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FDRE TECHNICAL & VOCATIONAL
TRAINING INSTITUTE

FACULTY OF AGRICULTURE AND AGRO PROCESSING TECHNOLOGY

DEPARTMENT OF FRUIT AND VEGETABLE PROCESSING TECHNOLOGY

EFFECT OF SOWING METHODS AND SEED RATES ON YIELD AND YIELD COMPONENTS OF BREAD WHEAT (*Triticum aestivum L.*) VARIETIES IN SEBETA DISTRICT, OROMIA REGIONAL STATE, ETHIOPIA

MSc. THESIS

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Effect of Sowing Methods and Seed Rates on Yield and Yield components of Bread Wheat (*Triticum aestivum L.)* Varieties in Sebeta District, Oromia Regional state, Ethiopia

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In Partial Fulfillment of the Requirements for the Degree of Master of Science in Crop Production Technology

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FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

POSTGRADUATE PROGRAM

THESIS APPROVAL SHEET

I hereby certify that I have read and evaluated this thesis entitled **"**Effect of Sowing Methods and Seed Rates on Yield and Yield components of Bread Wheat (*Triticum aestivum L.)* Varieties in Sebeta District, Oromia Regional state, Ethiopia**"** prepared by Daribe Kifalow Mokonin under my guidance**.** I recommend that it be submitted as fulfilling the thesis requirement.

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As a member of the Board of Examiners of the MSc. Thesis Open Defense Examination, I certify that I have read and evaluated the thesis prepared by Daribe Kifalow Mokonin and examined the candidate. I recommend that the thesis, be accepted, as it fulfills the thesis requirement for the Degree of Master of Science in Crop Production Technology.

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DECLARATION

I, the undersigned, hereby declare that this thesis entitled "Effect of Sowing Methods and Seed Rates on Yield of Bread Wheat (*Triticum aestivum L.)* Varieties in Sebeta District, Oromia Regional state, Ethiopia" is my original work and has not been presented for the award of any degree, diploma, or certificate in this or any other university or institution.

All sources of materials used for this thesis have been duly acknowledged. This work has been carried out under the supervision and guidance of Dr. Girma Megersa, Major Advisor, at the FDRE Technical and Vocational Training Institute, Faculty of Agro Processing, Department of Crop Production Technology.

I declare that this thesis contains no material previously published or written by another person, except where due reference is made in the text.

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BIOGRAPHICAL SKETCH

The author, Daribe Kifalow Mokonin, was born in 1995 in Mikawa town, Aleltu District of North Shewa, Ethiopia, which is located 50 km from Addis Ababa. When his age reach for school he attended his elementary school education at Sheno Elementary and secondary preparatory school from 2002 to 2012. Then he joined Bako Agricultural College in 2013 and graduated with a diploma in crop production 2015. He was employed as a trainer at Bako Agricultural College in 2015. Continued his study at Wollega University, Shambu campus, with a B.Sc. degree in plant science from 2016 to 2019. After graduating, he changed his workplace from Bako Agricultural College to Sebeta Polytechnic College, and until now, he has been employed at Sebeta Polytechnic College. He joined the FDRE Technical and Vocational Training Institute of Graduate Studies in 2024 to pursue his MSc degree in agriculture (crop production technology).

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DEDICATION

I dedicate this thesis to my beloved mother, Zinash Kebede Gudata, and my father, Kifalow Mokonin Yadate, in recognition of their unwavering devotion, unconditional love, and steadfast support throughout my academic journey. Their sacrifices, encouragement, and enduring belief in my potential have been the foundation of this achievement.

ABBREVIATIONS AND ACRONYMS

HARC	Holeta Agriculture Research Center
KARC	Kulumsa Agricultural Research Center
RCBD	Randomized Complete Block Design
DMRT	Duncan Multiple Range Test
CIMMYT	International Maize and Wheat Improvement Centre
FAO	Food and Agriculture Organization
SSA	Sub-Saharan Africa
SAS	Statistical Analysis System
MC	Moisture Content
CSA	Central Statistical Agency
LSD	Least Significant Difference
TABY	Total Above Ground Biomass Yield
ATA	Agricultural Transformation Agency
GYGA	Global Yield Gap Atlas
MARR	Minimum Acceptable Rate of Return

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Effect of Sowing Methods and Seed Rates on Yield and Yield components of Bread Wheat (*Triticum aestivum L.*) Varieties in Sebeta District, Oromia Regional state, Ethiopia

ABSTRACT

*Bread wheat (*Triticum aestivum *L.) is a major cereal crop in the central highlands of Ethiopia. However, its yield has been low due to many reasons, such as lack of improved varieties and optimal seed rate, improper sowing methods, and poor agronomic practices, among others. With this in view, an experiment was carried out to determine the effect of seed rates and sowing methods on the yield and yield components of bread wheat varieties in the Sebeta district, central Ethiopia, during the 2025/2026 cropping season. The treatments consisted of a factorial combination of three levels of seed rates (100, 125, and 150 kg ha^{-1}), two sowing methods (row planting and broadcasting), and three bread wheat varieties (Melka, Gutu, and Kakaba). The treatments were arranged in a randomized complete block design in a factorial arrangement with three replications. The results showed that varieties, seed rates, and sowing methods highly significantly ($P < 0.001$) affected days to heading, days to maturity, plant height, spike length, and most yield components. Interaction effects of varieties, seed rate, and sowing method were significantly influenced grain yield, thousand-kernel weight, and harvest index of bread wheat. The Melka variety produced the highest number of productive tillers, longest spikes (9.43 cm), highest number of kernels per spike (63.33), and maximum grain yield (5.512 t ha^{-1}) when sown at 125 kg ha^{-1} using the drilling method. The highest straw yield (4.633 t ha^{-1}) was obtained from the Gutu variety at 125 kg ha^{-1} seed rates under drilling methods of sowing. Melka variety sown at 125 kg ha^{-1} using drilling provided the highest net benefit ETB (27567.4 ha^{-1}) with a marginal rate of return of 408.1%. Therefore, the use of the Melka variety at a seed rate of 125 kg ha^{-1} with the drilling sowing method is recommended for bread wheat production in Sebeta District and similar agro-ecological conditions.*

Keywords: *Seed Rates, Sowing Methods and Varieties*

1. INTRODUCTION

1.1. Background and Justification

Wheat (*Triticum aestivum L.*) is one of the most widely cultivated cereal crops in the world and serves as a staple food for approximately one-third of the global population. It occupies a central position in global food systems due to its adaptability, nutritional value, and contribution to caloric and protein intake. Globally, wheat is among the most extensively grown grain crops Gupta *et al*., (2023), with more than 35% of the world's population depending on bread wheat. In 2023, global wheat production reached approximately 785 million metric tons Osama (2025), underscoring its strategic importance in ensuring food security and sustaining agricultural economies.

In Ethiopia, wheat ranks second among cereal crops in terms of total production, following maize. During the 2021/22 production season, national wheat output reached 5.8 million metric tons (Eskezia et al., 2025). Despite these production gains, the national average yield remains approximately 3.1 t ha^{-1}, which is considerably lower than yields achieved in leading wheat-producing countries such as Ireland (10 t ha^{-1}) and the Netherlands (9.2 t ha^{-1}) (Ishikawa et al., 2024). This substantial yield gap indicates that Ethiopia has not yet fully realized the genetic yield potential of improved wheat varieties, largely due to limitations in agronomic management and production practices.

Wheat production in Ethiopia is predominantly concentrated in the highland agro-ecologies, where environmental conditions are favorable for crop growth. The crop is typically cultivated at altitudes ranging from 1700 to 3000 meters above sea level, with optimal performance observed between 1900 and 2700 meters (Harfe, 2017). Major wheat-producing regions include Arsi, Bale, Shewa, Ilubabor, Western Hararghe, Sidama, Tigray, Northern Gondar, and Gojam (Chimdessa and Argaw, 2018). Nevertheless, despite its long-standing history of wheat cultivation and recent governmental efforts to enhance domestic production, Ethiopia remains a net importer of wheat. Approximately 25–35% of national wheat demand is met through imports, often in the form of food aid (Zewdu and Lindi, 2022). This dependency highlights persistent structural and productivity challenges within the domestic wheat sector.

Low wheat productivity in Ethiopia is attributed to a combination of biotic, abiotic, and management-related constraints. Key factors include the continued use of low-yielding local varieties, weed infestation, pest and disease pressures, soil fertility depletion, and recurrent moisture stress (Wilson, 2023). In addition to these challenges, inadequate agronomic practices significantly limit yield performance. Siddique et al., (2012) emphasized that inappropriate seed rates, traditional sowing methods, and improper row spacing are major contributors to reduced wheat productivity. These management-related factors directly influence plant establishment, resource utilization efficiency, and yield component development.

Although improved and certified bread wheat varieties have been released by various agricultural research institutions, their potential yield advantages are often not realized under farmer-managed conditions. The mere adoption of improved seed does not guarantee increased productivity unless accompanied by appropriate agronomic practices, including optimal seed rate, suitable sowing method, and proper plant spacing. As noted by Ahmed et al., (2024) improved varieties combined with appropriate seeding rates significantly enhance wheat phenology, vegetative growth, and grain yield. This finding underscores the importance of integrating genetic improvement with sound crop management practices.

Seed rate is a critical determinant of plant population density and subsequent crop performance. In many parts of Ethiopia, farmers commonly apply higher seed rates than recommended, based on the belief that increased plant density suppresses weeds and reduces the risk of crop failure (Temesgen and Yitayew, 2025). However, excessive seed rates may intensify intraspecific competition for light, nutrients, and moisture, leading to reduced grain size, lower thousand-kernel weight, and increased lodging (Gebremedhin and Abraha, 2025). Conversely, insufficient seed rates can result in poor stand establishment, inadequate spike density per unit area, and reduced overall yield. These contrasting effects highlight the need to determine location-specific optimum seed rates that balance plant population and resource use efficiency.

Similarly, the sowing method plays a fundamental role in determining crop establishment, spatial distribution, and yield performance. The method of sowing influences seed placement depth, plant spacing, canopy development, moisture availability, and nutrient uptake. Row planting, for instance, promotes uniform plant distribution, enhances sunlight interception, facilitates mechanical weeding, and improves overall crop management efficiency (Ochami, 2021). In

contrast, non-uniform or traditional broadcasting methods may result in uneven plant stands and increased competition, ultimately limiting yield potential. Therefore, optimizing sowing methods is essential to maximize the productivity of improved bread wheat varieties.

Despite the importance of seed rate and sowing method, recommendations in Ethiopia remain largely generalized rather than site-specific. Various authors recommend seed rates of 125 kg ha^{-1}, others suggest 150 kg ha^{-1}, while some advocate even higher rates. However, there are no clearly defined, location-specific seed rate recommendations tailored to particular agro-ecological zones or wheat varieties. Moreover, many improved bread wheat varieties released from research centers are not widely known to farmers, and large-scale demonstrations under local production conditions remain limited. Consequently, varietal performance under different combinations of sowing methods and seed rates has not been adequately evaluated at the district level.

Sebeta District, located in the Oromia Region, possesses favorable agro-ecological conditions for bread wheat production. However, wheat yields in the area remain below their potential. One of the primary constraints is the continued reliance on traditional agronomic practices, including uniform sowing methods and non-optimized seed rates, irrespective of varietal differences or seasonal variability. This practice may result in either insufficient plant density or excessive competition, both of which reduce resource use efficiency and compromise yield performance.

Furthermore, varietal responses to agronomic practices such as sowing method and seed rate are not uniform. Differences in tillering capacity, plant architecture, maturity period, and stress tolerance among bread wheat varieties may lead to variable performance under similar management conditions. However, such variety by management interactions have rarely been systematically evaluated under the specific agro-ecological conditions of Sebeta District. The absence of locally generated empirical data limits the development of evidence-based recommendations for farmers. Therefore, there is a clear need to generate location-specific information on the effects of sowing methods and seed rates on the growth and yield performance of different bread wheat varieties in Sebeta District. Identifying optimal combinations of sowing method, seed rate, and variety will contribute to improved productivity, enhanced resource use efficiency, and strengthened food security at both local and national levels. This study is thus justified as it seeks to address a critical knowledge gap and provide practical, scientifically grounded recommendations for bread wheat production in the study area.

1.2. Statement of the Problem

The adoption of improved certified bread wheat varieties in Ethiopia has not resulted in proportionate increases in productivity, largely because such genetic improvements have not been accompanied by the appropriate integration of complementary agronomic practices. Evidence suggests that the yield potential of bread wheat cannot be realized solely through improved seed use; rather, it requires the optimization of associated management practices, including appropriate seed rate, seed replacement systems, spacing, and tillage (Burke et al., 2024). In the absence of integrated agronomic management, the performance of improved varieties remains constrained, thereby limiting productivity gains at the farm level.

One of the major challenges in Ethiopian wheat production is the absence of location-specific seed rate recommendations. Currently, there is no standardized seed rate tailored to particular agro-ecological zones or specific bread wheat varieties. As a result, recommendations remain inconsistent and generalized. Some authors suggest a seed rate of 125 kg ha^{-1}, others recommend 150 kg ha^{-1}, while a few propose even higher rates. However, these recommendations are not supported by site-specific empirical validation and often fail to consider varietal differences, environmental variability, and local management conditions. Consequently, farmers frequently apply seed rates based on generalized advice rather than scientifically established, location-specific evidence.

In addition, several improved bread wheat varieties released by agricultural research institutions have not been widely disseminated or adequately demonstrated under farmer-managed conditions. Many of these varieties are not well known to farmers in specific localities, and large-scale demonstrations or participatory adaptation trials have been limited (Jannat et al., 2025). This gap between varietal release and effective field-level adoption has contributed to persistent yield stagnation. As a result, national bread wheat production remains below its potential, partly due to insufficient agronomic management and limited integration of improved technologies (Yadelew, 2025).

Wheat is a critical staple crop in Ethiopia, particularly bread wheat (*Triticum aestivum L.*), which plays a central role in national food security and provides important market opportunities for smallholder farmers. Despite its strategic importance, the national average yield remains

significantly below the crop's genetic potential. Sebeta District in the Oromia Region, although characterized by favourable agro-ecological conditions for wheat production, continues to experience notable yield gaps. A major contributing factor is the continued reliance on traditional agronomic practices.

