specific Zone, District or kebele | Citation                                                                                     |
|------------------------------|--------------------------|---------------------------|--------------------|--------------------------------------|---------------------|-----------------------------------|--------------------------------------------------------------------------------------------|
| Agronomic factors            |                          |                           |                    |                                      |                     |                                   |                                                                                             |
| Nitrogen (Urea) Fertilizer   | 1856                     | 0, 46 and 92              | Local variety      | 92                                   | Amhara              | Kechin Abeba Lasta district, North Wollo Zone | (Workat et al., 2018)                                                                      |
|                              | 2006                     | 0, 52.5, 80, 105 and      | Chelenko I’        | 130                                  | Oromia              | Haramaya University main campus, Rare Research Field | (Fikru & Fikreyohannes, 2018)                                                              |
|                              | 1750                     | 0, 50, 100 and 120        | Minjar nech shunkurt | 100                                  | Oromia              | Jimma University, college of Agriculture and Veterinary medicine, Horticultural farm | (Adem et al., 2014)                                                                      |
|                              | 2800-2845                | Below recommend level by 50% (114.13), recommended rate (228.28), above recommend level by 25% (278.33), and control (0-0-0) | Local variety      | Above recommend level by 25% (278.33 kg N ha⁻¹) | Amahara              | Debre Berhan University agricultural demonstration site, north Shewa zone | (Amare & Mamo, 2020)                                                                      |
|                              | 1860-1900                | 0, 92 and 138             | Tseday             | 92                                   | Oromia              | Experimental research station of Debre Zeit Agricultural Research Centre (DZARC) | (Diriba et al., 2015)                                                                    |
| Phosphorus fertilizer        | 3207                     | In the form of TSP 0, 46, 69 and 92 | Not indicated     | 46                                   | Oromia              | At Dinsho district of Bale zone                                           | (Guta, 2019)                                                                               |
### Table 10. Production and management determinant (fertilization) affecting yield production of garlic in Ethiopia

| Factor                     | Study altitude (m.a.s.l) | Fertilizer levels kg ha−1 | Variety used                           | Recommended fertilizer level (kg/ha) | Specific region                      | Specific Zone, District or kebele | Citation                                                                 |
|----------------------------|--------------------------|---------------------------|----------------------------------------|-------------------------------------|-------------------------------------|-----------------------------------|----------------------------------------------------------------------------|
| Agronomic factors          |                          |                           |                                        |                                     |                                     |                                   |                                                                            |
| Phosphorus fertilizer (P2O5) | 1856                     | Four P2O5 levels (0, 23, 46 and 69 kg P2O5 ha−1) | Local variety                          | 46                                  | Amhara                              | Kechein Abeba Lasta district, North Wollo Zone | (Workat et al., 2018)                                                       |
|                            | 2450                     | 0, 46, 92                 | Tsedey 92 (G-493)                      | 92                                  | Amhara                              | Mertule Mariam Agricultural Technical and Vocational Education and Training (MMATVET) College, | (Alemu et al., 2016)                                                        |
|                            | 1860–1900                | 0, 40, and 80             | Tseday                                 | 40                                  | Oromia                              | Experimental research station of Debre Zeit Agricultural Research Centre (DZARC) | (Diriba et al., 2015)                                                       |
| N-P-S fertilizer           | 3,108                    | 0–0–0; 70–21–9; 112–37–16; and 159–58–25 | Local garlic cultivar “Gayint Necho”   | 112–37–16                           | Amhara                              | Rural village of 011 At Taria irrigation site in one of northwest Ethiopian highlands known as Lay Gayint. | (Alemayehu & Abate, 2021)                                                    |
### Table 11. Production and management determinant (Disease) affecting yield production of garlic in Ethiopia

| Factor                        | Study altitude (m.a.s.l) | Type of management to | Variety used          | Recommended management                                      | Specific region | Specific Zone, District or kebele | Citation                                                                 |
|-------------------------------|--------------------------|------------------------|-----------------------|----------------------------------------------------------------|-----------------|-----------------------------------|--------------------------------------------------------------------------|
| Diseases (Garlic rust)        | 2400                     | Tilt 250EC, Rex Due, Propiconazole, Rova and untreated control | Tseday                | Spraying Rex Duo twice at 21-days interval starting from the onset of the disease | Oromia          | At Holetta Agricultural Research center for two years 2017 & 2018 | (Habtewold et al., 2019)                                                |
|                               | 2750                     | Five rates of propiconazole (0.5, 0.75, 1, 1.25, and 1.5 L/Ha) and three spraying frequencies in 10 day interval (one, two, and three times spray) and unsprayed treatment as a control check. | Local garlic variety | Spraying of 0.5 liters propiconazole with two times | Amahara         | Woreilu District on two farms (Kabe and Segna Kebeles).            | (Kassaw & Ayalew, 2021)                                                 |
| Disease (garlic rust and rot) | 2463, 2724, and 2509, respectively. | Apron Star, Hot Water, Hot water + chemical and Farmers Practice | Bora local garlic variety | Hot water treatment is feasible | Tigray          | 3 major garlic growing highland Kebeles of Emba-Aloje(Atsela and Ayba) and Enda Mekoni (Simret Woredas) | (Abraha et al., 2015)                                                   |
| Factor                                    | Study altitude (m.a.s.l) | Type of management to            | Variety used                  | Recommended management | Specific region | Specific Zone, District or kebele | Citation                                      |
|------------------------------------------|--------------------------|----------------------------------|--------------------------------|------------------------|-----------------|-----------------------------------|-----------------------------------------------|
| **Agronomic factors**                    |                          |                                  |                                |                        |                 |                                   |                                               |
| Disease (garlic rust)                    | Bale High land           | 1 L·ha⁻¹ in four different spray schedules viz., every 7, 14, 21 and 28 days. | Improved “MM-98” variety and local | Every 7 days       | Oromia           | At Sinana Agricultural Research Center | (Y Worku & Dejene, 2012)                     |
|                                          | 1980                     | Bayleton, mancozeb, ridomil and propiconazole and a control | local garlic variety (chiro)   | Propiconazole          | Oromia           | At Raaree, Haramaya, Eastern Ethiopia | (Worku et al., 2016)                          |
| Disease (garlic white rot)               | 2000                     | Tebuconazole (Folicur 25 EC 2.1 ml kg⁻¹), mancozeb (80 WP 4.17 g kg⁻¹) and captan (Merpan 50 WP 4.17 g kg⁻¹). | Local garlic cultivar          | Tebuconazole (Folicur 25 EC 2.1 ml kg⁻¹) | Tigray           | At Mekell Agricultural Research Center experimental site | (Siyoum & Yesuf, 2013)                       |
|                                          | 1980                     | Tebuconazole as a clove treatment and supplemented basal spray, benomyl, mancozeb, captan and thiram | Tseday (G-493) and local garlic cultivars captan | Tebuconazole and captan | Oromia           | At the Debre Zeit and Bakelo areas of North Shewa | (Tamire et al., 2007)                         |
| Factor                     | Study altitude (m.a.s.l) | Type of post-harvest factor and management | Variety used | Recommended post-harvest management | Specific region                                      | Specific Zone, District or kebele | Citation                                                                 |
|---------------------------|--------------------------|------------------------------------------|--------------|-------------------------------------|-----------------------------------------------------|-----------------------------------|----------------------------------------------------------------------------|
| Harvesting                | 2,002 and 1,160          | Harvesting time (60%, 80%, and 100% top fall) | Tseday       | At 80% top fall                     | Oromia and Dire Dawa                                 | Haramaya University and Tony farm(Dire Dawa) | (Bizuayehu, Kebede, et al., 2021)                                          |
| Curing                    | 2,002 and 1,160          | curing levels (non-cured and cured-topped) | Tseday       | cured-topped                        |                                                     |                                   |                                                                            |
| Storage method            | 2,002 and 1,160          | storage methods (wooden shelf, nylon net bag, and floor) | Tseday       | wooden shelf and net bag            |                                                     |                                   |                                                                            |
| storage sites             | 2,002 and 1,160          | storage sites (Haramaya University and Dire Dawa representing lowland) | Tseday       | Haramaya University                 |                                                     |                                   |                                                                            |
| Storage season            | 1860                     | the off-season of 2011/12 under irrigation (first season) and during the rainy Season of 2012/13 (second season). | Tseday       | rainy season storage                | Oromia At the experimental farm of Debre Zeit Agricultural Research Centre |                                   | (Diriba et al., 0000)                                                     |
| Storage duration          | 1900                     | Storage duration (weeks 2,4,6,8,10, and 12) | Garlic cultivars (W-011,W-014, G-457 and G-571) | more than 12 weeks of ambient temperature and RH storage |                                                     |                                   | (G Tabor et al., 2004)                                                    |
2007, Table 7] also revealed that the drip method saved 27.20% and 29.40% of water during Kharif & Rabi periods, respectively. In another setup, Ashebir Haile et al. (Ashebir et al., 2021) indicated that garlic production with varied irrigation methods at different levels of depletion had statistically affected the bulb yield. Accordingly, 7.45 t/ha marketable yield had observed from the frequently irrigated plot as the highest record compared to the yield (4.68 t/ha) of the wider interval which was 40% plus of allowable soil moisture level [Table 8]. Mandefro Chala and Shoeb Quraishi (Mandefro & Shoeb, 2015) concluded that the application of 80%ETc can produce a comparatively high garlic yield than that of full irrigation which saves water efficiently to boost the yield of garlic [Table 8]. In Ethiopia, only survey reports and publications on the impact of small-scale irrigation schemes, data acquisition and modeling of Irrigation strategies in a Small-scale irrigation scheme, and wastewater irrigation is indicated [Nasir, 2018, Tindal, 1986, Weldemariam et al., 2017, Workat et al., 2018, Worku et al., 2016, Table 8]. However, watering or irrigation method/ system research and publication is very limited which needs holistic support for research and publications to work.

In Ethiopia where garlic has been produced, low soil nutrients are the 2nd main factor affecting the production of garlic next to moisture stress. According to reference (Shege et al., 2021), garlic can be cultivated in a variety of soil types including black heavy soils and red soils. Suitable soil contains organic matter, adequate moisture-holding capacity, pH of 6.5–7.5, and is well-drained is ideal for garlic production in Ethiopia highlands. Fertilizing garlic medicinal plants is an important production and management practice like any vegetable production for those fertilizers needed as promote yield. Worldwide including in Ethiopia, as it is investigated by several scholars, in-organic and organic fertilizers have a significant impact on garlic yield and yield-related traits (Diriba, 2016). In Ethiopia, urea and diammonium phosphate (DAP) fertilizer had been utilized for a long time as nitrogen and phosphorous for maximum yield (Bewuket, 2021). Consequently, a new inorganic fertilizer (NPS) to replace DAP, consisting of phosphorous (P2O5), nitrogen (N), and sulfur (S) by the ratio of 38%, 19%, and 7%, respectively, had introduced by Ethiopian Ministry of Agriculture. In the country, several studies have been studied for optimum rate recommendation. Accordingly, Fikru and Fikreyohannes [Habtu et al., 2019, Table 9-10] indicated that garlic clove weight had significantly risen by 18.47% due to increasing the rate of nitrogen from control (without N-fertilizer) to 130 Kg ha−1. In their study, nitrogen fertilizer application revealed very high significant effects on fresh biomass which is increased by 73.80% over without N fertilizer application (control). Economically, about 398,701 ETB 10 ha−1 (highest net benefit) had been obtained from the application of 130 kg nitrogen fertilizer per hectare, whereas 336,800 ETB ha−1 (the least net benefit cost) had been obtained from unfertilized (Fikru & Fikreyohannes, 2018). Verma et al. [Abraha et al., 2015] also reported that nitrogen fertilizer increases the net returns of garlic [Table 4]. Testing this, a maximum marginal rate of return % (1,976.36%) with an application of 130 kg N ha−1 had been recorded, whereas the minimum (336,800, 1,127.07%) had indicated with nil nitrogen application. Similarly, a study from northern Ethiopia indicated that 7.11 t ha−1 of bulb yield is obtained from a land fertilized with a nitrogen rate of 92 nitrogen kg ha−1 followed by 46 nitrogen [Table 9-10] While other levels of nitrogen rates had shown a declining trend in bulb yield and the least mean yield (4.8 t ha−1) had been recorded from a plot without nitrogen fertilizer (Workat et al., 2018). Reference [Habtewold et al., 2019, Table 9-10] also revealed that nitrogen fertilization highly (p < 0.01) influenced garlic yield dry weight, the maximum dry weight had been recorded at 278.33 kg N per hectare. (Diriba et al., 2015) reported a similar pattern which indicates that nitrogen fertilizer increases the growth, yield, and yield components of the garlic [Table 9-10].

Phosphorus is another essential nutrient for the development of roots which affects the growth, development, and yield of plants including garlic due to its involvement in a lot of biochemical and physiological processes (Guta, 2019; Workat et al., 2018). Alemu Degwale et al. [AW Worku & Mehari, 2018, Table 9-10] revealed that phosphorous application at the rate of 92 kg P2O5 ha−1 has risen the mean garlic clove weight by 20.7% more than the control (without application of phosphorous fertilizer). Reference (Diriba et al., 2015) also shows that phosphorus application on
both Vertisols and Andosols at the rate of 40 kg P ha⁻¹ led to the production of maximum garlic clove compared with application of zero kg per hectare.