Farmers in Sebeta commonly employ uniform sowing methods and seed rates without considering varietal characteristics, plant population dynamics, or seasonal variability. This practice often results in suboptimal plant density. Low seed rates may lead to inadequate plant population and reduced spike density per unit area, whereas excessive seed rates may intensify intra-specific competition for light, nutrients, and moisture. Both extremes negatively affect resource use efficiency and limit yield performance.

Furthermore, varietal responses to agronomic practices such as sowing method and seed rate are not uniform. Differences in tillering capacity, plant architecture, growth duration, and stress tolerance among bread wheat varieties may lead to differential performance under similar management conditions. However, these varieties by management interactions have rarely been systematically investigated at the district level. In Sebeta District, there is a lack of location-specific empirical data evaluating the combined effects of sowing method and seed rate across different bread wheat varieties.

The absence of such evidence limits the development of precise agronomic recommendations tailored to local conditions. Without scientifically validated information on optimal sowing methods and seed rates for specific varieties, farmers continue to rely on generalized practices, thereby constraining productivity improvements. Therefore, there is a clear need to generate empirical data on the interaction effects of sowing method and seed rate on the growth and yield performance of bread wheat varieties under the agro-ecological conditions of Sebeta District.

1.3. Objective of the Study

1.3.1. General Objective

To evaluate the effects of sowing method and seed rate on the growth, yield, and yield components of bread wheat (*Triticum aestivum L.*) varieties under the agro-ecological conditions of Sebeta District, Oromia Regional state, Ethiopia.

1.3.2. Specific Objectives

1. To determine the effect of sowing methods on the growth performance and grain yield and yield components of bread wheat varieties in Sebeta District.
2. To evaluate the influence of seed rates on yield and yield components of bread wheat varieties.
3. To identify the most suitable bread wheat varieties for Sebeta District based on performance under different combinations of sowing methods and seed rates.

2. LITERATURE REVIEW

2.1. Bread Wheat (*Triticum aestivum L.)* Production and yield potential

As part of the "Neolithic Revolution," which witnessed a transition from hunting and gathering food to established agriculture, wheat was first cultivated approximately 10,000 years ago (Smith and Berger, 2023). The earliest cultivated varieties of wheat were diploid (genome AA) (einkorn) and tetraploid (genome AABB) (emmer), and their genetic relationships suggest that they originated in southeast Turkey (Baloch et al., 2022). When hexaploid bread wheat first appeared around 10,000 years ago, growth began to expand over the Near East (Levy & Feldman, 2022).

According to Farooq et al. (2009), Yousefi et al. (2025) wheat can be grown in a variety of agricultural environments. It may grow in a variety of climates, soil fertility conditions, and elevations. The crop is produced at an altitude ranging from 1450 to 3000 meters above sea level (m.a.s.l.), between 6-16°N latitude and 35- 42°E longitude in Ethiopia. However, rainfall between 1900 and 2700 m.a.s.l. is ideal for agro-ecological zones.

2.2. Global and National Significance of Bread Wheat

Approximately one-third of the world's population depends on wheat, one of the most significant cereal crops in general. In order to achieve national food self-sufficiency, income generation, poverty reduction, and socioeconomic growth of the county, it has been chosen as one of the target crops (Shikur, 2023). Over 35% of the world's population relies on bread wheat as a staple meal, with an annual production of 772.6 million tons (Tesfaye et al., 2023). South Africa and Ethiopia are the top producers of wheat in sub-Saharan Africa, while China, India, and Russia are the top producers worldwide (Tesfaye et al., 2023). Asefa (2024) stated that wheat is the most widely cultivated crop, making up an average of 533 MMT annually, or nearly one-third of all cereal production.

Phillips and Norton (2012) reported that imports total 12.7 million tons, while average production for nations south of the Sahara is 5.6 million tons. Economic and demographic changes have led to a rapid increase in wheat demand and a reliance on imports, which could render the countries in the region more vulnerable to political upheaval as food prices (Usman, 2016). With a population of roughly 123.4 million in 2023, Ethiopia is a landlocked nation whose agriculture accounts for 40% of GDP, 80% of exports, and an estimated 75% of the workforce (Fayisa, 2025).

Roughly, 95% of agricultural production comes from smallholder farming. Production of crops and livestock makes for about 65% and 25% of agricultural GDP (Fayisa, 2025).

Table 1. World production of bread wheat.

No.	Country	Wheat production (million metric tons)	% of Global Production
1	China	140.1	17%
2	European union	121-122.15	15%
3	India	113.29	14%
4	Russia	81.6	10%
5	United states	53.65-53.85	7%
6	Canada	34.96-35.94	4%
7	Australia	34.11	4%
8	Pakistan	31.4	4%
9	Ukraine	23.4	3%
10	Turkey	19	2%
11	Global Total	793-800.8	100%

Source: Kumari and Mohapatra, (2023).

2.3. Yield Potential and Actual Productivity

After Egypt, Ethiopia is the continent's second-largest producer and importer of wheat (Shikur, 2022). Over thirty percent of smallholder farmers in the nation depend on wheat farming as their primary source of income. Both urban and rural people rely on wheat for food and income (Mekonnen, 2024). About 14% of Ethiopians' total caloric intake comes from wheat and wheat-derived products (Melese et al., 2019). The government must spend a significant amount of foreign currency to import roughly 46% of its entire domestic wheat production, which is mostly earned from coffee and oilseed exports, due to the significant imbalance between wheat supply and demand. Inappropriate wheat policies, the growth of the wheat processing industries, and population growth are the primary causes of the significant reliance on wheat imports growth and the increased national income per capita at an average rate (Tadasse, 2025).

Both large-scale industrial farms and small-scale subsistence farmers can cultivate wheat in Ethiopia (Anteneh and Asrat, 2020). However, small-scale farmers outperform large-scale commercial farms in terms of output and area covered. According to last study, large-scale

commercial farms produce 1.5–2.0 million quintals of wheat on only 50–80 thousand hectares of land. Ethiopia is one of the leading producers of wheat in sub-Saharan Africa (Tadesse and Aman, 2017). However, due to their traditional production technique and the predominance of small-scale farmers that relied on rain-fed agriculture, Ethiopian wheat ranks 67th internationally in terms of total output, even behind other sub-Saharan countries (Anteneh and Asrat, 2020), and (Asefa, 2024). The food security of farm households is greatly impacted by wheat production due to rainfall, low rates of technology adoption, soil degradation, limited irrigation, lack of investment infrastructure, gender disparity in technology access, vulnerability to climate change, subsistence production, and lack of value addition, especially in the country's highland regions (Zenbaba et al., 2025).

Table 2. Ethiopia bread wheat production

Region	At National Stage of Wheat Production (%)	Main Producing Zones stage
Oromia	53-57%	Arsi, Bale, West Arsi, Shewa zones
Amhara	28-32%	East Gojam, North Shewa, South Wollo zones
SNNP	7-9%	Hadiya, Kenbata zones
Tigray	3-6%	Northern Gonder, Gojam
Other region	<1%	irrigated production in Afar, Somali, and Gambela

Source: Alemu, (2024).

2.4. Importance of Wheat

According to FAO statistics on wheat production from 2004, there are more than 100 nations that produce wheat, and in other places where wheat cannot be farmed, wheat is widely consumed by people (Jibat, 2025). For instance, in the humid tropics, especially those with a culinary inheritance that dates back to colonial occupation, imported wheat is used to satisfy customer needs for bread and other food products. Although data for the UK show that about one-third of the total production is consumed directly by humans as opposed to feeding livestock (approximately 5.7 metric tons per annul are milled, with home production being 15-16 metric tons), statistics regarding the total volume of wheat consumed directly by humans are not available.

There is no question that several billions of people rely on wheat as a significant portion of their food. Wheat is frequently regarded as little more than a source of calories due to its high starch

content (roughly 60–70% of the total grain and 65–75% of white flour), (Meenu et al., 2025). This is especially true for the production of animal feed, where high-yielding, low-protein feed varieties are supplemented by other protein-rich crops (most notably soy-beans and oilseed residues (Shurtleff and Aoyagi, 2021). However, wheat still supplies as much protein for human and animal nutrition as the entire soybean crop, which is expected to be over 60 m tons annually, despite its comparatively low protein content typically 8–15%.

Wheat is one of the most significant grains of choice in Ethiopia today, dominating dietary practices and eating habits and serving as a major source of protein and energy for the country's highland population (Alemu, 2024). Conversely, according to Bekele (2011), wheat has 10.3 g of protein, 49 mg of calcium, 1.5 mg of iron, and 339 kcal of calories per 100 g of whole grain (Bekele, 2011). However, the use of unimproved wheat varieties, inadequate weed control techniques, the presence of aggressive and virulent crop diseases, the depletion of soil minerals, the low use of chemical fertilizers, and the lack of other current crop management inputs varieties all contribute to the low national mean grain yield of wheat (Feyissa, 2023).

2.5. Wheat Production Constraint in Ethiopia and Sebeta District

Ethiopia has a lower potential for wheat production than the rest of the globe. According to Assefa (2018) Ethiopia's national average wheat production is 2.77 tons ha^{-1}, while the global average is 3.32 tons ha^{-1} according to (Zewide and Admasu, 2023). For instance, Ethiopia's wheat output in 2012 was 32% below the global average, 13% below the African average, and 29% below the Kenyan average (Anteneh and Asrat, 2020). Technical and socioeconomic factors are the two main barriers to raising production.(Liu et al., 2026).

2.5.1. Biotic Stresses

Weeds, insects, and illnesses are the main biotic factors affecting Ethiopia's wheat output. Important wheat diseases prevalent in Ethiopia's highlands include rusts (Puccinia spp.), helminthosporium, septoria (Septoria tritici), tan spot (Pyrenophora tritici repentis), fusarium (Fusarium spp.), smuts, take-all, and root rots. Epidemics of temperature-tolerant yellow rust races and aggressive stem rust strains have been linked to the current consequences of climate change in Ethiopia (Tadesse et al., 2022).

The most common and destructive disease in Ethiopia and other highlands of east Africa is yellow (stripe) rust, which is brought on by Puccinia striiformis f. sp. tritici (Mengesha, 2020). The

collapse of the dominant wheat varieties, such as the semi-dwarf variety Laketch in 1977; Dashen, a poplar high-yielding variety with Yr9 gene from 1B/1R translocation in 1988 and 1994; and cultivar Wabe in 1998, is proof that it has caused significant yield losses in the Ethiopian highlands, reaching up to 100%. In a similar vein, Galema and Kubsa, two high-yielding wheat cultivars carrying the year 27 gene, were widely grown for over 15 years before being declared, 100% susceptible in 2010 and prohibited from cultivation.

2.5.2. Abiotic Stresses

The most significant abiotic stresses in natural rainfall conditions are waterlogging, pre-harvest sprouting, soil acidity, erosion, low soil fertility, and drought, particularly in lowland areas (Haufiku et al., 2025). These limitations are most prevalent in Ethiopia's highlands. The wheat-growing regions receive between 600 and 1200 mm of total rainfall. These issues are prevalent in the highlands. When rainfall occurs during the crop's maturity period (pre-harvest sprouting), it influences the crop production calendar, productivity, and grain quality more than the overall amount of rainfall. One of the biggest obstacles affecting roughly 6.3 million hectares, or 43% of Ethiopia's arable land area, is soil acidity. An attempt has been made to reduce the acidity of the soil by applying of liming. However, applying 2 to 3 t/ha for sandy soils and up to 5 t/ha^{-1} for clay and humifere soils necessitates a big amount of lime, which quickly becomes a very bulky affair (Tadesse et al., 2022).

2.5.3. Yield Gaps and Stagnation

The stage at which crop productivity hits its limit due to a genetic ceiling in crop breeding programs, adverse variables like biotic and abiotic stressors, climate change, and ineffective policies along the entire value chain is known as yield stagnation (Begna, 2020). While some scientists have documented genetic increase in both spring wheat and facultative winter wheat, others have linked production stagnation to the genetic ceiling in Europe and India. However, it is clear that the majority of developing nations have not fully realized the potential of new cultivars because of inadequate agronomic management, limited application of input packages, diminished incentives, and volatile market pricing that lead to significant yield gaps (Ruben, 2026).

Global wheat yield gap levels have been observed to range from 26 to 69%, Albanna et al. (2026) However, the disparity still exists, particularly in developing nations, as a result of inadequate infrastructure and a lack of knowledge and data regarding the effectiveness of extension services

and seed/input delivery systems. While the national average yield is approximately 3.1 and 4.4 t/ha^{-1} under rain-fed and irrigated environments, respectively, indicating the existence of 44.3 and 55% yield gaps, progressive farmers in Ethiopia might harvest 7 t/ha^{-1} under favorable rain-fed environments and 8 t/ha^{-1} under irrigated habitats.

2.5.4. Infrastructure and Policies

Policies related to agriculture include: (1) land use and tenure; (2) technological advancement, purchasing, testing, and adoption; (3) subsidies or support (4) inputs marketing and distribution; (5) taxation; (6) infrastructure and human capital development; (7) public-private partnerships, etc. The primary obstacles to Ethiopia's wheat production continue to be low governmental and private investments, inadequate extension systems, poor market and infrastructural connections, etc. (Yadesa, 2025).

In addition to limiting farmers' access to agro-inputs (seeds and agrochemicals), inadequate rural road networks and transportation also, restrict wheat grain's ability to be aggregated, stored, and transported to markets. Irrigation plans, technology development, and the growth of agro-processing enterprises are all impacted by power and energy shortages. For Ethiopia's wheat industry to succeed, it is crucial to overcome the major policy and regulatory obstacles that limit technology development, access, and deployment (Effa et al., 2025). These obstacles include contract farming, creative financing, public-private partnerships, and integrated wheat production, marketing, and agro-processing (Urugo et al., 2024).

2.5.5. Socio economic constraints

Rural households account for the majority of Ethiopia's wheat production, and its productivity is still very low in part because inputs like fertilizers, improved seeds, irrigation water, pesticides, and farm equipment are not readily available, affordable, or accessible (Shikur, 2022). Because fertilizers are imported, their cost rises in tandem with energy prices and global demand. Additionally, the timely distribution of fertilizers to farmers is impacted by the cost and accessibility of transportation as well as finance availability. Expanding wheat output in irrigated regions is limited by water availability and irrigation scheme construction costs.