Sulfur and Potassium uptake imbalance to nitrogen and Phosphorous can incline to dangerous plant disease and insect damage (Diriba et al., 2015). As a result, the crops tend to have less shoot growth and low yields as well as the quality which minimizes the viability of such precious crops. Therefore, NPS fertilizer is currently stabilizing the gap between the interaction of nitrogen, phosphorous, and Sulfur which significantly affects the yield of garlic in Ethiopia. Alemayehu Getachew and Abate Asefa [Ashebir et al., 2021, Table 9–10] reported that application of the combined NPS inorganic fertilizers with 112–37–16 kg ha⁻¹ had provided the highest yield, net returns, and MRRs which is recommended for garlic producer farmers in the northwest Ethiopian highlands. The study from Gurage zone, southern Ethiopia revealed that the bulb yield of garlic had significantly affected by the various rates of NPS fertilizer, the highest yield (14.91 t ha⁻¹) was recorded from 57: 114: 21 kg/ha NPS which is 65% higher than no application of NPS fertilizer (Bewuket, 2021). However, reference (Amare & Mamo, 2020) point out that 78.75–69-12.75 N-P-S ha⁻¹ had recommended for fresh garlic production as it shows significantly higher fresh yield and quality. The varied recommendation is due to different experimental setup and other agro-ecological contributions [Table 9–10].

Organic fertilizer like compost is often used as an option for inorganic fertilizers. As cited in reference (Alemu et al., 2016) reported by Hargreaves et al., (2008) bio-fertilizers application including vermicomposts had been known as an effective means for modifying soil structure, aggregation, and fertility, rising microbial populations, and diversity increasing Cation Exchange Capacity (CEC) of soil, improving soil moisture-holding capacity and thereby increasing crop yields. According to Alemu Degwele et al. (Alemu et al., 2016) report, risen application of vermicompost from 0 to 5 t per hectare significantly had increased the total bulb yield of garlic by 9.57%. Cattle manure application can result in significant improvement of physic-chemical properties of soil. In agreement with the (Alemu et al., 2016) results, Alemayehu Getachew and Abate Asefa (Alemayehu & Abate, 2021) also revealed that applications of different levels of organic fertilizer improved the Physico-chemical properties of crop soils and thereby significantly influenced the yield of garlic.

Insect pests and diseases have been a problem for garlic production in Ethiopia (Abraha et al., 2015; Abraham et al., 2019; Adem et al., 2014; Agegnehu et al., 2013; Amare & Mamo, 2020; Assefa & Abro, 2015; Bewuket, 2021; Dejene M. Worku & Dejene, 2012; Fikru & Fikreyohannes, 2018; Gashaw & Gashaw, 2021; Habtu et al., 2019; Kassaw & Ayalew, 2021; Mengesha, 2015; Merga, 2019; Shege et al., 2021; Siyoum & Yesuf, 2013; Taffesse et al., 2012; Tamire et al., 2007; Workat et al., 2018; Zewde Fininsa et al., Zewide et al., 2007). Several scholars revealed pests and diseases including Garlic Rust (Puccinia allii Rudolphii) (Adina et al., 2022; Habtewold et al., 2019; Kassaw & Ayalew, 2021; Shege et al., 2021; Siyoum & Yesuf, 2013; Worku et al., 2016; Y Worku & Dejene, 2012), Purple blotch (Adina et al., 2022), downy mildew (Peronospora destructor Berk.) (Shege et al., 2021), basal rot (Sclerotium rolfsii Sacc.) (Shege et al., 2021), white rot (Sclerotium cepivorum Berk.) (Abraha et al., 2015; Shege et al., 2021; Siyoum & Yesuf, 2013; Tamire et al., 2007) and Onion thrips (Thrips tabaci Lind.) (Shege et al., 2021), thrips (Thrip stabaci L.) (Shege et al., 2021). Viruses are also one of the major important factors in the garlic-producing area of the world including Ethiopia. In Ethiopia, the existence of four garlic viruses OYDV, LYSV, GV-B, and GV-C was established (Kero et al., 2015). According to Abraham (Abraham et al., 2019) Garlic collected from 75% of producer’s fields in Ethiopia had found to be present by at least one virus belonging to either allievirus, potyvirus, tospovirus or carlaviruses groups. In addition to previously reported viruses like Onion yellow dwarf virus (OYDV), Leek yellow stripe virus (LYSV), and Garlic virus C, for the first time reference (Abraham et al., 2019) revealed new viruses such as Garlic viruses-X, –D, Iris yellow spot virus (IYSV) and Shallot latent virus (SLV). These viruses were introduced to Ethiopia from Europe and Asia as indicated by Phylogenetic analysis. It is also revealed that the high incidence of IYSV and OYDV which leads to severe yield loss individually or together infection with
garlic viruses and allenviruses is a pain for the producers. Supporting this, K. Jerim et al. (Kero et al., 2015) investigated that common symptoms are stunting of the plants, strip, and yellow mosaic. GV-B is the most frequently occurred virus followed by OYDV which indicated that both Allenvirus and Potyvirus are common in Ethiopia (Abel, 2017; Debebe et al., 2017; Kero et al., 2015; Yohanis et al., 2020). Reference (Abel, 2017; Debebe et al., 2017) revealed that Potyvirus is widely spread across a garlic-producing area of Ethiopia by infecting either improved varieties like Tseday, Kuriftu, and Bishoftu nec, improved cultivars, or frequently used local accessions.