2.5.6. Factors Affecting Improved Bread Wheat Seed

New technology for the production of staple crops is essential to altering rural Africa in order to achieve food security, lower poverty, and raise the standard of life for millions of disadvantaged households throughout the continent (Yusuf et al., 2026). The success of many Green Revolution-style systems has been established by the adoption of high yield plant varieties and related packages across millions of hectares; nonetheless, smallholders in Africa have not fully embraced the application of upgraded technology. Despite having considerable agricultural potential, low-income countries in Africa have been net importers of agricultural products in recent decades (Yalew, 2026). This implies that cereal imports are now more important for ensuring food security. Sub-Saharan Africa's growing GDP, population, female labor force participation, and governmental policies are the main drivers affecting wheat consumption (Hu et al., 2026). There is a dearth of new information on the use of improved wheat technology in this field of study.

Recent studies on the country's adoption of improved wheat varieties include those conducted by to mention a few (Teshome, 2025). He stated that farmers may not employ improved wheat varieties because they are unable to adopt due to high input costs, lack variety information, have limited access even though they would like to, or lack financial incentives (such as an alluring price). Other studies, however, have concentrated more on the causes of some farmers' non-utilization. According to Tesfaye et al. (2014), gender, involvement in field days, access to highways, and an active labor force were important factors associated with the adoption of enhanced wheat varieties (Abdella, 2025).

2.5.7. Wheat Production Constraint in Sebeta District

Wheat production is a semi intensive subsistence type of production usually undertaken on black Vertisols mainly characterizes the study area. Wheat production in the district is mainly challenges by the problem of water logging in most of the cases. There is also a problem of (Wagi in local name) rust highly affecting wheat production and productivity, shortage of training service delivery and awareness creation to the community including fertilizer use, seed rates use and lack of improved varieties and poor monitoring and evaluation of activities. Wheat in the district is cultivated under a rain fed system. However, these could not solve the challenge of overall production and productivity due to the problem of disease. The productivity yield performance of crop shows 30.5- 33 q/ha^{-1}. This a productivity range for wheat obtained from normal red soil. From black Vertisol average wheat productivity is less than the red soil.

2.6. Impact of Seed Rate on yield and yield component of wheat

2.6.1. Importance of Optimum Seed Rate

One of the most important agronomic elements affecting Ethiopian bread wheat (*Triticum aestivum L.*) growth, yield, and yield components is seed rate. It describes how much seed is sown per unit area (sometimes measured in kilos per hectare) in order to reach the target plant population for the best possible use of resources and productivity (Fuglie et al., 2024). One of the crop management strategies that has the biggest impact on grain and yield components is seeding scheme modification (Gautam et al., 2024).

A uniform crop stand with suitable spacing, effective use of light and nutrients, and a balance between vegetative and reproductive growth are all ensured by the ideal seed rate (Mekonnen, 2017). Plant population dynamics, interplant competition, and eventually grain output are all adversely affected when the seed rate is either too high or too low (Mohammed, 2025). Achieving the right seed rate is crucial for optimizing wheat production and input efficiency in Ethiopia, where smallholder farmer's work under unpredictable rainfall and soil fertility conditions (Layo et al., 2023).

The quantity of tillers, canopy structure, and light interception are all impact by the plant population, which is directly determinate by seed rate. Because there is less ground cover and initial competition at lower seed rates (less than 100 kg ha^{-1}), individual plants are able to compensate by producing more tillers. However, excessive plant density causes fierce competition for light, water, and nutrients at high seed rates (over 150 kg ha^{-1}), which reduces tillering and weakens plant vigor (Anbes et al., 2025). Additionally, this rivalry limits photosynthetic efficiency and root development, which may limit assimilate partitioning to the growing grains (Mohammed, 2025).

In Ethiopian highland habitats, moderate seed rates between 125 and 150 kg ha^{-1} have been shown to balance these interactions, promoting optimal resource use efficiency and canopy development (Tadasse, 2025). By reducing competition for resources, optimal seeding densities (125–150 kg ha^{-1}) offer the ideal circumstances for wheat growth. According to the findings, moderate densities contribute to improved yields by improving tiller development, spike length, and grain number per spike. Although the 1000-grain weight may be higher because there are fewer total grains per spike (62–65), high seeding densities (200–250 kg ha^{-1}) enhance competition and decrease yield.

These results emphasize how crucial it is to balance resource allocation and plant population in order to maximize production potential. The risk of lodging, a condition in which the stems bend or break as a result of thin, elongated internodes brought on by dense stands, can also be increased by high seed rates. Lodging causes yield losses by interfering with both harvesting and photosynthesis during grain filling. According to research conducted in the Arsi and Bale highlands, lodging incidence increases dramatically over 150 kg ha^{-1} seed rate because of reduced stem strength and competition for nutrients (Motuma and Hunduma, 2020).

As a result, choosing the best seeding rate reduces lodging while preserving sufficient plant density. This balance guarantees all better stand establishment, stronger stems, and resistance to unfavorable weather conditions typical in Ethiopian wheat-growing locations. Ethiopian research has extensively demonstrated the impact of seed rate on yield and its constituent parts. Seed density affects yield components like thousand kernel weight, grains per spike, and spike number per square meter (Mokhtar and Elsayed, 2024). Because there is less competition at low seeding rates, plants tend to produce bigger grains with more kernels per spike; nevertheless, the total yield per area is decreased because there are fewer tillers and spikes. Equally, very high seed rates increase the number of spikes per unit area but reduce grains per spike and individual grain weight due to excessive competition for assimilates (Feyissa, 2023).

2.6.2. Effect of seed rates on growth, yield and yield components of wheat

Plant height is dependent on plant density. Due to interspecific competition for increased light absorption, increasing plant density resulted in changes in plant height and stem thickness. Wheat sown at a higher seed rate generated plants that were taller, while wheat sown at a lower seed rate produced plants that were shorter. Higher seed rates of wheat resulted in much longer internodes and taller plants. Short, upright plants with little to no lodging were seen due to low seeding rates, which reduced competition for space, nutrients, and water (Biset, 2025).

Compared to plants cultivated at seeding rates ranging from 125 to 175 kg ha^{-1}, the height of plants planted at the lowest seeding rate (100 kg ha^{-1}) was significantly lower (Arshad et al., 2025). According to experimental findings from central Ethiopia, grain yield increases as seed rate increases up to an optimal point of 125–150 kg ha^{-1}, after which it drops because of lodging and competition (Reda et al., 2018). Haile and Worku (2020) observation that wheat production peaked at 5.1 t ha^{-1} at a seed rate of 150 kg ha^{-1} compared to 4.1 t ha^{-1} at 175 kg ha^{-1} highlighted the

significance of precision seeding. A high seed rate makes crops more competitive for shared resources, especially water, nutrients, and sunlight, which leads to poor quality and low yield. Fayisa et al. (2023) noted that for many years, smallholder farmers in Ethiopia, especially in the majority of Oromia, primarily planted wheat in broadcast using 150–200 kg ha^{-1}. In a similar vein, Adinewu (2015) found that in Kersa, Eastern Ethiopia, a seed rate of 150 kg ha^{-1} produced the highest grain production of bread wheat. Additionally, Staggenborg et al. (2003) note that higher seeding rates made up for fewer tillers in cultivars that generate fewer tillers. According to Abboye et al. (2020), using a low seed rate results in a lower yield because there are less plants per unit area (Abboye and Teto, 2020). However, according to Rafique et al. (2010), raising the seed rate above optimal could result in higher production costs without enhancement in yield.

Similarly, decreased seed rates greatly improved the number of fertile tillers generated per plant, which does have a noticeable impact on variety production, (Batool et al., 2022). Wheat sown with a higher seed rate 175 kg ha^{-1} produced larger plant heights, followed by 150 and 125 kg ha^{-1}, (Tufa et al., 2019). Plants sown at a seed rate of 125 kg/ha^{-1} using the sowing method drilling produced more grains per spike. Similarly, Sharma et al. (2016) found that varied seeding rates caused changes in plant height.

Larger plants up to 70.89 and 71.47 cm were produced by wheat sown at a higher seed rate of 140 kg ha^{-1}, which was followed by wheat sown at a seed rate of 130 kg ha^{-1}. When compared to the 100 kg ha^{-1} seed rate, a 10.62% increase in tillers was seen under the 140 kg ha^{-1} seed rate. Additionally, the higher plant population m^{-2} at the 140 kg ha^{-1} seed rate may be responsible for a higher number of effective tillers m^{-2}. (A. Tadesse et al., 2017) found that the highest grain yield of 3.9 t ha^{-1} and the lowest grain yield of 2.7 t ha^{-1} were obtained by seed rates of 125 kg ha^{-1} and 200 kg ha^{-1}, respectively. The quantity of grains per spike is decreased by raising the seed rate (Farhad et al., 2025).

Higher seeding rates can be advantageous, particularly for cultivars that typically produce fewer tillers, since they compensate for decreased tiller growth and encourage more main stem spikes (Liu et al., 2021). Planting density has a significant impact on the quantity of productive tillers, which depends on the environment and cultivars. However, sufficient moisture availability, increased light, and optimal nitrogen availability during the vegetative phase boost tiller capacity, which varies significantly according on the variety (Neupane et al., 2025). Different seed rates had

a substantial impact on plant height, number of tillers per plant, spikelet per spike, grains per spike, biological yield, grain yield, and straw (Aklilu, 2025).

Conversely, the reduction in plant height that occurs when the seeding rate is lowered to 100 kg ha^{-1} may be due to the production of more secondary tillers in less populated stands, which are typically smaller in stature (Batool *et al*., 2022). Due to reduced light penetration into the plant's canopy bed and increased interspecific competition for more absorption light, higher seeding rates resulted in changes in plant height and stem thickness (Mohammed, 2025).

Similarly, Alemu (2024) found that when wheat was sown using the drilling method at a seed rate of 150 kg ha^{-1}, plant vigor and yield increased significantly. The highest numbers of spikes per plant, grains per spike, thousand grain weights, and grain and straw weight per plot were found when the seed rate remained at 125 kg ha^{-1}. In a different manner, shown that whereas seed thousand weights increased at low densities, they decreased at high densities (Bastos et al., 2020). Also, Woldekiros, (2020) found that seeding rate had a substantial impact on the number of seeds per spike, with a maximum number of seeds per spike (50.13) resulting from a seed rate of 100 kg/ha^{-1} and a minimum number of seeds per spike (40.85) obtained from the seeding rate of 150 kg ha^{-1}.

In a similar vein, Fazily (2021) found that increased seeding rates promote more main stem spikes and compensate for decreased tiller development, which might be advantageous, especially for genotypes that typically generate fewer tillers (Liu, 2025). However, some research indicates that the production of aboveground biomass and straw increased as the seeding rate increased up to 140 kg ha^{-1} (Aklilu, 2020). According to Fazily (2021) the results showed that seed rates and sowing techniques had a significant impact on all growth and yield indices. Additionally, reported that variations in climate, soil types, sowing date, and genotypes cause large regional variations in seed rate (Pervin *et al*., 2025).

According to (Tehulie and Zewdie, 2021) observed that a lower seed rate led to a lower grain yield, whereas a higher seed rate was responsible for a larger yield, which is consistent with the current conclusion. On the other hand, Kassa (2024) found that days to 50% heading varied depending on the seed rate. As stated by those writers compared to plants produced at seed rates of 100 kg ha^{-1} and 125 kg ha^{-1}, plants grown at the highest seed rate of 150 kg ha^{-1} achieved early

heading, and the spike length was impacted by seed; that is, when the seed rate increased from 100 kg ha^{-1} to 150 kg ha^{-1}, the spike length decreased (Mekonnen, 2017).

2.7. Sowing Method and Their influence on Wheat on Growth and Yield

2.7.1. Concept and Importance of Sowing Method

Planting technique is a main agronomic factor that affects the growth, development, and yield of bread wheat (*Triticum aestivum L.*) in Ethiopia. The predominant sowing methods are broadcasting (manual) and row or drill sowing mechanized or semi-mechanized (Amoozad-Khalili *et al*., 2023). Broadcasting, which involves randomly scattering seeds by hand, is an inexpensive and straightforward approach but often results in uneven plant distribution and inefficient resource use. Conversely, mechanical or row sowing ensures better seed-to-soil contact, improved germination rates, and more precise management of inputs like fertilizer and irrigation by providing uniform seed placement and appropriate spacing (Atwal and Jaswal, 2024). These sowing methods have a significant impact on crop establishment, tillering, weed control, and ultimately, the yield of bread wheat (Josan et al., 2025).

2.7.2. Common Sowing Method in Ethiopia Wheat Production

2.7.2.1. Broadcasting

In lightly covering the soil with plowing or harrowing, broadcasting involves spreading seeds throughout the soil surface. Despite being labor-intensive, this method is often employed because it is straightforward and has minimal initial soil disturbance. However, broadcasting frequently leads to uneven seed distribution, resulting in lower plant density and increased competition among plants for water and nutrients. Research has shown that compared to more precise sowing methods, broadcasting can cause yield reductions of up to 15–20% (Huo et al., 2026). Additionally, broadcasting is particularly vulnerable to environmental factors such as wind and water erosion, which can negatively affect seed germination and dispersal (Owiny et al., 2026).

According to Owiny et al. (2026) low bread wheat production is significantly influenced by factors such as poor seed rate, inappropriate row spacing, traditional sowing techniques, and delays in sowing. Similarly, Iqbal et al. (2010) reported that broadcasting, a conventional sowing method, reduces bread wheat yield. Planting techniques are consequently critical agronomic factors that affect wheat productivity (Ali et al., 2026). Proper sowing methods ensure that seeds are planted

at the correct depth, which enhances seed emergence and supports better crop growth and development.

2.7.2.2. Drilling

Seeds mechanically sown using a seed drill are placed at uniform depths and spacing, which improves seed-to-soil contact and encourages consistent germination and strong root development (Tsyliuryk et al., 2025). Studies have shown that drilling increases wheat yields by 10–20% compared to broadcasting, thanks to more efficient resource utilization (Shen et al., 2025). This method also allows for precise fertilizer application near the seeds, promoting better nutrient availability and uptake. Furthermore, by optimizing plant spacing, drilling reduces the area available for weed growth, effectively minimizing weed competition. As a result, drilling is the preferred sowing method for bread wheat to enhance yield and overall crop performance (Dembi et al., 2025).

However, Ethiopia's high labor and time requirements prevent drill-sowing wheat by hand. It concurs that the seeding technique has a major impact on the bread wheat grains production in south Omo, Ethiopia. Plant height and the quantity of tillers per plant are significantly affected by the drilling sowing technique. He added that wheat planted using the drilling method produced plants that were up to 101.95 cm tall, with seed broadcasting coming in second at 97.49 cm, the results indicate that the drilling sowing method produced plants with a larger mean number of grains per spike (60.60 spike) and that wheat produced more tillers (10.32/plant) than broadcasting methods. Even yet, plants that were disseminating had the fewest grains or spikes (Hussain et al., 2023). In contrary to the 400 tillers m^{-2} broadcasting method of sowing, Dorado et al. (2025) reported that the drilling method of planting recorded significant maximum tillers m^{-2} of bread wheat. Additionally, Latif et al. (2018) found that planting techniques had a major impact on wheat emergence. He found that the drilling sowing method produced the greatest number of wheat plants within a given day, followed by broadcast beds.

In a similar vein, Wato et al. (2020) reported on his discovery of a significant difference in plant height between the drilling, dibbling, and disseminating sowing methods; that is, the drilling sowing method produced the maximum plant height. There was a significant variation in the number of tillers per plant in addition to plant height. Additionally, Assefa and Kassaye (2017) found that when bread wheat was sown using the drilling method at a seed rate of 150 kg ha^{-1}, the

number of spikes per plant, thousand grain weight, number of grains per spike, and grain and straw weight per plot were all highest when the seed rate was maintained at 125 kg ha^{-1} (Mohammed, 2025).

According Hossain et al. (2015) claims that broadcasting outperformed traditional techniques in terms of maximum grain weight, longer spike length, and the number of plant spikes per square meter. Due to greater yield features, bed planting also demonstrated the highest grain output. Meleh *et al.* (2020) found that the bed spread planting method produced the highest mean values for every parameter examined, with the exception of plant height, which was measured using drilling seeds at a 15 cm planting method during the two growing seasons.

2.7.2.3. Manual Sowing method

Manual sowing methods, including traditional broadcasting and hand row planting, remain widely used among smallholder farmers because they are affordable and well-suited for small plots (Kare, 2024). However, broadcasting tends to produce uneven plant distribution and requires 20–30% more seed compared to mechanical sowing systems. These manual approaches are often marked by irregular seed placement (Abate and Abebe, 2024). Although hand row planting offers greater precision than broadcasting, recent research shows it still results in 10–15% lower yields than mechanical sowing due to inconsistent seed depth and spacing (Damte and Tafes, 2023).

2.7.2.4. Mechanized Sowing method

The mechanized sowing method refers to the use of machinery and equipment, such as seed drills or planters, to plant seeds into the soil at precise depths and spacing. This method ensures uniform seed distribution, improves seed-to-soil contact, and promotes consistent germination and seedling establishment. Mechanized sowing enhances efficiency by reducing labor and time requirements, optimizing seed use, and enabling better management of inputs like fertilizers and irrigation. It is widely adopted in modern agriculture to increase crop productivity and improve overall field management compared to traditional manual sowing techniques (Kumar and Doan, 2025).

Agricultural output growth in Ethiopia has been limited by low mechanization levels, over-cultivation of densely populated highland areas, and a lack of focus on conservation agriculture (Tefera, 2025). Improving the productivity of bread wheat, profitability, and sustainability of smallholder farming is essential for reducing poverty (Shiferaw et al., 2013). Achieving

agricultural growth and enhancing rural household welfare will require increased efforts to supply resources that boost crop yields (Kumar et al., 2026).

Recent studies in small-scale mechanization, including two-wheel tractor-mounted planters, has shown promise by increasing yields by 30% and lowering operating costs by 40% compared to traditional mechanization methods (Amponsah et al., 2025). Recognizing that improved mechanization could raise national wheat production by 1.5 to 2.0 million tons annually, the Ethiopian government initiated the National Wheat Mechanization Initiative (2023–2030), which aims to address these challenges through focused subsidies and training programs (Effa et al., 2025). To promote effective implementation and equitable adoption across different farming systems, it is crucial to develop tailored solutions that account for local agro-ecological factors and the resource constraints faced by smallholder farmers (Majina, 2025).

2.7.3. Influence of sowing method on Crop emergence, tiller, weed management and yield

The uniformity and rate of seed germination are determined by the sowing technique in relation to crop emergence. Due to changing soil moisture levels and seed coverage, manual broadcasting usually produces non-uniform seed depth, which can result in uneven and occasionally poor emergence (Askarzadeh, 2025). On the other hand, precise seed planting at a constant depth of 3–5 cm is made possible by mechanical or row sowing, which enhances seedling emergence and stand establishment. When compared to manual broadcasting, mechanical sowing boosts seedling emergence by 15–25%, according to studies done in the Oromia and Amhara regions (Jibat, 2025). For healthy wheat stands in Ethiopian highland locations, uniform crop emergence encourages improved canopy development (Aga, 2025).

The planting technique has a significant impact on wheat's ability to tiller (Akbar et al., 2025). Due to uneven plant dispersal, plants in broadcast fields compete erratically, leading to limited growth in some areas and intense competition in others. However, row or drill sowing increases the number of productive tillers by giving every plant equal area and access to sunlight, water, and soil nutrients. Wheat planted in rows produced 35–40% more effective tillers per square meter than those sown by broadcasting, according to research done in central Ethiopia by (Anbes et al., 2025). Better nutrient utilization and more spike development are further supported by the stronger, more consistent tillering that comes with row planting, both of which directly increase grain output.

The method of sowing also has a significant effect on weed control (Zhao and Zhang, 2025). Broadcasting frequently produces uneven stands that impede manual weeding and inter row cultivation, allowing weed species to flourish and compete with the crop for moisture and nutrients. On the other hand, robotic sowing's uniformly spaced rows make it easier to weed manually or mechanically and encourage quick canopy closure, which effectively inhibits weed development (Gronewold, 2025). According to field tests conducted in the Bale zone, row planting improved crop growth and nutrient uptake by reducing weed biomass by over 45% when compared to broadcasting (Guye, 2019).

As a result, mechanical sowing improves the effectiveness of weed management and resource conservation, both of which are critical given Ethiopia's labor shortage .The biggest distinction between human and automated sowing techniques is the effect on yield. Because of increased plant population, greater nutrient and light interception, and effective weed control, mechanized row or drill sowing regularly results in higher yields. Broadcasting, on the other hand, frequently leads to uneven stands, heightened plant competition, and decreased spike and kernel development. In important wheat-producing regions like Arsi, Bale, and Shewa, switching from manual broadcasting to mechanical sowing has been shown to increase yields by 20 to 40% (Asefa, 2024). For example, Haile and Tesfaye (2019) found that yields from robotic drill planting were 4.8 t ha^{-1}, while broadcast fields of the same variety and fertilizer level were 3.1 t ha^{-1}. Additionally, robotic sowing uses about 80–100 kg of seed per hectare as opposed to 120–150 kg per hectare for broadcasting, which lowers production costs while preserving or increasing yields (Pradhan et al., 2024).

2.8. Interaction Effect of Sowing Method and Seed Rate

2.8.1. Theoretical foundation of interaction effect

In Ethiopia, wheat establishment, growth, and yield are greatly influenced by the interaction between sowing technique and seed rates the best combinations differ depending on the agro-ecological zone. When compared to typical broadcast sowing, row sowing (20–25 cm spacing) at moderate seed rates (120–150 kg ha^{-1}) improves light penetration, decreases intra-row competition, and boosts tiller growth, especially for high-yielding varieties like Kakaba and Ogolcho (Dawit et al., 2018). Broadcast sowing, on the other hand, frequently necessitates 10–20% higher seed rates

(150–180 kg ha^{-1}) to make up for uneven seed distribution and poor crop stand, but this raises input costs and lodging risk.

Particularly in regions with limited moisture, like Tigray and North Wollo, precision sowing techniques like drilling and dibbling maximize seed location and lower seed rates (100–120 kg ha^{-1}) while preserving yield potential (Alemu, 2024). However broadcast distribution increases disease pressure and yield losses under dense stands, row sowing at lower seed rates reduces lodging in high-rainfall zones (such as Bale and Illubabor) by enhancing airflow and stem strength. According to recent research, wheat yields can be increased by 15–25% when mechanical row sowing is combined with modified seed rates depending on variety and soil type (Sharma and Singh, 2020). To improve resource use efficiency and climate resilience, policymakers and farmers should give priority to context-specific sowing techniques and seed rate combinations Ethiopia's wheat sector (Aga, 2025).

2.9. Agronomic Practices of Wheat Production

2.9.1. Land requirements and preparation

Healthy, productive plants are produced when fertile soil with a good water-retention capacity is selected area. Most seed crops have a cropping cycle that needs at least one fallow season between two seed crops of the same variety and generation in order to avoid disease and volunteer stand contamination from the previous seed crop (Bedadi et al., 2023). Agronomic practices to ensure the soil is clean and free of weeds and illnesses prior to planting include slashing, burning any existing vegetation, plowing, harrowing, and applying a herbicide (Umeghalu et al., 2022).

2.9.2. Seed rate

Stable seed rates are an essential part of the wheat seed production system. Different wheat cultivars react differently to different seed rates. Grain weight, tillers per square meter, total seed yield, and the number of plants per square meter are all impacted by seed rate. Reda et al. (2018) demonstrated that the pace of seeding had a considerable impact on the weight of 1000 seeds, with the weightiest seeds being produced at the lowest rate. Gebeyehu (2020) discovered that while an optimal seed rate may produce more tillers, more spikelets per spike, and high seed output, an inappropriate seed rate results in low yield and poor quality seed.

This is due to the fact that a higher seed rate is a result of shorter spikes, fewer grains per spike, smaller seeds, and more competition for moisture and nutrients. The dry matter content, or weight,

of the seed is a significant factor in seed vigor. Asefa (2024), Rukavin et al. (2002) indicates that the percentage of seeds that germinate and their weight are positively and significantly correlated. This is because seed storage oxidation prepares the energy needed for germination and seedling emergence.

2.9.3. Seed storage

Seed is a crucial component that has a significant impact on agricultural output and productivity. Local seeds are used to establish 90% of Ethiopia's cultivated wheat region. Usually seeds from past season harvests that farmers have stored (Kifle et al., 2022). Historically, Ethiopian farmers have stored their seeds in subpar conditions, either in polythene bags at home or in mud-based goteras that don't need bags. Lower yields and risked food security result from improperly handled seeds during field operations and storage.

Inadequate storage conditions decrease the potentiality loss, germination capability, and deterioration of seed quality. A number of factors may influence the physiological quality of seeds during storage, including temperature, humidity, chemicals, manufacturing conditions, harvesting, infections, and insects. Furthermore, the seed's proximate composition and quality are greatly affected by the storage conditions and packaging materials (Chala and Bekana, 2017).

2.10. Effect of Varieties on Bread Wheat Production

Breeders in the nation released a large number of enhanced wheat varieties from research institutions (Mohammed, 2021). However, because of anthropogenic and environmental factors that impact wheat production, the actual yield of these wheat varieties in farmers' fields typically stays below the global average yield of wheat crop (Dube, 2023). Breeders examine new wheat varieties for yield performance in various places when they are created to boost overall productivity. A new wheat variety's production and capacity for adaptation in such areas determine its success.

Farmers and breeders greatly value wheat varieties with high and consistent yields (Shibeshi, 2024). There are now breeding stock varieties with various physical and economic traits (Parihar and Singh, 1995). Wheat genotype performance is primarily influenced by soil and climate conditions, input application, and other management factors (Osama, 2025). For wheat cultivation and improvement, a genotype's performance in a particular environment is particularly crucial (Shibeshi, 2024). According to study each variety has a genotype-specific capacity to sustain performance under a variety of environmental circumstances (Degife and Demis, 2020).

This capacity is commonly known as a variety's sensitivity or adaptability. Farmers naturally want to adopt varieties that perform well in their own fields, so this capacity is important. According to Majid and Mohsen (2012), there were notable variations for spikes between cultivars. In contrary, Igorpirez et al. (2013) found that the quantity of grains per ear achieved in different seeding densities was unaffected by wheat genotypes. In terms of days to heading, plant height, spike length, thousand kernel weights, and grain production, highly significant differences amongst wheat types (Mengistu et al., 2025).

According study of Iqbal et al. (2010) discovered that a high grain yield is produced by sowing bread wheat at the ideal seeding rate, which enhances the number of grains per spike, spike length, grain weight per spike, and thousand grain weight. The crop yield and yield components, such as plant height, number of tillers m^{-2}, grain $spike^{-1}$, thousand grain weight, and grain yield are greatly effect by the various bread wheat varieties; however, the plant population m^{-2} was not significantly affected by the various varieties. Kumera et al. (2020) found that types had a very large impact on bread wheat spike length (Manu et al., 2020).

Similarly, Kumera et al. (2020) found that varieties had a substantial effects on grain yield. The Liben variety of bread wheat had the highest mean grain yield and thousand grains weight, while the Hidase variety had the lowest mean (3.79 t ha^{-1}) (Eskezia and Fentahun, 2025). In a similar vein Feyisa et al. (2023) found a significant variation in grain yield between bread wheat cultivars. Thousand grain weights are greatly influence by both grain and variety. In the Guji zone of the Oromia area, the Hidase and Ogolcho varieties showed a considerable difference in thousand seed weight when compared to the Liben variety.

In a same vein, different bread wheat varieties have varying days to 50% heading. According to Habtamu and Ahadu (2019), different types of bread wheat had varied days to 75% of heading; the Kekeba variety had shorter days to heading, whereas other kinds had longer days to heading (Mohammed Ibro, 2021). Similarly, Assefa and Mulatu (2017) found that cultivars under varying seed rates had a substantial impact on days to 50% heading and spike length (Getahun, 2020).

2.11. Varietal Performance under Different Agronomic Practices

2.11.1. Genetic Variability Bread Wheat (*Triticum aestivum L.*)

According to Tola (2020), Kumar et al. (2013), variability is the occurrence of differences among varieties (individuals) as a result of differences in their genetic composition and/or environment. Genetic variety is the term used to describe the modifications to character expression that would occur due to genetic control if both individual's environments were identical (Welsh, 1990; Falconer et al., 1996). Breeders will be able to take use of genetic variety more effectively if the amount of variability among germplasm collections for significant plant traits is estimated (Tola et al., 2024).

Any plant breeder who wants to improve yield and other desired agronomic features must engage in the establishment of genetic diversity and selection for important characteristics. A specific environment is made up of everything that is not directly related to themselves. Depending on whether they are biological or non-biological, these different environmental elements are referred to as biotic or abiotic (Mesele, 2015). Therefore, the component of variance is influenced by environmental deviations, such as seasonal fluctuations, soil moisture levels, and differences in the fertility level of fields.