Among garlic diseases, white rot (Sclerotium cepivorum) and garlic rust (Puccinia aalii) are the most serious diseases in the world including Ethiopia (Abraha et al., 2015; Abraham et al., 2019; Abrha et al., 2015; Adam et al., 2014; Adina et al., 2022; Agegnehu et al., 2013; Amare & Mamo, 2020; Assefa & Abraha, 2015; Bewuket, 2021; Dejene M. Worku & Dejene, 2012; Fikru & Fikreyohannes, 2018; Gashaw & Gashaw, 2021; Habtewold et al., 2019; Habtu et al., 2019; Kassaw & Ayalew, 2021; Mengesha, 2015; Merga, 2019; Shege et al., 2021; Siyoum & Yesuf, 2013; Taffesse et al., 2012; Tamire et al., 2007; Workat et al., 2018; Worku et al., 2016; Y Worku & Dejene, 2012; Zewde Fininsa et al., Zewide et al., 2007). Garlic rust is caused by Puccinia allii fungal disease which is the major destructive disease in approximately all garlic-producing areas of Ethiopia (Mengesha, 2015; Worku et al., 2016). It has been known that rust infects garlic plants at the bulb formation growth stage which significantly affects the yield of garlic (Shege et al., 2021)

According to Habtewold Kifelew et al. [Yimer, 2020, Table 11] Propiconazole and Rex Duo had found to be a superior solution in controlling garlic rust and contribute to the highest yield of 1913 kg/ha and 1881 kg/ha in 2017 and 2018 respectively. It is revealed that about 106% yield advantage had obtained from Rex Duo sprayed treatment in 2017, while 37.8% in the 2018 producing season [Yimer, 2020, Table 11]. At the Kabe area (Kassaw & Ayalew, 2021) it was also reported that the maximum 8047 kg ha−1 yield is recorded from treatment treated with 1.25 Litter of propiconazole by three times spraying frequency, while, at Segno, a similar 8047 kg ha−1 yield had reported from 1.5 L by three times spraying frequency. Oppositely, the lowest yield (4660 and 4740 kg ha−1) had been found from untreated plots from Kabe and Segno, respectively (Kassaw & Ayalew, 2021). However, it has been indicated that spraying frequency is an economically paramount factor in rates of propiconazole for the management of rust disease in which the highest (6896.36%) marginal rate of return had obtained at the average plot treated with 0.5 L with two times spraying of propiconazole fungicide [Table 4]. According to [Worku & Dejene, 2012, Table 11-12] the highest severity of garlic rust level (82.77%), was recorded in the unsprayed fungicide garlic plantation which tends to total garlic yield losses of 58.75%. Moreover, reference [Worku et al., 2016, Table 11-12] indicates that among the garlic plantation treated with 4 fungicides (propiconazole, mancozeb, ridomil, and bayleton, garlic plantations treated with propiconazole lowered disease severity (3.72%), whereas greater disease severity (73.47%) had observed from garlic plantations treated with bayleton which is not significant compared with the control/no chemical spray (83.45%) at the 128 days. Consequently, a very low (5.59 t ha-1) yield had harvested from the plantation with high severity of the garlic rust which is treated with bayleton, whereas the highest yield from garlic plantation treated with ridomil and mancozeb had recorded 7.35 t ha-1 and 6.43 t ha-1, respectively, which is near to the best fungicide (propiconazole) resulted in higher (8.28 t ha-1) garlic yield. Worku [Worku et al., 2016] cost-benefit analysis supported that using propiconazole forges a high net return of 139,050 Ethiopian birr ha-1 due to fungicide effectiveness. Generally, it has been revealed that garlic rust disease could cause more than 49.33% yield loss if garlic plantations are not protected. Thus, propiconazole is suggested to protect against garlic rust disease.

White rot garlic disease is caused by Sclerotium cepivorum Berk (Tamire et al., 2007). Garlic marketable yield production has been significantly reduced due to White rot (Abrha et al., 2015). According to [Abrha et al., 2015, Table 11] in both seasons, white rot could be reduced by different management chemicals, hot water, chemical + hot water. Traditionally, hot water followed by
chemical treatment lowered the incidence and severity of white rot which tends to result in a high yield. However, the lowest marketable yield and the highest infected yield had recorded from the control plantation due to higher incidence and severity of white rot. Therefore, hot water treatment is important to manage the incidence and severity of white rot disease which seems to result in higher marketable yield and is preferable by farmers in easiness accessibility and environmentally sustainable. But, in the Simret Kebele, even though white rot disease incidence had 100% in the garlic plantation, relatively the highest garlic yield had observed from the chemical treated plantation in the second season [Table 11].

Siyoun M, and Yesuf M (Siyoun & Yesuf, 2013) reported that tebuconazole, capatan and mancozeb treatment reduced final garlic white rot disease incidences by 74.33%, 34.45%, and 31.25%, respectively, as compared to no treatment of chemicals [Table 11]. Besides, different levels of tebuconazole treatment of garlic cloves resulted in significant differences in white-rot incidence and severity thereby varying the yield of garlic. According to (Tamire et al., 2007) treating garlic plantation with tebuconazole at the rate of 2.1 ml kg\(^{-1}\) and spray at 0.25 l ha\(^{-1}\) at stem bases resulted in a significant reduction of white-rot incidence, progress rate, and severity on bulbs [Table 11-12]. Comparatively, benomyl at 5.2 g kg\(^{-1}\) and Captan at the rate of 4.17 g kg\(^{-1}\) had resulted in a significant reduction by 24% and 16% respectively, compared with control at Bakelo, while at Debre Zeit these fungicides decreased the garlic white rot disease incidence by 40–44% (Tamire et al., 2007). As a result, it had revealed that the highest marketable yield had recorded from garlic treated with captan (48–77%), tebuconazole (43–73%), and benomyl (42–64%) over the control, while Thiram subsequently had not proven effective [Table 11–12]. Generally, the Garlic yield of varieties or cultivars could be improved by fungicide application depending on the season, location, and general setup.

The best garlic cultivation technology method is holistic and comprehensive by applying appropriate production and management practices like propagation, spacing, mulching, irrigation, fertilization, integrated pest and disease control, and suitable production area with monoculture and intensive cropping system depending on varieties.

5.4. Post-harvest factors
Post-harvest handling is the branch of horticultural science which addresses issues of harvesting time, handling, curing, storage method, site, duration and season, and transportation of the crops. This affects planting material of garlic lends to influence germination, growth and bulb yield production of garlic. According to (Debebe, 2022). The extent of post-harvest losses for fruit and vegetables is 33.38%. To reduce post-harvest losses appropriate management of post-harvest factors including harvesting, curing, and storage condition is paramount. Garlic maturity is depending on its intended utilization. When garlic is to be harvested, the proper time of physiological and commercial or horticultural maturity is a primitive for an appropriate clove to plant. Early and/or delayed harvesting of garlic cloves causes post-harvest losses in the field of horticulture. It leads to yield small bulbs that boost rapid weight loss, cracking of the bulbs, and shrinking skins, whereas beyond harvesting time results in discolored, split, burned, and sprouted bulbs. Therefore, searching for appropriate post-harvest practices is mandatory to maintain quality and prolong the shelf life of garlic.