Phenotypic variation, or the observable variation present in a character in a population, includes both genotypic and environmental components of variation, and as a result, the extent of it varies under different environmental conditions (Rajput, 2019). However, proper experimentation can reduce environmental variations, but it is impossible to completely eliminate them because they include non-genetic variance, many of which are beyond experimental control (Gomez and Gomez, 1984).

Accordingly, environmental deviation and genotypic variation lead to phenotypic variation. Thirty genotypes examined for days to 50% flowering, days to maturity, plant height, effective tillers per plant, spike length, number of kernels per spike, thousand-kernel weight, and seed output per plant showed moderate to high variability, according to (Angassa, 2021). According to Dabi et al. (2019), thirteen bread wheat genotypes differed significantly in terms of grain output, days to heading, days to maturity, and thousand-kernel weight.

2.12. Yield and Yield Components of Bread Wheat

2.12.1. Determination of Grain Yield

Understanding how it is determined at the genetic and physiological levels is the first step towards achieving genetic gain for improved wheat production. In addition to interactions with environmental indicators, grain production itself is a result of plant growth and development during its whole lifecycle. Yield component techniques have long been utilize to analyze this characteristic because of its complexity. That is, either physiologically or numerically, yield can be broken down into several comparatively smaller components (Carrera et al., 2024).

Grain number per unit area and individual grain weight for instances of numerical components the former comprises four sub-components, plants per unit area, spikes per plant, spikelets per spike, and grains per spikelet. The other technique is physiological and takes harvest index and biomass into explanation when calculating yield. Therefore, final grain yield would be indirectly determine by factors affecting these components. Finding the genetic and physiological foundations of yield components and their secondary determinants while accounting for trait trade-offs is the next stage in this process.

The quantity of plants per unit of land area is determined by the establishment and sowing of seeds. In order to create dense plant populations, farms characteristically have high seed rates (>

250 seeds m^{-2} in the UK). Sowing date, sowing depth, soil type (lower for loams and clays), soil moisture, overwinter weather (e.g. temperature), and pest and disease damage all affect establishment, which includes seed germination, emergence, and overwinter existence if winter type (Foulkes et al., 2011).

However, a slightly smaller plant population brought on by compensatory tillering would not result in a decrease in yield (Foulkes et al., 2011). Depending on when the plants are sown and their subsequent temperature, tillering might take place in the fall or spring. Determining the final spike number per plant is a crucial task of tillering. Depending on the genotype, season, growing location, seeding rate, and nutrient supply, a plant may produce up to 35 shoots in total, but not all tillers that are initiated eventually form spikes; 10–80% typically die between the onset of stem elongation and anthesis.

2.12.2. Resource use efficiency and yield stability

In Ethiopia, success the best and most reliable wheat harvest means carefully balancing how much seed to use, how it's planted, and which variety fits the local environment best (Anbes et al., 2025). While the standard recommendation is to use 150 kg of seed per hectare, studies show that using a bit less around 100 to 125 kg can actually help the plants use water and nitrogen more efficiently without hurting the grain yield much. This happens because fewer plants mean less crowding and a lower chance of lodging, where plants fall over and lose productivity (Assefa et al., 2021).

The technique seeds are sown materials just as much. Switching from the old-fashioned broadcasting method to planting seeds in rows spaced about 20 cm apart makes a big difference. Row sowing helps seedlings emerge evenly, captures sunlight better, and places nutrients where plants can use them most effectively, all of which lead to more stable yields. Choosing the right wheat variety is also crucial. Newer, high-yielding, and early-maturing varieties like Lemu, Deka, and Dursa have consistently outperformed older ones like Kakaba, delivering better yields and higher profits across different parts of Ethiopia (Tadesse et al., 2022), (Balcha and Mekiso, 2025). When farmers combine a seed rates of around, 125 kg per hectare with row planting and these resilient varieties, they can better manage their resources and protect their crops from challenges like dry spells at the end of the season and unpredictable rainfall (Kebede et al., 2024).This smart approach helps ensure healthier crops and more reliable harvest for Ethiopian farmer.

2.12.3. Yield gap Closure Wheat Production

In agronomy, crop production ecology, and agricultural economics, the yield gap was hardly new, but it has resurfaced in light of the challenges of feeding the world's population of over 9 billion people by the year 2050 (Mumah et al., 2025). The yield gap for irrigated systems is the difference between the actual farm produce and the projected yield (Senbeta and Worku, 2023). The yield gap is the difference between the water-limited yield potential and the actual yield that farmers achieve on their fields, whereas crops in rainfed agricultural systems have at least temporary water shortfalls (Senbeta and Worku, 2023).

Reducing the yield gap has various advantages, including decreasing the development of farmed lands and the corresponding drop in the pace of deforestation and biodiversity loss in nations like Ethiopia where the yield gap is extremely significant due to biophysical and socioeconomic limitations. Ethiopia is ranked 60th in terms of yield, 25th in terms of production, and 24th in terms of harvested area worldwide (Robi et al., 2025). Even by the standards of several African nations, like South Africa (4.14 t/ha^{-1}), Namibia (6 t/ha^{-1}), Egypt (6.57 t/ha^{-1}), and Zambia (7.37 t/ha^{-1}), Ethiopia's 3.0 t/ha^{-1} output is lower (Robi et al., 2025).

The current yield gap presents a chance for future food self-sufficiency if its causes are found and efforts are taken to close it (Ongoma et al., 2025). For example, increasing the 2020 average national yield from 3.0 to 4.0 t/ha^{-1} (50 percent of GYGA's water-limited yield potential) may increase the country's wheat production by 2 million tons. This is more than the 1.6 million tons of wheat that are imported each year, and it indicates that the nation can become wheat self-sufficient if 50% of the production potential is reached (Asfaw et al., 2026). Therefore, funding for closing the yield gap through increased and more effective use of inputs (water, fertilizers, and pesticides) and crop management enhancements could contribute to wheat self-sufficiency while reducing the effects of climate change (Kedir et al., 2022).

Without the adoption of improved wheat varieties, fertilizer acceptance, enhanced extension services, and improved agronomic techniques, Ethiopia's recent improvement in wheat production would not have been achieved. Since the late 1960s, more than 100 bread wheat varieties have been successfully introduced by regional and national wheat projects in collaboration with ICARDA and CIMMYT. In contrast to recently released modern varieties like Danda’a, Wane,

Hidase, Abay, Dursa, Boru, and Daka, older types like Lakech, Esrael, and Enkoy have low productivity (Kassie et al., 2025).

The yields have exhibited a steady linear improvement over time. Many of the older wheat varieties became obsolete due to emerging rust races, low productivity, slow early generation seeds multiplications, and weak extension systems in scaling-up of the newly released wheat varieties The government of Ethiopia is promoting agro-clustering as a pathway to reduce yield gap and consequently reduce poverty and stimulate economic growth agricultural transformation agency (Zhang et al., 2025).

Agro-clustering involves combining little smallholdings located in wheat producing agro-ecological zones into crop-specific clusters (larger farmlands) to ease mechanization and access to long-term capital investment (Dawit, 2024). In particular agro-clustering aims to ease access to inputs, credit, information, extension support and mechanization services such as development of irrigation schemes, renting tractors to prepare land and combiners to harvest. The agro-clustering also helps small-scale farmers to get improved market access with higher prices and higher value-added production (Senbeta and Worku, 2023).

The lack of both high quality and high-quantity inputs is the other barrier to closing the yield gap through agro-clustering. The agricultural production clusters must implement the most recent full-package farm recommendations, which include the use of inputs (better seeds, inorganic fertilizer, and pesticides) and other farming best practices. However, there is a deficiency or low level of timely distribution and availability of certified seeds, fertilizers, and instruction in agronomic practices (row planting, lower seed rating) (Bachewe et al., 2018).

One of the biggest challenges and complaints raised by farmers is the timely supply and availability of the required quantity of seed and fertilizer during the busiest planting seasons. Due to the formal seed sector's limited ability to supply the vast amounts of seed needed for planting, the national seed system needs to be made more efficient in order to accommodate farmers' varietal preferences. Currently, only 13% of seed, 19% of farmed area, and 19% of smallholders use improved wheat varieties. The informal wheat seed system in the nation accounts for around 80% of seed distribution to smallholder farmers (Bishaw and Alemu, 2017).

Prioritizing policies and actions towards wheat self-sufficiency under future scenarios requires an understanding of the yield gap's limits. Several authors in Ethiopia have written about the

constraints of the yield gap (Silva et al., 2021). Efficiency, resource, and technological yield gap restrictions were broken down in many of the research. Crop management flaws (inefficiencies) in production, such as inadequate knowledge, expertise, or information on planting density, planting/application time, and poor fertilizer and chemical application, are the cause of the technical efficiency yield gap. The primary policy tools for closing the technical efficiency yield gap are farmer education investments and extension services (Alemu, 2024).

The resource yield gap refers to the difference between the maximum farmer production and the most technically efficient yield. The highest farmer yield is the average yield across the top 10% of actual yields in a sample of farmers who share similar biophysical circumstances and use similar technology. The resource yield gap is generated by inefficient input application and can be divide into two types: allocative and economic yield gaps. Investment in road infrastructure, financing to overcome financial difficulties, insurance, national input support, and production transaction cost improvements have the ability to close the resource yield gap (Silva et al., 2021).

According to Morley et al. (2019), the resource yield gap accounts for 32.6% of the wheat yield gap in Ethiopia. The technology yield gap is defined as the difference between water-limited productions and the highest farmer or practical yield. One of the primary causes of the technological yield gap in Sub-Saharan Africa is a lack of access to the availability of adequate and improved technologies for smallholders, which will continue to play an important role under future climate change scenarios (Evenson, 2001).

The technologies needed include development of new improved varieties, use of advanced technologies and site specifics fertilizer application, which consequently shift the frontier response bend upwards in the direction of the theoretical yield response curve. Silva et al. (2021) found that the technology yield gap contributes for more than 50 % of water limited yield of wheat in Ethiopia. (Morley et al., 2019) suggested that technology yield gap contributes for 57 % of the wheat yield gap in Ethiopia.

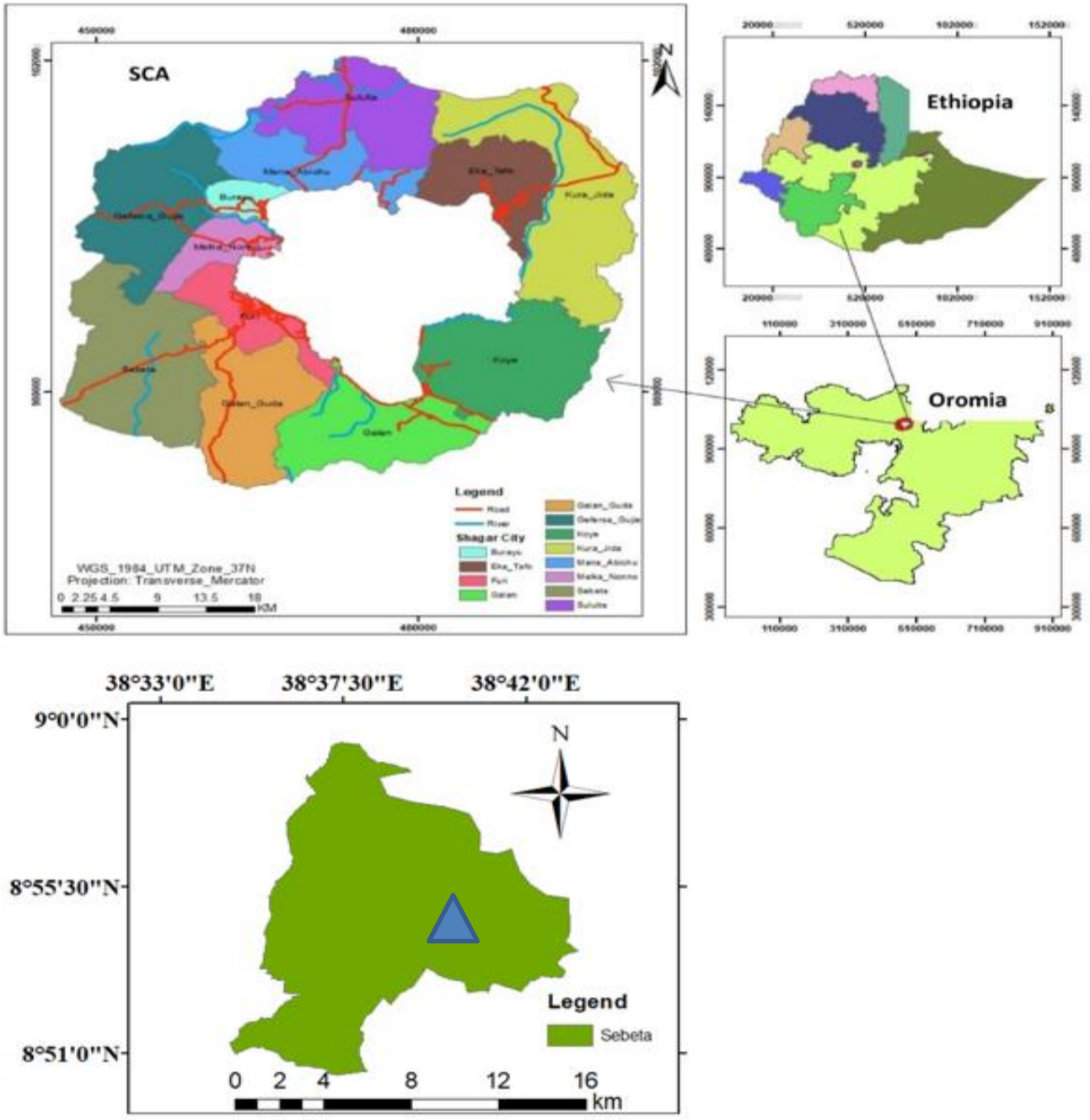
3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted in Sebeta Town, located in Sebeta Hawas District of the Shager City Administration, Oromia Region, Ethiopia. The study area is situated approximately 24 km west of Addis Ababa along the Jimma Road. Geographically, it lies between 8°53′38.50″–8°59′58.17″ N latitude and 38°35′11.91″–38°39′33.75″ E longitude (Figure 1). Sebeta borders Addis Ababa to the north, northeast, and east; Burayu town to the north; and rural kebeles of Sebeta Hawas District to the south and west.

Agro-ecologically, the area falls within the Woynadega (mid-altitude) zone and shares several climatological characteristics with Addis Ababa. The altitude ranges from approximately 1,700 to 3,200 meters above sea level, and the mean annual temperature ranges between 12.7 and 24.4°C. The area is characterized by bimodal rainfall distribution, favourable for cereal crop production. Dominant soil types include black Vertisols and red Nitisols, both of which are suitable for wheat cultivation; however, Vertisols are particularly prone to waterlogging during periods of excessive rainfall. It has an annual rain fall ranging from 800 to 1200 mm and soil pH is 6.0 to 7.05 according to Sebeta Hawas agricultural office report.

Under research-managed conditions, wheat productivity in the area ranges from 3.05 – 5.4 t ha^{-1} on red soils and up to 3.3 t ha^{-1} on black Vertisols (Bekele, 2025). Despite this potential, waterlogging and suboptimal agronomic practices constrain yield realization.



Source: (Bekele, 2025).

Figure 1. Map of the study area

3.2. Experimental Planting Material

Three bread wheat (*Triticum aestivum* L.) varieties Gutu, Melka, and Kakaba (local standard check) were used for the experiment. Gutu and Melka were recently released in 2024 by Holeta Agricultural Research Center (HARC), while Kakaba was released in 2010 by Kulumsa Agricultural Research Center (KARC). These varieties were selected based on their yield potential, disease tolerance, adaptation to mid- and high-altitude agro-ecologies, and relevance to farmers in the study area.

The varieties have similar adaptation ranges and maturity periods, although Kakaba has a relatively shorter maturity duration compared to the newly released varieties (Tadesse *et al.*, 2022; Dabi *et al.*, 2024).

All agronomic management practices including land preparation, fertilizer application, pest and disease management, and weed control were conducted uniformly across treatments following recommended practices (Earecho, 2021).

Table 3. Source wheat varieties used for the study

No	Name of variety	Years of released	Altitude (m)	Rainfall (mm)	Day of maturity	Maintain	Under Research	Under farmer
1	Gutu	2024	2200-3200	700-1000	120-135	HARC	4.6 t ha^{-1}	- 4.0 t ha^{-1}
2	Melka	2024	2200-3200	700-1000	125-135	HARC	4.7 t ha^{-1}	-4.0 t ha^{-1}
3	Kakaba (local standard)	2010	1500-2200	500-800	90-120	KARC	3.3-5.2t ha^{-1}	2.6 t ha^{-1}

Source: - (Tadesse et al., 2022, Dabi et al., 2024, and Duga et al., 2024).

3.3. Experimental and Design

The experiment was laid out in Randomized Complete Block Design (RCBD) with factorial arrangement three replications. The treatments consisted of: Three bread wheat varieties (V1 = Gutu, V2 = Melka, V3 = Kakaba), Two sowing methods (SM1 = broadcasting, SM2 = drilling/row planting) and Three seed rates (SR1 = 100 kg ha^{-1}, SR2 = 125 kg ha^{-1}, SR3 = 150 kg ha^{-1}). These factors resulted in 18 treatment combinations (3 × 2 × 3) and 54 plot numbers. Each gross plot measured 3 m × 2 m (6 m^2), (571 m^2), consisting of 10 rows spaced 20 cm apart in drilled treatments. The spacing between plots and replications was 0.5 m and 1.0 m, respectively. To minimize border effects, two outer rows and 20 cm at each end of rows were excluded, resulting in a net plot size of 2.6 m × 1.6 m (4.16 m^2).

Table 4. Treatment arrangement and combination

Treatment code	Varieties	Sowing Methods	Seed Rate	Combination
1	V1	SM1	SR1	V1 SM1 SR1
2	V1	SM1	SR2	V1 SM1 SR2
3	V1	SM1	SR3	V1 SM1 SR3
4	V1	SM2	SR1	V1 SM2 SR1
5	V1	SM2	SR2	V1 SM2 SR2
6	V1	SM2	SR3	V1 SM2 SR3
7	V2	SM1	SR1	V2SM1 SR1
8	V2	SM1	SR2	V2 SM1 SR2
9	V2	SM1	SR3	V2 SM1 SR3
10	V2	SM2	SR1	V2 SM2 SR1
11	V2	SM2	SR2	V2 SM2 SR2
12	V2	SM2	SR3	V2 SM2 SR3
13	V3	SM1	SR1	V3SM1 SR1
14	V3	SM1	SR2	V3 SM1 SR2
15	V3	SM1	SR3	V3 SM1 SR3
16	V3	SM2	SR1	V3 SM2 SR1
17	V3	SM2	SR2	V3SM2 SR2
18	V3	SM2	SR3	V3 SM2 SR3

Where: V1: Variety 1, V2: Variety 2, V3: Variety 3, SM1: Sowing method 1(broad casting), SM2: Sowing method 2(drilling), SR1: Seed rate 1, SR2: Seed rate 2, SR3: Seed rate 3.

3.4. Experimental procedures and Management Practices

Land preparation followed local farming practices using an oxen-driven traditional plough. The field was ploughed three times between mid-February and early June 2025. Final plot layout and levelling were completed in June 2025 prior to sowing. The experiment was harvested in October and November 2025.

Seeds were sown manually according to treatment specifications. Broadcasting treatments involved uniform surface distribution followed by light soil covering, while drilling treatments involved placement in furrows at the specified row spacing.

Fertilizer was applied uniformly across all plots following regional recommendations. Diammonium phosphate (DAP) was applied at 100 kg ha^{-1} at planting. Urea was applied at 200 kg ha^{-1}, split as one-third at planting and two-thirds at maximum tillering stage (Rajni et al., 2025). Weed, pest, and disease management practices were applied uniformly across treatments to avoid confounding effects.

3.5. Data Collection and measurement

Data were collected on phenological traits, vegetative growth parameters, yield components and yield following standard experimental procedures.

3.5.1. Crop Phenology parameter

Days to 50% emergence: Number of days from sowing until 50% of plants emerged in each plot.

Number of 50% Days to heading: Number of days from sowing to the stage when 50% of plants exhibited spike emergence.

Days to 90% physiological maturity: Number of days from sowing until 90% of plants reached physiological maturity, indicated by leaf senescence and grain hardening.

3.5.2. Vegetative growth parameters

Plant height: Measured from ground level to the tip of the spike (excluding awns) at maturity from ten randomly selected plants per net plot.

Number of effective tillers per plants: Productive tillers bearing spikes counted from ten sampled plants at harvest.

Number of total tillers: Counted from ten randomly selected plants at late tillering stage

Spike length: Measured from spike base to tip (excluding awns) from ten randomly selected plants at maturity.

3.5.3. Yield Related Traits

Kernels per spike: Average number counted from ten randomly selected spikes per plot.

Total biomass yield: Sun-dried aboveground biomass harvested from the net plot and converted to hectare basis.

Thousand Kernel weight: Determined by weighing 1,000 grains adjusted to 12.5% moisture content.

Grain yield: Grain weight harvested from net plot, adjusted to 12.5% moisture content, and converted to hectare basis.

Straw yield: Calculated as total biomass minus grain yield.

Harvest index: Calculated as the ratio of grain yield to the total aboveground biomass (Nakachew et al., 2025).

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)} * 100}{\text{Total biomass yield (kg ha}^{-1}\text{)}}$$

3.6. Statistical Data Analysis

The collected data were subjected to analysis of variance (ANOVA) appropriate for a factorial RCBD using R-Studio software (R-Studio, 2025), version 9.2. Treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level when treatment effects were significant. Correlation analysis among measured parameters was conducted following the procedures described by (Gomez and Gomez, 1984).

3.7. Estimation of Correlation on growth, yield and yield component of bread wheat

To determine the strength and degree of relationship, correlation coefficient values (r) were calculated. The Pearson correlation technique, which is provide by in R software, was used to create a test of significance. Pearson's correlation coefficients (r) were calculated to estimate the strength and direction of linear relationships among growth traits, yield components, and grain yield. The significance of correlation coefficients was evaluate at the 5% probability level (Pearson, 1931). To further delineates the direct and indirect effects of yield components on grain yield, path coefficient analysis was conducted following the method described by (Singh et al., 2022).

3.8. Economic Analysis

The partial budget method provided by CIMMYT (1988), was used for the economic analysis. The partial budget analysis was applied after the mean grain and straw yield data were reduced by 10% (CIMMYT, 1988). Treatments were arranged by sorting their total variable cost (TVC) in ascending order, and dominance analysis was performed to exclude those that cost more. The costs that differed for each treatment (seed cost and labor cost during planting) were determined. The economic study considered of costs and prices that were in production at the time of use in the local market. The cost of labor was ETB 600 per person per day, whereas the cost of seed was ETB 80 kg^{-1}. Grain and straw were selling for ETB 75 and ETB 3 kg^{-1}, respectively. The cost of production per hectare was calculated from gross income per hectare to determine net returns per hectare.

4. Results and Discussion

4.1. Crop Phenology and Growth Parameter

4.1.1. Days to 50% emergence

The analysis of variance indicated that days to 50% emergence were no significantly influenced by bread wheat varieties, seed rates, sowing methods, or their interactions (Appendices 1). This lack of significant variation suggests that the emergence process in bread wheat is largely insensitive to genetic differences and the tested agronomic practices under the prevailing environmental conditions (Marti et al., 2014).

4.1.2. Days to 50% heading

The analysis of variance demonstrated that days to 50% heading were highly significantly ($P < 0.001$) affected by the main effects of bread wheat varieties and seed rates but the interaction effect of sowing methods and varieties was non-significant (Table 5 and Appendices 1). Among the varieties, Melka exhibited the longest duration to reach heading (80.78 days), whereas Kakaba reached heading earliest (63.28 days) (Table 5). This variation is attributable to inherent genetic differences controlling photoperiod sensitivity, temperature response, and vernalization requirements, which collectively regulate the transition from vegetative to reproductive growth. These findings are consistent with those of Kefale and Menzir (2019), who reported significant variation in days to heading among tested varieties, Also Duressa and Ayana (2020), observed a significant effect of variety ($P < 0.05$) on heading time.

Regarding seed rates, the maximum days to heading (74.5 days) occurred at a seed rate of 100 kg ha^{-1}, while the minimum days to heading (69.83 days) were recorded at a seed rate of 150 kg ha^{-1}. This variation is likely mediated by plant density effects on resource availability and stress-induced developmental responses. At lower seed rates, reduced intra-specific competition allows plants to allocate more resources to vegetative growth, thereby extending the vegetative phase and delaying heading. In contrast, higher seed rates intensify competition for light, nutrients, and water, prompting an accelerated transition to reproductive growth and resulting in earlier heading. These observations align with the findings of Mekonnen (2017), who reported that days to 50% heading were very highly significantly ($P < 0.001$) influenced by seeding rate.

4.1.3. Days to 90% physiological maturity

The main effects of bread wheat varieties, sowing methods, and seed rates were significantly ($P < 0.001$) influenced the days to 90% physiological maturity of bread wheat but not interaction (Table 5 and Appendices 1).

Among the varieties, Melka required the longest period to reach physiological maturity (136.44 days), whereas Kakaba attained maturity in the shortest time (110.33 days) (Table 5). This variation is likely attributable to inherent genetic differences among the varieties that regulate growth duration and developmental rates. Similarly, Mekonnen (2017) reported that days to 90% physiological maturity were very highly significantly ($P < 0.05$) influenced by seeding rate.

Regarding sowing methods, the longest duration to physiological maturity (127.37 days) was observed under broadcasting, whereas the shortest (124.67 days) occurred under drilling. This difference can be attributed to variation in plant spacing and intra-specific competition. Drilling ensures uniform plant spacing and reduced competition, allowing sustained growth and prolonged development, whereas broadcasting often results in uneven plant distribution, higher competition, accelerated development, and earlier maturity. In contrary, Mengie et al. (2021), reported that sowing method did not significantly affect tef maturity, suggesting crop-specific responses.

With respect to seed rates, an increase from 100 to 150 kg ha^{-1} resulted in a decrease in days to physiological maturity from 128.89 to 122.94 days. This reduction is likely due to higher plant density inducing resource competition and physiological stress, which accelerate developmental processes. This observation aligns with Bekele (2020), who reported that increasing seeding rates from 100–175 kg ha^{-1} reduced days to 90% physiological maturity by approximately 5 days.

Table 5. Mean performance for phenological parameters day to 50% heading and day to 90% physiological maturity as affected main of variety, sowing method and seed rates.

Treatments	Day to 50% heading	Day to 90% physiological maturity
Varieties		
Melka	80.78[a]	136.44[a]
Gutu	72.39[b]	131.28[b]
Kakaba	63.28[c]	110.33[c]
LSD (5%)	2.073	2.254
Sowing Methods		
Broadcasting	72.33	124.67[b]
Drilling	71.96	127.37[a]
LSD (5%)	Ns	1.53
Seed rates (kg ha^{-1})		
100	74.5[a]	128.89[a]
125	72.11[b]	126.22[b]
150	69.83[c]	122.94[c]
LSD (5%)	2.07	2.254
CV (%)	3.52	2.19

Where, Means followed by the same letter along columns are not significantly different from each other at 5% probability level, Ns non-significant.

4. 2. Vegetative Growth Parameter

4.2.1. Plant height

Analysis of variance indicated that plant height of bread wheat was highly significantly ($P < 0.001$) influenced by varieties, and significantly ($P < 0.05$) affected by seed rates but the interaction effect of sowing methods and varieties was non-significant (Table 6 and Appendices 1).

Among the varieties, Gutu produced the tallest plants (87.38 cm), whereas Kakaba had the shortest plants (75.95 cm) (Table 6). This variation is attributable to genetic differences controlling growth habit, stem elongation, and nutrient use efficiency. Similar findings were reported by Duressa and Ayana (2020), who noted significant varietal effects on bread wheat plant height.

The tallest plants height (83.75 cm) were observed at 150 kg ha^{-1}, while the shortest (80.45 cm) were recorded at 100 kg ha^{-1}. The observed variation is likely a consequence of plant density, which affects competition for light, nutrients, and space. Higher seed rates stimulate stem elongation as plants compete for light, whereas lower seed rates reduce competition, resulting in shorter plants. Similarly Laghari et al. (2011) reported that plant height increases with rising seed rates from 75 kg ha^{-1} to 175 kg ha^{-1}.