[Bizuayehu, et al., 2021, Table 12] revealed that the largest weight loss had been recorded in bulbs harvested at 60% of top fall followed by 100% top fall harvest. The study also indicated that the minimum bulb weight loss (22.10%) and some sprouted bulbs (8.33%) had been observed in bulbs harvested at 80% top fall, respectively. Curing is the technique that exposes garlic to dry off the necks, roots, and outer scale leaves of the bulbs, and runoff moisture from the outer layers of the garlic bulb before storage. Cured garlic bulbs are more advantageous by 23.52% than non-cured bulbs and bulbs stored on a shelf or in a net bag maintain the quality and prolong shelf life over floor storage. [Diriba-Shiferaw et al., 2016, Table 12] reported real differences in weight losses of stored garlic bulbs as influenced by storage season. It indicates that higher bulbs weight loss
had observed in the dry storage season than in the rainy season which implies that storing garlic bulbs in the dry season risen bulbs' temperature, and rate of respiration and in turn boosts garlic bulb's weight loss that reduces shelf life and quality under normal storage environment [Table 12]. Regarding sprouting, (G Tabor et al., 2004) it has been revealed that even if garlic cloves are stored for twelve weeks, additional 6.5 weeks is required to attain maximum sprouting time [Table 12]. These additional weeks determine the time to maturity of the garlic crop. Uniformity of garlic maturity and harvesting, therefore, after harvesting longer than 12 weeks is recommended under Ethiopian ambient conditions to maintain quality and enhance the yield of the garlic crop.

6. Summary, conclusion and recommendation
Nationally and internationally, Garlic has been a big demanded crop due to its medical and economical contribution. Even though Ethiopian agro ecology has been an opportunity and potential for garlic production, currently garlic productivity in Ethiopia is below potential due to several abiotic and biotic factors. To solve these problems several scholars have been tried to investigate; assessing constraints of garlic production including institutional and farmer’s characteristics, selection of appropriate locations, variety, propagation, spacing, mulching irrigation or watering, fertilization, pests and diseases, harvesting time, and method, curing, storage site, storage season and storage duration. Additionally, the interaction of those factors has been also considered. However, it could be concluded that findings published in reputable journals discussing determinants affecting garlic production are limited. Specifically, studies concerned about insect pests, farmer’s characteristics, location, propagation (clove size and weight), spacing, mulching, watering/irrigation methods, and post-harvest practices like harvesting time and methods, curing, storage (storage site, methods, duration and season), value chain management and transportation are very low. Research institutions and universities; and agricultural office have not been multiplied and provided enough planting materials, training and extension service about entire production and management; and post harvesting technology for farmers who engaged garlic production which is negatively affected garlic production in the country. Besides, finance institutions has not been provided sufficient credit access for the farmer’s. Farmer’s characteristic like garlic production experience, farmer’s perception, farmer’s knowledge and skill regarding with garlic production strongly influenced garlic production. This study also shows the lack of accessibility for producers by the market information institutions. Therefore, firstly, the current systematic review study revealed a gap (limitation of the published research work) of research focused factors affecting garlic production. Secondly, the presence of poorly done and unpublished research works was also observed, in bachelors, masters, and doctorate13 degree students and researchers from at least 30 Government universities and research institutions have been conducting research. Finally, based on ten year strategy of agriculture transformation agency, it is also concluded that government research affairs haven’t specific strategic plan to wards factors affecting garlic production in Ethiopia. Thus, based on this systematic review, the following suggestions are pointed out as recommendations.

- To have opportunity, potential, bases and use different agricultural innovation and technology, research on national wide (Ethiopian country-wide) institution determinants and farmers’ characteristics that affects garlic production should be investigated. There might be unknown opportunity and potentials to boost garlic production in Ethiopia.
- Especial movement for scientific research and publication on insect pests, farmer’s characteristic, location, propagation (clove size and weight), spacing, mulching, watering/irrigation methods, and post-harvest practices like harvesting time and methods, curing, storage (storage site, methods, duration and season), value chain management and transportation should be initiated and engaged by national research and publication affairs.
- Unpublished quality research should be published and researcher who poorly conducts research should follow a web of science, Scopus/Elsevier, and PubMed research principles and methodologies.
- Ethiopian agriculture research institutions, universities, national research directorate, Ethiopian horticulture producers and export association, Ethiopian horticulture association, and horticulturists should focus on factors that affect the production of garlic and play their role in the gaps pointed out via this systematic review.
Extension and Capacity building training for farmers or producers should be given by research institutions, universities, associations, and horticulturists to set up farmers’ or producers’ perceptions.

Variety/cultivars/germplasm/accessions/ should be cultivated in the preferable weather condition (location) to boost the production and productivity of garlic.

Since scholars reported high yield from other spacing than national recommended spacing, specific area research-based spacing is recommended.

Black polyethylene mulching followed by the grass (straw) mulching is optionally suggested.

60%, 80%, and 100% of ETC (Crop evapotranspiration) and Trickle irrigation method is available as a suggestion based on the weather condition of the area.

Scholars revealed higher yields from other fertilization rates and types than national recommendation and it is also highly varied over locations. Thus, a specific area of research-based fertilization is suggested.

Spraying Rex Duo twice at 21-days intervals starting from the onset of the disease, 0.5 liters propiconazole two times, and hot water treatment is used to control garlic rust diseases based on location and other production and management practices.

Tebuconazole (Folicur 25 EC 2.1 ml kg-1) and captan are the most effective chemotherapy used to control garlic white rot.

Harvesting at 80% top fall, top-curing, wooden shelf and net bag, rainy season storage with more than 12 weeks of ambient temperature, and RH storage are suggested to maintain quality and prolong the shelf life of garlic. Furthermore, research and publication on garlic are too limited, thus it is kindly recommended to do so.

It is also an important problem that there is no specific journal for garlic production, garlic products, traditional, technological and molecular techniques used in garlic products, and the use of garlic in medicine. Therefore, the author suggests that specific journal for garlic production, products, traditional, technological and molecular techniques used in garlic products, and the use of garlic in medicine should be established.

For the future climate change might challenge garlic production in Ethiopia. Therefore, garlic breeders should stand up for garlic improvement program.

Acknowledgements
The author appreciate Simeneh Tamrate for his technical editing.

Funding
This work was supported by the Bule Hora University [55].

Author details
Gebre Garmame Galgaye
E-mail: gebregarmame@gmail.com
ORCID iD: http://orcid.org/0000-0001-6700-8240
1 Department of Horticulture, Bule Hora University, Bule Hora, Ethiopia.

Disclosure statement
No potential conflict of interest was reported by the author(s).

Citation information
Cite this article as: Revealing determinants that affects garlic production in Ethiopia using PRISMA methodology, Gebre Garmame Galgaye, Cogent Food & Agriculture (2022), 8: 2132845.