Table 6. Mean values for plant height, as affected main of varieties, sowing method and seed rates

Treatments	Plant height
Varieties	
Melka	83.38[b]
Gutu	87.38[a]
Kakaba	75.95[c]
LSD (5%)	2.804
Seed rates (kg ha^{-1})	
100	80.45[b]
125	82.51[ab]
150	83.75[a]
LSD (5%)	2.8
CV (%)	4.17

Where, Means followed by the same letter along columns are not significantly different from each other at 5% probability level, Ns=non-significant.

4.3. Yield Related Traits

4.3.1. Number of Effective tiller per plant

The analysis of variance indicated that the main effects of bread wheat varieties, sowing methods, and seed rates significantly influenced plant height, whereas their interaction effects were not significant (Table 6 and Appendices 1). Among the varieties, Melka produced the highest number of effective tillers per plant (4.83), which was statistically comparable to Gutu, whereas Kakaba exhibited the lowest number of effective tillers per plant (3.67) (Table 6). This variation is likely attributable to genetic differences among varieties that regulate tillering capacity, plant vigor, and resource utilization efficiency.

Seed rate had a significant effect on the number of effective tillers per plant. The highest number of effective tillers (5.0) was obtained at the lowest seed rate of 100 kg ha^{-1}, while the lowest (3.44) occurred at the highest seed rate of 150 kg ha^{-1}. This pattern can be explained by plant density effects: lower seed rates reduce competition, allowing individual plants greater access to light, nutrients, and space, thereby promoting tiller production, whereas higher seed rates intensify competition, restricting tiller development. In contrast, Berhanu (2024) reported that the main effects of variety and seed rate did not significantly influence the number of productive tillers per plant of bread wheat.

Sowing with drilling methods produced the highest number of effective tillers per plant (4.52), whereas broadcasting resulted in the lowest (4.04). This difference is attributable to more uniform plant spacing and reduced intra-specific competition under drilling, which promotes better tiller development, whereas broadcasting often leads to uneven spacing and higher competition. Similarly, Berhanu (2024) found no significant effect of sowing method on productive tillers, highlighting potential site- or crop-specific responses.

4.3.2. Spike Length

Analysis of variance revealed that the main effects of varieties, sowing methods, and seed rates significantly ($P < 0.001$) affected spike length, whereas their interactions were not significant (Appendices 1). Among the varieties, Melka exhibited the longest spike length (9.43 cm), followed by Gutu (8.56 cm), whereas Kakaba had the shortest spikes (6.91 cm). This variation is likely due to genetic differences affecting spike development and assimilate partitioning (Table 6). Similarly,

Tariku et al. (2022) reported highly significant ($P < 0.001$) variation in spike length among bread wheat varieties.

Regarding sowing methods, drilling resulted in longer spikes (8.64 cm) compared to broadcasting (7.97 cm), likely due to uniform plant spacing and reduced competition, which allow optimal spike elongation. Additionally, spike length decreased with increasing seed rate; the longest spikes were observed at 100 kg ha^{-1}, whereas higher seed rates (125 and 150 kg ha^{-1}) resulted in shorter spikes, probably due to increased competition for light, nutrients, and space. In line with this, Geleta (2017) reported that sowing method and seed rate significantly influence spike length in bread wheat.

Table 7. Mean performance for plant height, number of effective tillers per plant, and spike length as affected main of varieties, sowing method and seed rates.

Treatments	Plant height	Number of effective tillers per plant	Spike length
Varieties			
Melka	83.38^{b}	4.83^{a}	9.43^{a}
Gutu	87.38^{a}	4.33^{a}	8.567^{b}
Kakaba	75.95^{c}	3.67^{b}	6.91^{c}
LSD (5%)	2.804	0.593	0.314
Sowing Method			
Broadcasting	82.12	4.04^{b}	7.97^{b}
Drilling	82.36	4.52^{a}	8.64^{a}
LSD (5%)	Ns	0.4	0.213
Seed rates (kg ha^{-1})			
100	80.45^{b}	5.00^{a}	8.84^{a}
125	82.51^{ab}	4.39^{b}	8.04^{b}
150	83.75^{a}	3.44^{c}	8.03^{b}
LSD (5%)	2.8	0.59	0.31
CV (%)	4.17	16.96	4.63

Where, Means followed by the same letter along columns are not significantly different from each other at 5% probability level, Ns=non-significant.

4.3.3. Total number of tillers per plant

The main effects of varieties and seed rates, as well as the interaction between variety and sowing method, significantly ($p < 0.01$) influenced the total number of tillers per plant (Table 6 and Appendices 1). The highest total number of tillers per plant (7.33) was recorded in Melka sown using the broadcasting method, followed by Melka with drilling (6.89), whereas the lowest (4.33) occurred in Kakaba under broadcasting (Table 7). This variation may be attributed to genetic differences in tillering capacity and the influence of sowing method on plant spacing and competition, which affect tiller development and survival. Similar studies have shown that tiller number is significantly affected by the interaction of variety, seed rate, and sowing method, highlighting the importance of agronomic management on yield components (Yadelew, 2025).

Table 8. Mean values numbers of total tillers per plant as affected by interaction effect of variety and sowing methods of bread wheat.

	Sowing methods	
Varieties	**Broadcasting**	**Drilling**
Melka	7.33[a]	6.89[ab]
Gutu	5.56[c]	6.11[bc]
Kakaba	4.33[d]	5.11[cd]
LSD (5%)	1.03	
CV (%)	12.77	

Means followed by the same letter along columns are not significantly different from each other at 5% probability level, Ns non-significant.

4.3.4. Number of Kernels per Spike

The number of kernels per spike was significantly influenced by the main effects of varieties and sowing methods ($P < 0.001$), as well as by the interaction between varieties and seed rate ($P < 0.05$) (Table 8 and Appendices 2).

The highest number of kernels per spike (63.33 and 61.00) was recorded for Melka variety at 100 and 125 kg ha^{-1}, whereas the lowest occurred in Kakaba at 150 kg ha^{-1} (Table 8). This variation is likely due to genetic differences in floret fertility, assimilate allocation, and the effects of plant density on competition for nutrients and light. Similarly Soliman and Koubisy (2025), reported that the interaction between sowing method and cultivar significantly affected kernel number per spike, emphasizing the importance of both genetic potential and agronomic management in determining yield components.

Table 9. Mean values of kernels per spike as affected by interaction effects of varieties and seed rates of bread wheat.

	Seed rates (kg ha^{-1})		
Varieties	100	125	150
Melka	63.33[a]	61.00[a]	58.83[ab]
Gutu	52.50[c]	53.17[c]	55.17[bc]
Kakaba	39.00[d]	35.83[d]	35.50[d]
LSD (5%)	4.94		
CV (%)	5.12		

Means followed by the same letter along columns are not significantly different from each other at 5% probability level

4.3.5. Thousand Kernel Weight

The combined effects of bread wheat varieties, seed rate, and sowing methods highly significantly ($P < 0.001$) influenced thousand-kernel weight of bread wheat (Table 9 and Appendices 2).

The highest (56 g) thousand-kernel weight was recorded for Melka variety at a seed rate of 125 kg ha^{-1} under drilling methods of sowing, whereas the lowest (36 g) thousand-kernel weight occurred in Kakaba at higher seed rates (125 and 150 kg ha^{-1}) under broadcasting methods of sowing (Table 9). This variation is likely attributable to differences in genetic potential for grain filling, as well as the effects of plant density and sowing method on assimilate availability, nutrient partitioning, and inter-plant competition. Similarly, Behanu (2024) reported that the three-way interaction of variety, seed rate, and sowing method significantly affected thousand-kernel weight in bread wheat.

4.3.6. Grain Yield

The analysis of variance revealed that the three-way interaction among varieties, seed rates, and sowing methods had a highly significant ($P < 0.001$) effect on grain yield (Table 10 and Appendices 2). The highest (5512 kg ha^{-1}) grain yield was recorded for Melka variety at 125 kg ha^{-1} sown through drilling methods, whereas the lowest (2600.00 kg ha^{-1}) mean grain yield obtained in Kakaba at 100 kg ha^{-1} under broadcasting methods of sowing (Table 9). This variation is likely due to the optimization of seed rate and sowing method, which enhance plant density, reduce intra-specific competition, and improve the efficiency of nutrient, light, and assimilate utilization. Conversely, lower yield in Kakaba at a lower seed rate and drilling method may result from suboptimal plant population, uneven plant distribution, and reduced resource use efficiency. Also, Berhanu (2024) reported that the three-way interaction of varieties, sowing methods, and seed rates significantly influenced bread wheat grain yield. Similarly, the highest grain yield (4.17 t ha^{-1}) was observed in the Lemu variety at 125 kg ha^{-1} under row sowing, further highlighting the importance of optimal agronomic management combined with genetic potential.

4.3.7. Harvest Index

Harvest index (HI) reflects the physiological efficiency of a crop in converting accumulated dry matter into grain yield, with higher values indicating greater potential for grain production. The analysis of variance revealed that the three-way interaction among bread wheat varieties, seed rates, and sowing methods had a highly significant ($P < 0.001$) effect on harvest index (Table 9 and Appendices 2). The highest (55.86) harvest index of bread wheat was observed in Gutu variety at the highest seed rate (150 kg ha^{-1}) under drilling methods of sowing, whereas the lowest (36.84) harvest index was obtained from Melka variety at the lowest seed rate (100 kg ha^{-1}) also under drilling methods of sowing (Table 9). This variation is likely attributable to differences in genetic potential for biomass partitioning, as well as the influence of plant density and sowing method on assimilate allocation between grain and straw. Specifically, higher seed rates can promote more competitive vegetative growth and enhance the efficiency of straw accumulation in some varieties, affecting the proportion of biomass allocated to grain. Likewise, Geleta (2017) reported that the three-way interaction among variety, sowing method, and seed rate significantly affected the mean harvest index of bread wheat, highlighting the importance of genotype × management interactions in optimizing crop productivity.

Table 10. Mean of grain yield thousand kernel weight and harvest index of bread wheat as affected by interaction of varieties, seed rates and sowing methods.

		Grain yield (kg ha^{-1})			Thousand kernel weight (g)			Harvest index (%)		
		Seed rates (kg ha^{-1})								
Varieties	Sowing method	100	125	150	100	125	150	100	125	150
Gutu	Broadcasting	3933.33^{fgh}	4183.33^{efg}	4406.67^{de}	45.33^{de}	44.67^{de}	44.00^{def}	44.41^{c-g}	46.68^{b-f}	48.56^{a-e}
	Drilling	4083.33^{efg}	4633.33^{cd}	4983.33^{bc}	48.67^{bcd}	48^{bcd}	46.00^{cd}	44.40^{c-g}	51.06^{a-d}	55.86^{a}
Kakaba	Broadcasting	2800.00^{kl}	3483.33^{ij}	3066.67^{jk}	38.00^{g}	36.00^{g}	36.00^{g}	40.20^{efg}	50.77^{a-d}	43.87^{c-g}
	Drilling	2600.00^{l}	3650.00^{hi}	3800.00^{ghi}	40.00^{efg}	38.00^{g}	38.33^{fg}	38.05^{fg}	52.58^{abc}	54.88^{ab}
Melka	Broadcasting	4073.00^{efg}	5085.67^{b}	5082.70^{b}	54.67^{a}	51.67^{abc}	53.33^{ab}	37.18^{g}	46.26^{b-f}	48.68^{a-e}
	Drilling	4258.67^{def}	5512.00^{a}	4961.00^{bc}	52.00^{ab}	56.00^{a}	39.67^{efg}	36.84^{g}	48.55^{a-e}	43.56^{d-g}
LSD (5%)		418.99			5.73			8.84		
CV (%)		3.29			4.14			6.22		

Means followed by the same letter along columns are not significantly different from each other at 5% probability level

4.3.8. Dry biomass yield

The analysis of variance revealed that only the main effect of bread wheat varieties significantly ($P < 0.001$) influenced dry biomass yield of bread wheat (Table 10 and Appendices 2). The highest (11,139.8 kg ha^{-1}) dry biomass yield of bread wheat was recorded in Melka variety, followed by Gutu variety, whereas the lowest (6,924 kg ha^{-1}) was observed in Kakaba variety (Table 10). This variation is likely attributable to genetic differences among varieties that regulate plant vigour, tillering capacity, and the efficiency of assimilate production and partitioning, ultimately affecting total biomass accumulation. Similarly Wondimu et al. (2022) observed significant differences ($P < 0.05$) in biomass yield among bread wheat varieties, indicating that varietal effects may vary with environmental conditions and management practices. In contrast, Abichu et al., (2020) reported that the main effect of variety had a non-significant influence on dry biomass yield.

4.3.9. Straw Yield

Straw yield of bread wheat was highly significantly ($P < 0.001$) affected by the main effects of bread wheat varieties and seed rates (Table 10 and Appendices 2). Melka varieties produced the highest (6,311 kg ha^{-1}) straw yield, whereas Kakaba had the lowest (3,690.7 kg ha^{-1}) (Table 10). This variation is likely due to genetic differences in vegetative growth, tillering capacity, and biomass allocation, which determine the amount of straw produced per plant.

The highest (5,457 kg ha^{-1}) straw yield was observed at the lowest seed rate of 100 kg ha^{-1}, while the lowest straw yield (4,597 kg ha^{-1}) obtained at the highest seed rate of 150 kg ha^{-1}. This trend can be explained by plant density effects: lower seed rates reduce competition, allowing individual plants to produce more tillers and accumulate greater vegetative biomass, whereas higher seed rates increase competition for light, nutrients, and space, limiting straw production per plant. Similarly Berhanu (2024), who reported that the main effects of varieties, sowing methods, and seed rates significantly influenced straw yield in bread wheat.

Table 11. Mean for dry biomass and straw yield of bread wheat as affected main of variety and seed rates.

Treatments	Dry biomass yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Varieties		
Melka	11139.8^{a}	6311.0^{a}
Gutu	9044.3^{b}	4673.8^{b}
Kakaba	6924.0^{c}	3690.7^{c}
LSD (5%)	435.9	430.77
Sowing Methods		
Broadcasting	8927.6	4914.8
Drilling	9144.5	4868.8
LSD (5%)	Ns	Ns
Seed rates (kg ha^{-1})		
100	9081.7	5457.0^{a}
125	9046.0	4621.4^{b}
150	8980.4	4597.0^{b}
LSD (5%)	Ns	430.77
CV (%)	5.91	10.78

Means followed by the same letter along columns are not significantly different from each other at 5% probability level ns=non-significant.

4.4. Pearson correlation among growth, yield and yield component of bread wheat

The correlation analysis among bread wheat agronomic traits revealed strong and significant associations between phenological traits, yield and yield components (Table 11).