Notes
1. Planting material used to propagate garlic
2. SNNPR represents the southern Nation Nation Nationality People Region
3. NGO-Non Government Organization
4. EHDA stands for Ethiopian Horticulture Development Agency
5. EHDA stands for Horticulture Producers and Exporters Association
6. GGE-Genotype plus Genotype by Environment interaction
7. AMMI-Additive Main effects and Multiplicative Interaction
8. M.a.s.l-stands for meter above sea level
9. EIAR stands for Ethiopia Institute of Agricultural research
10. ETB-Ethiopian Birr(currency)
11. Doctorate stands for Doctor of philosophy
12. Extents of factors according to the scholars study
13. Regional state consists collection of zones
14. Zone is the unit of administrative structure consists a group of districts.
15. District/mereda, a group kebeles
16. Kebele is the lowest administrative structure unit in Ethiopia
17. Special district is a special structure which is directly responsible to regional state though they do not qualify to have zonal status.
18. S.C. Stands for standard check
19. DZARC-Debre Zeit Agricultural Research Center
20. EIAR-Ethiopia Institution of Agricultural Research

References
Abate, A. B. A., & Habteyesus, D. G. (2022). The implication of intra-rural migration on crop output commercialization in Ethiopia. Migration and Development (Abingdon, Oxfordshire, UK), 11(1): 126–141. https://doi.org/10.1080/21632324.2020.1723212
Abel, D. (2017). Comparison of meristem culture and heat therapy to clean garlic (Allium sativum L.) infecting virus in Ethiopia. Ethiopian Journal of Agricultural
Atinofu, G., Tewolde, F. T., Asfaw, Y., Tabor, G., Mengistu, F. G., & Deseta, F. (2021). Morphological characterization and evaluation of garlic (Allium sativum L.) accessions collected from Northern Highlands of Ethiopia. Advances in Crop Science and Technology, 9(7), 4. https://doi.org/10.17223/8863.1000474

Ayalew, A., Tadesse, D., Medhin, Z. G., & Fantaw, S. (2015). Evaluation of garlic (Allium sativum L.) varieties for bulb yield and growth at Dabat, Northwestern Ethiopia. Open Access Library Journal, 2, 1216. http://dx.doi.org/10.4236/oalib.1101216

Azene, T. (2021). Revealing the therapeutic uses of garlic (Allium sativum) and its potential for drug discovery. Hindawi Scientific World Journal, 1–7. https://doi.org/10.1155/2021/8817288

Benyam, T., Yaregol, T., Tilahun, B., & Getachew, M. (2021). Assessment of challenges of crop production and marketing in Bench-Sheko, Kaffa, Sheka, and West-Omo zones of southwest Ethiopia. Heliyon, 7, 07319. https://doi.org/10.1016/j.heliyon.2021.e07319

Bewuketu, H., Sefawdin, B., Biruk, G., & Habitalu, K. Agromorphological based evaluation and proximate analysis of garlic (Allium sativum L.) varieties at Sheka Zone, South West Ethiopia. Journal of Horticulture and Forestry. https://doi.org/10.5897/JHF.

Belzahib, E.,Victor, A.-S., & Fekadu, F. D. (2015). Characterization and assessment of vegetable production and marketing systems in the humid tropics of Ethiopia. Quarterly Journal of International Agriculture, 54(2), 163–187. https://www.researchgate.net/publication/277714764_Characterization_and_assessment_of_vegetable_production_and_marketing_systems_in_the_Humid_tropics_of_Ethiopia

Bruzyczuk, D., Kebede, W., & Wassu, M. A. (2021). Effect of harvesting time, curing and storage methods on storability of garlic bulbs. The Open Biotechnology Journal, 15(1), 36–45. https://doi.org/10.2174/1874070721515010036

Bruzyczuk, D., Netsanet, T., & Getachew, A. (2021). "Garth and bulb yield of garlic as influenced by clove size", Hindawi. The Scientific World Journal, 1, 7. https://doi.org/10.1155/2021/7151873

Bongiorno, P. B., Fratellone, P. M., & Giudice, P. L. (2008). Potential health benefits of garlic (Allium Sativum): A narrative review. Journal of Complementary & Integrative Medicine, 5(1). https://doi.org/10.2202/1553-3840.1084

CSA (Central Statistical Agency). The federal democratic republic of ethiopia central statistical agency agricultural sample survey, 2017/18 volume i report on area and production of major crops K clears, April, 2018.

Debebe, S. (2022, 11). Post-harvest losses of crops and their determinants in Ethiopia: Tobit model analysis. Agriculture and Food Security, 11(1), 13. https://doi.org/10.1186/s40066-022-00357-6

Debebe, A., Mijena, D., Abrahm, A., Akiilu, S., Asami, P., & Holton, T. (2017). Prevalence and incidence of garlic (Allium sativum L.) infecting viruses in Ethiopia. Journal of Agricultural Research, 2(1), 000122. https://doi.org/10.23880/OAR-16000122

Dessie, G. A. (2020). Performance of trickle irrigation system on growth and yield of garlic in case rabi and Kharif Seasons Wonkakebele, Ethiopia. Journal of
Engineering Research and Reports, 13(1), 44–51. https://dx.doi.org/10.9734/JERR/2020/v13i117094

Dessie, G., & Mulat, G. (2019). Dessie getahun and mulat getahun performance of garlíc cultivars under rain-fed cultivation practice at south Gondar Zone, Ethiopia. African Journal Of Agricultural Science, 14(5), 272–278. https://doi.org/10.5897/AJAR2018.13757

Diribo, S. G. (2016). Review of management strategies of constraints in garlíc (Allium sativum L.) production. The Journal of Agricultural Science, 113(3), 186–207. https://doi.org/10.4038/jas.v113i3.2041259.

Diribo, S. G., Hallu, D. M., & Mebrat, T. (2020). Horticultural crops production potentials and challenges assessment in Arsi Zone, Oromia-Ethiopia. International Journal of Forestry and Horticulture, 6(4), 24–41. https://doi.org/10.20431/2454-9487.0604004

Diribo, S. G., Kebede, W., Nigussie, D. R., Getachew, T., & Sharma, J. J. Postharvest quality and shelf life of garlíc bulb as influenced by storage season, soil type and different compost fertilizers. Journal of Postharvest Technology, 01(1), 069–083. www.jhpt.info

Diribo, S. G., Nigussie, D. R., Kebede, W., Getachew, T., & Sharma, J. J. (2015). Effect of applying mineral nitrogen, phosphorus, and sulphur fertilizers on growth, yield, yield attributes, and economic returns of the garlíc. Science, Technology and Arts Research Journal. http://dx.doi.org/10.4314/star.v4i2.2