Days to heading exhibited a very strong and positive correlation with days to physiological maturity (0.89), indicating that genotypes that headed later also matured later. Days to maturity was positively and significantly correlated with plant height (0.61), spike length (0.88), kernels per spike (0.93), dry biomass (0.88), grain yield (0.73), and thousand-kernel weight (0.81), suggesting that extended growth duration contributes to enhanced yield formation (Mohan et al., 2022).

Plant height showed positive and significant correlations with spike length (0.51), number of kernels per spike (0.60), total biomass (0.51), grain yield (0.60), and thousand-kernel weight (0.42), indicating that taller plants tend to accumulate more biomass and achieve higher grain yield. The number of effective tillers per plant was strongly and positively correlated with total tillers (0.62), spike length (0.58), kernels per spike (0.48), total biomass (0.46), thousand-kernel weight (0.46), and straw yield (0.57), highlighting the pivotal role of productive tillers in yield improvement (Mesele Reta, 2015).

Spike length exhibited strong positive correlations with kernels per spike (0.87), dry biomass (0.85), grain yield (0.59), thousand-kernel weight (0.70), and straw yield (0.83), demonstrating its central contribution to yield determination. Similarly, kernels per spike were very strongly associated with grain yield (0.77), total biomass (0.92), and thousand-kernel weight (0.81), indicating that kernel number is a key determinant of yield (Kuru et al., 2025).

Grain yield was positively and significantly correlated with days to 90% physiological maturity (0.73), plant height (0.60), number of total tillers (0.51), spike length (0.59), kernels per spike (0.77), dry biomass (0.78), thousand-kernel weight (0.66), and straw yield (0.46).

Harvest index showed a positive and significant correlation with grain yield (0.36), but had significant negative correlations with effective tillers (0.46), spike length (0.36), and straw yield (0.65), indicating a trade-off between vegetative growth and grain partitioning. This suggests that increases in vegetative biomass or straw yield can reduce the proportion of assimilates allocated to grain, thereby lowering harvest index (Alemu et al., 2025).

Table 12. Pearson correlation coefficient among growth and yield related components on bread wheat

	DE	DH	DM	PH	ET	TT	SL	KPS	TABY	GY	TKW	SW	HI
DE													
DH	0.15												
DM	0.15	0.89***											
PH	0.18	0.44**	0.61***										
ET	0.15	0.53***	0.54***	0.02									
TT	0.12	0.74***	0.68***	0.24	0.62***								
SL	0.16	0.85***	0.88***	0.51***	0.58***	0.67***							
KPS	0.26	0.86***	0.93***	0.60***	0.48***	0.69***	0.87***						
TABY	0.22	0.90***	0.88***	0.51***	0.46***	0.70***	0.85***	0.92***					
GY	0.13	0.67***	0.73***	0.60***	0.14	0.51***	0.59***	0.77***	0.78***				
TKW	0.09	0.81***	0.81***	0.42**	0.46***	0.67***	0.70***	0.81***	0.75***	0.66***			
SW	0.23	0.84***	0.77***	0.33*	0.57***	0.66***	0.83***	0.81***	0.91***	0.46***	0.63***		
HI	-0.12	-0.31*	-0.20	0.13	-0.46***	-0.26	-0.36*	-0.20	-0.29	0.36*	-0.12	-0.65***	

*Note: *** = represent very highly significant at $P \leq 0.001$; ** = represent highly significant at $P \leq 0.01$; * = represent significant at $P \leq 0.05$ and ns represent none significant at $P \geq 0.05$, DE=day of emergence, DH= Day of heading, DM= day of physiological maturity, ET= effective tiller, TT = total tiller, PH = plant height (cm); SL = spike length (cm); KPS = kernel per spike; GY = grain yield (kg ha^{-1}); TABY = Total above ground biomass yield (kg ha^{-1}); SY = straw yield (kg ha^{-1}); HI = harvest index (%); TGW = thousand kernel weight (g).*

4.5. Effects of seed rates and sowing methods of economic feasibility of bread wheat production

The partial budget analysis was conducted to assess the profitability of different combinations of seed rates, and sowing methods are indicated in Table 12.

The highest net benefit of ETB (27567.4 ha^{-1}) was obtained from a seed rate of 125 kg ha^{-1} with the drilling methods of sowing from melka variety, accompanied by a substantial marginal rate of return (MRR) well above the minimum acceptable threshold of 100%.

The MRR was used to evaluate the profitability of transitioning from a lower-cost treatment to a higher-cost treatment. Results demonstrated exceptionally high MRR values when shifting from 100 kg ha^{-1} to 125 kg ha^{-1} using the row drilling method, with observed values of 395.4%, 193.81%, and 408.1% in multiple trial instances. In agricultural economics, a minimum acceptable rate of return (MARR) is typically 100%, meaning that for every 1 Birr invested in additional seed and labor for the 125 kg ha^{-1} row drilling treatment, the farmer is expected to recover that 1 Birr plus an additional profit ranging from 14 to 40 Birr.

Although the 150 kg ha^{-1} seed rate occasionally produced a higher total yield, the diminishing marginal returns and frequent dominance classifications suggest that the additional investment beyond 125 kg ha^{-1} is not the most efficient use of capital.

Therefore, for farmers in the Sebeta area, the row drilling method with a seed rate of 125 kg ha^{-1} is highly recommended. This treatment provides the most stable and highest marginal rate of return, enabling resource-poor farmers to maximize profits relative to their investment costs during the 2025 cropping season.

Table 13. Partial budget analysis on bread wheat response to seed rates and sowing methods at Sebeta during 2025 cropping season

TRT	GY ($t.ha^{-1}$)	AGY($t.ha^{-1}$)	SY($t.ha^{-1}$)	ASY ($t.ha^{-1}$)	SC(birr)	TGB(birr)	TVC(birr)	NB(birr)	MRR (%)
100*BC	3.933	3.54	4.9723	4.48	10000	29664	10600	19064	-
100*D	4.259	3.8328	7.307	6.58	10000	32636.4	11200	21436.4	395.4
125*BC	5.086	4.5771	5.943	5.34	12500	38218.8	13100	25118.8	193.81
125*D	5.512	4.9608	5.851	5.27	12500	41267.4	13700	27567.4	408.1
150*BC	5.083	4.5744	5.417	4.88	15000	38059.2	15600	22459.2	D
150*D	4.961	4.4649	6.448	5.80	15000	37459.2	16200	21259.2	D

AGY= Adjusted Grain Yield; ASY= Adjusted Straw Yield; TGB= Total Growth benefit; TVC= Total Variable Cost; NB= Net benefit; MRR =Marginal Rate of Return; D = Dominance; SC=Seed Cost, Cost of labor 600ETB/day/person, Seed cost 100ETB/kg and 80ETB/kg, Grain price 80ETB/kg, Straw price 3ETB/kg.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

Bread wheat is a major staple food and an important income-generating crop in Ethiopia; however, its productivity remains below potential due to suboptimal agronomic practices, particularly inappropriate seed rates and inefficient sowing methods. To address these constraints, a field experiment was conducted during the 2025 main cropping season at Sebeta District, Shager City, to evaluate the effects of seed rate and sowing method on the growth, yield, yield components, and economic performance of bread wheat varieties.

The experiment employed a factorial arrangement of three bread wheat varieties (Melka, Gutu, and Kakaba), three seed rates (100, 125, and 150 kg ha^{-1}), and two sowing methods (broadcasting and drilling), implemented in a randomized complete block design with three replications. Data were collected on phenological traits, growth parameters, yield components, grain yield, biomass, and harvest index, and analyzed using R software.

Analysis of variance indicated that bread wheat traits were significantly influenced by varieties, seed rates, and sowing methods. Days to heading, physiological maturity, and plant height were significantly affected by varieties and seed rates. The total number of tillers per plant was influenced by varieties, seed rates, and the interaction between variety and sowing method. Spike length was significantly affected by the main effects of all factors, while interactions were generally non-significant. Kernels per spike were influenced by the interaction between variety and seed rate, whereas above-ground biomass was significantly affected only by varieties. Straw yield was influenced by varieties and seed rates, while grain yield, harvest index, and thousand-kernel weight were strongly affected by the three-way interaction among variety, seed rate, and sowing method.

Among the varieties, Gutu exhibited the longest days to heading (80.78 days), whereas Kakaba headed earliest (63.28 days). Melka required the longest period to reach physiological maturity (136.44 days), while Kakaba matured in the shortest time (110.33 days), likely due to genetic differences. The tallest plants were recorded in Gutu (87.38 cm), whereas Kakaba was the shortest (75.95 cm). Melka produced the highest number of effective tillers per plant (4.83), statistically comparable to Gutu, while Kakaba had the fewest (3.67). Spike length was greatest in Melka (9.43

cm) and shortest in Kakaba (6.91 cm). Above-ground biomass yield was highest in Melka (11,139.8 kg ha^{-1}), followed by Gutu, and lowest in Kakaba (6,924 kg ha^{-1}).

Seed rate effects showed that the longest days to heading (74.5 days) occurred at 100 kg ha^{-1}, while the shortest (69.83 days) was recorded at 150 kg ha^{-1}. Similarly, days to physiological maturity decreased from 128.89 to 122.94 days as seed rate increased from 100 to 150 kg ha^{-1}, likely due to higher plant density inducing competition for resources and stress. Regarding sowing methods, physiological maturity was longest under broadcasting (127.37 days) and shortest with drilling (124.67 days). The highest number of effective tillers per plant (4.52) was obtained with drilling, whereas broadcasting produced the lowest. Total tiller number was highest in Melka under broadcasting (7.33) and lowest in Kakaba under broadcasting (4.33).

The highest thousand-kernel weight (56 g) and grain yield (5,512 kg ha^{-1}) were recorded in Melka at 125 kg ha^{-1} with drilling, whereas the lowest TKW (36 g) and grain yield (3,933.33 kg ha^{-1}) were observed in Kakaba and Gutu under higher seed rates with broadcasting and 100 kg ha^{-1} with broadcasting, respectively.

Overall, these results highlight that optimizing seed rate and sowing method in combination with variety selection is critical to maximizing bread wheat productivity under the agro-ecological conditions of Sebeta District.

5.2. RECOMMENDATION

Based on the findings of this study, the following recommendations are proposed:

1. The use of Melka bread wheat variety using a seed rate of 125 kg ha^{-1} with the drilling sowing method of sowing are recommended farmers in Sebeta District and similar agro ecological areas.
2. Row drilling at 125 kg ha^{-1} provides the most stable and highest marginal rate of return, enabling resource-limited farmers to maximize profits relative to their investment costs.

Further multi-location and multi-season studies are recommended to validate these findings and refine site-specific agronomic recommendations for wider adoption.

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7. APPENDICES

7.1. APPENDICES TABLE

Appendix 1. Mean square values of phenological and growth parameters of bread wheat as influenced by variety, seed rate and sowing method.

SV	Df	DE	DH	DM	PH	ET	TT	SL
Rep	2	0.129	11.8	8.9	69.00**	0.72	1.06	0.17
Var	2	0.074	1378.91***	3441.58***	605.41***	6.17***	25.72***	29.56***
SM	1	0.0185	1.85	98.7***	0.81	3.13*	1.19	6.13***
SR	2	0.13	98.02***	159.6***	50.02*	11.06***	3.5**	3.87***
Var*SM	2	0.296	3.02	0.24	11.27	0.13	1.91*	0.06
Var*SR	4	0.292	4.91	16.85	30.44	0.89	0.81	0.235
SM*SR	2	0.241	4.13	2.02	3.98	0.13	1.24	0.06
Var*SM*SR	4	0.019	5.13	3.41	14.19	0.96	0.21	0.112
Error	**34**	**0.463**	**6.44**	**7.61**	**11.78**	**0.53**	**0.57**	**0.148**
CV		**10.01**	**3.52**	**2.19**	**4.17**	**16.96**	**12.77**	**4.63**
Mean		**6.796**	**72.15**	**126.02**	**82.34**	**4.28**	**5.89**	**8.3**

Where, *DE=days to emergence, DH= Days to 50% heading, DM= Days to 90% physiological maturity, PH= Plant height, ET= effective tillers number per plant, TT= total numbers of tillers per plant, SL=Spike length.*

Appendix 2. Mean square values of yield and yield components of bread wheat as influenced by variety, seed rate and sowing method.

SV	Df	KPS	AGBY	GY	TKW	SY	HI
Rep	2	9.46	786171.5	26805.63	0.57	741460	13.44
Var	2	2784.57***	79980760.8***	12146739.46***	836.24***	31539666.39***	114.87***
SM	1	150.00***	635274.1	933781.50***	1.5	28656.69	61.36*
SR	2	17.35	47545.7	3651289.85***	63.57***	4315439.25***	496.41***
Var*SM	2	3.39	545782.8	61852.06*	64.06***	828836.78	34.44*
Var*SR	4	23.49*	65170.4	231109.85***	25.38**	297012.48	28.05*
SM*SR	2	1.17	10859.2	162706.89**	46.17***	234738.72	32.46*
Var*SM*SR	4	7.97	110500.5	177075.78***	39.14***	444068.82	38.71**
Error	**34**	**6.64**	**284795.5**	**18566.18**	**3.48**	**278127.71**	**8.26**
CV		**5.12**	**5.91**	**3.29**	**4.14**	**10.78**	**6.21**
Mean		**50.48**	**9036.05**	**4144.24**	**45.02**	**4891.81**	**46.24**

***Where**, KPS=kernel per spike, AGBY= above ground biomass yield, GY=grain yield, TKW=Thousand kernel weight, SY=Straw yield, HI=Harvest index, LSD=Least Significant Difference, CV= Coefficient of Variation, ns=non-significant.*

7.2. APPENDICES FIGURE



Appendix figure 1.Land preparation and bed leveling



Appendix figure 2. Sowing time









Appendix figure 3. Emergence stage



Appendix figure 4. Tiller stage



Bread wheat growth in sebeta area Malka, Gutu and Kakaba



Appendix figure 5. Tiller counting



Appendix figure 6. Herbicide application for weed control




Plant height measuring




Appendix figure 7. Heading stage



Appendix figure 8. Day 90% physiological Maturity stage



Appendix figure 9. Harvesting by manual





Number of kernel per spike



Appendix figure 10. Spike length measuring and numbers kernel per spike



Malka, Gutu and Kakaba variety



Appendix figure 11. Thousand seed counting