Elyas, A., Zemen, A., Mohertliner, H., & Aye, G. (2022). Impact of smallscale irrigation schemes on farmer’s livelihood, the case of Mekela Woreda, North-East Ethiopia. Cogent Economics & Finance, 10(1), 2041259. https://doi.org/10.1080/23322039.2022.2041259

FAO. (2015). Major food and agricultural commodities and producers countries by commodity. http://faostat.fao.org/site/567

FAOSTAT (Food and Agriculture Organization of the United Nations Statistics). (2011). http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567&Lang=en; 21/Dec/2013

FAOSTAT (Food and Agriculture Organization Statistics), “Garlic, production quantity (tons) for Ethiopia,” 2018. http://www.factfish.com/statistic/garlic/

Fasikow, B., Guesh, T., & Shushay, C. (2020). Evaluation of genotypes × environment interaction effect on performance of garlic (Allium sativum L.) genotypes in Tigray region, Northern Ethiopia using AMMI and GGE biplot analysis. African Journal of Agricultural Research, 16(5), 691–701. https://dx.doi.org/10.5897/AJAR2019.14562

Fikre, W., W., K., & Getachew, T. (2017). Emergence of garlic (Allium sativum L.) as influenced by low storage temperature and gibberellic acid treatments. Journal of Agriculture and Ecology Research International, 10(2), 1–7. https://doi.org/10.9734/JAERI/2017/29843

Fikru, T. K., & Fikreyohannes, G. (2018). Response of garlic (Allium sativum L.) to vermicompost and mineral N fertilizer application at Haramaya, Eastern Ethiopia. African Journal of Agricultural Research, 13(2), 27–35. https://doi.org/10.5897/AJAR2017.12708

Gashaw, B. Gashaw (2021). Evaluation of different rates of NPS on growth and yield performances of garlic (Allium sativum L.) in Cheha District, Garage Zone, Ethiopia. International Journal of Agriculture, 2021, 1–5. https://doi.org/10.1155/2021/7742386

Gebrehiwot, A. H., Taheer, F., Taheer, F., & Van Passel, S. (2018). Van passel show participation in vegetables market affects livelihoods: empirical evidence from Northern Ethiopia. Journal of International Food & Agribusiness Marketing, 30(2), 107–131. https://doi.org/10.1080/08974438.2017.1402725

Getachew, T., & Asfaw, Z. Achievements in shallot and garlic research. Report No36, Ethiopian Agricultural Research Organization. 2010.

Getachew, T., Yosef, A., Selamawit, K., Mohammed, Y., & Gashawbeza, A. (2021, October). Agricultural research for Ethiopian renaissance, challenges, potentials and directions. Vegetable Crops Research in Ethiopia: Achievements and Future Prospects. https://www.researchgate.net/profile/Abbeke-Kirub/publication/319153628_Agricultural_Research_for_Ethiopian_Renaissance_Challenges_Opportunities_and_Directions/links/5955a9107e9b5895f35830/Agricultural-Research-for-Ethiopian-Renaissance-Challenges-Opportunities-and-Directions.pdf

G., G., Getachew, H., Yemane, T., Alem, G., & Mitiku, H. Proceedings of the Regional Workshop On Promotion of Best Practices for Value Chain Development in Vegetable Production in Tigary Mekelle, Ethiopia, 2 December, 2017. https://www.researchgate.net/publi

Guta, E. G. (2019). Effects of compost and phosphorus fertilizer rate on the yield and yield related traits of garlíc at Bale Highlands, South Eastern Oromia. Journal Equality Sustainability Science Development, 3(1), 20–28. http://197.156.115.18/index.php/jessd

Habtemariam, A. G., Heluf, K., Bobe, B., & Enyew, A. (2016). Fertility status of soils under different land uses at Wujiraba Watershed, northwestern highlands of Ethiopia. Agric Forestry Fisheries, 3(5), 410–419. https://doi.org/10.11648/j.aif.20140305.24

Habtekwold, K., Zebenay, D., & Samuel, T. (2019). Result of fungicides efficacy evaluation for the control of garlíc (Allium Sativum L).trust (Puccinia Allii Rudolph) at Holeta, Ethiopia. International Journal of Research Studies in Agricultural Sciences (IJRAS), 5(1), 1–4. https://doi.org/10.20431/2454-6224.0505001

Habtu, A. D. W., Fantu, S. W., Admasu, B. T., & Bitew, M. A. Advances of Science and Technology 7th EAI International Conference, ICAST 2019, Bahrain Dar, Ethiopia, August 2-6, 2019, Proceedings(1st ed. 2020.). Springer International Publishing. [2020]. https://doi.org/10.1007/978-3-030-43690-2

Hanibol, L., Habtamu, Y., & Tsedalul, J. (2010, June). Analytical documentation of traditional practices and farmer innovations in agricultural water management in two traditional irrigation schemes in north-west Ethiopia. In EDA (pp. 10). Hol open science.

Harnet, A., & Yibrah, G. (2015). Evaluating local garlic (Allium sativum L) accessions using multivariate analysis based on agro-morphological characters in Southern Tigray, Ethiopia. Journal of Natural Sciences Research, 3(2). https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.926.6031&rep=rep1&type=pdf

James, B. (2008). Onions and Other Vegetable Alliums (2nd ed., pp. 448). Horticulture Research International.

Kalkidan, T., Nitsuh, A., Emebet, R., Helen, G., Obsi, D., Demilew, D., & Sera, G. (2021). Molecular characterization of garlic (Allium sativum L.) using SSR markers in Ethiopia. African Journal of Plant Science, 15(2), 59–63. https://dx.doi.org/10.5897/AJPS2020.2013

Kassaw, M. A., & Ayalew, A. (2021). Rate and spraying frequency determination of propiconazole fungicide
for the management of garlic rust at Woreilu District, Northeastern Ethiopia. Advances in Agriculture (Hindawi Publishing Corporation), 1–9. https://doi.org/10.1155/2021/8847782

Kero, J., Adone, A., & Tileye, F. (2015). The occurrence and distribution of four viruses on garlic (Allium sativum L.) in Ethiopia. International Journal of Basic and Applied Sciences, 4(1), 5–11. https://www.researchgate.net/publication/27174456_The_Occurrence_and_Distribution_of_Four_Viruses_on_Garlic_Allium_sativum_L_in_Ethiopia

Ketema, M., & Bauer, S. (2011). Determinants of manure and fertilizer applications in eastern highlands of Ethiopia. Quarterly Journal of International Agriculture, 50, 237–252. https://doi.org/10.22004/agron.155533

Labu, Z., & Rahman, M. (2019). Proven health benefits of garlic-a review. In Department of Pharmacy (pp. 1205). World University of Bangladesh (WUB), Dhanmondi, Dhaka, Bangladesh-1205.

Lema, M., Mensa, A., & Hazo, H. (2017). Identification and prioritization of major constraints of crop productivity and production system in the case of Melkorka District of Southern Ethiopia, Hawassa Ethiopia. International Journal of Research in Agriculture and Forestry, 4(12), 38–43. https://doi.org/10.19080/AIM.2018.01.555553

Lencha, B., & Duke, T. (2017). Effects of clove size and plant density on the bulb yield and yield components of garlic (Allium sativum L.) in Sodo Zuria Woreda, southern Wolaita zone. Journal of Natural Sciences Research, 7(21), 1–7. https://doi.org/10.5829/ijoss.ajnes.2017.315.319

Mandefo, C., & Shoeb, Q. (2015). Effect of deficit irrigation on yield and water productivity of garlic (Allium sativum L.) under drip irrigation and Mulching at Wolaita Sodo, Ethiopia. International Journal of Life Sciences, 4(4), 232–239. www.crdeep.com

Mengesha, T. A. (2015). Effect of spacing in incidence and severity of garlic rust (Puccinia Allii (Rudolph)) and bulb yield and related traits of garlic at Eastern Ethiopia. Plant Pathology & Microbiology, 6(10), 1–4. https://doi.org/10.4172/2157-7471.1000314

Merga, B. (2019). Haji factors impeding effective crop production in Ethiopia J. Agricultural Science, 11(10), 1–14. https://doi.org/10.5539/jas.v11i10p98

Mohammed, J., Gezu, D., Girma, W., & Gebiso, B. (2021). Adaptation trail of garlic (Allium sativum L.) varieties in the high land of Eastern Haragehe Zone, Oromia, Ethiopia. American Journal of Life Sciences, 9(1), 7–10. https://doi.org/10.11648/j.ajls.20210901.12

Mohammed, A., Shiberu, T., & Thangavel, S. (2014). White rot (Sclerotium cepivorum Berk) an aggressive pest of onion and garlic in Ethiopia: An overview. Journal of Agricultural Biotechnology and Sustainable Development, 6(1), 6–15. https://doi.org/10.5897/JABSD2013.0210

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta analyses: The PRISMA statement. Annals of Internal Medicine, 151(4), 264–269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135

Motuma, G., Thangavel, S., Teshale, J., & Abera, A. (2020). Evaluations of garlic varieties and fungicides for the management of white rot (Sclerotium cepivorum Berk) in West Showa, Ethiopia. Journal of Science and Sustainable Development (JSSD), 8(2), 74–84. https://doi.org/10.20372/au.jssd.8.2.2020.351

Mululek, T., & Yebo, B. (2015). Review on integrated soil fertility management for better crop production in Ethiopia. Sky Journal of Agricultural Research, 4, 21–12. http://www.skyjournals.com/SJAR

Mulu, T., & Negasi, T. (2023). Growth and yield response of garlic (Allium Sativum L.) to intro-row spacing and variety at Selekeleko, Northern Ethiopia. The Open Biotechnology Journal, 15, 1–11. https://doi.org/10.2174/187407021150100011

Nasir, S. (2018). Review on effect of garlic clove weight on yield and yield components of garlic (Allium sativum L.). Academic Research Journal of Agricultural Science and Research, 6(9), 554–557.

Pandey, U. B. (2012). Garlic, handbook of herbs and spices. Woodhead Publishing.

Panthee, D. R., Kc, R. B., Regmi, H. N., Subedi, P. P., Bhattarai, S., & Dhokal, J. (2006). Diversity analysis of garlic (Allium sativum L.) germplasms available in Nepal based on morphological characters. Genetic Resources and Crop Evolution, 53(1), 205–212. https://doi.org/10.1007/s10722-006-6690-z

Rabatzy, V., & Yamasuichi, M. (1997). World vegetables, principles, production and nutritive values chapman and hall (2nd scientific research ed.), pp. 843.

Seid, H., Fikrite, M., & Abeba, T. (2014). Effect of intro-row spacing on growth performance of garlic (allium sativum) at the experimental site of Wollo University, South Ethiopia. Journal of Agriculture and Forestry Research, 2(4), 54–61. https://www.ejournals.org/

Semirna, N., & Tefero, R. (2017). Mihret Y. influence of clove weight and planting depth on yield and yield components of garlic (Allium sativum L). American-European Journal of Agricultural & Environmental Sciences, 17(4), 315–319. https://doi.org/10.5829/doi.ojaej.2017.315.319

Shege, G. Y. Assessment of garlic production practices and effects of different rates of nps fertilizer on yield and yield components of garlic (allium sativum l) under irrigated farming system in yilmana disctrict, Amhara region, Ethiopia. Msc thesis, Bahir Dar University 2015.

Shege, G. Y., Melkamu, A., Amare, H., & Yigzaw, D. (2021). Assessment of small holder farmer’s garlic (Allium sativum L.) production practices under irrigated farming system in the Highlands of Ethiopia. African Journal of Agricultural Research, 17(9), 1172–1179. https://doi.org/10.5897/AJAR2019.14033

Shibabaw, A., Alemayehu, G., Adigo, E., Germer, J., Ash, F., & Freyser, B. (2017). Growth and biomass yield response of clover (Trifolium decorum) to preceding crop and organic treatment in the highlands of Awi Administrative Zone, Ethiopia. Ethiopian Journal of Science and Technology, 10(3), 151–164. https://doi.org/10.4314/ejst.v10i3.1

Singh, Y., & Chard, R. (2003). Performance studies of some garlic (Allium sativum L.) clones. Himchal Journal of Agricultural Research, 29(1&2), 35–42. https://doi.org/10.29588/0976-4415.2016.00387

Siyomu, Z., & Yesuf, M. (2013). Searching and evaluating of cost effective management options of garlic white rot (Sclerotium cepivorum Berk) in Tigray, Northern Ethiopia. Journal of Plant Pathology & Microbiology, 4, 189. https://doi.org/10.4172/2157-7471.1000189

Tabor, G., Getahun, D., & Zelleke, A. (2004). Influence of storage duration on field spraying, maturity and yield of some garlic (Allium sativum L.) cultivars at Debre Zeit, Ethiopia. The Journal of Horticultural Science and Biotechnology, 79(6), 871–876. https://doi.org/10.1080/09607455.2016.11513859

Tabor, H. S., Poe, D. H., Hong, S., Gebretinsay, F., Fikru, D., & Fikru, D. (2021). Performance of some introduced korean garlic (Allium sativum L.) cultivars in Ethiopia. Journal of the Korean Society of International
