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Effects of Sowing Date and Wheat Variety on Grain Yield and Soil Physicochemical Properties in North Gondar Zone, Ethiopia

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Abstract

The cultivation of wheat (Triticum aestivum L.) is of utmost importance in Ethiopia, both for consumption and generating income; however, its production capacity is limited due to climate change and low soil fertility status. Sowing date and wheat variety play crucial roles in determining plant phenology, biomass, and grain yield, but their effects vary depending on the different types of agro-ecologies. Data are insufficient for the North Gondar Zone. This research was conducted to evaluate the effects of sowing date and wheat variety on growth, biomass, yield, and some selected soil parameters in 2026. The experimental design of the factorial arrangement included three sowing dates and three varieties of wheat, with a RCBD of three replications each. The data was subjected to analysis of variance using SAS version 9.4 for each trait, and means separation was done using LSD at 5%. For Dabat, there was significant effect of sowing date on maturity, total biomass, grain yield (from 2,911.1 kg ha⁻¹ for early sowing to 1,344.4 kg ha⁻¹ for late sowing), and by-product biomass. There was a significant effect of variety on phenology, plant height, biomass, and grain yield. For Debark, there was significant effect of sowing date on maturity, plant height, total biomass, grain yield, and by-product biomass, whereas variety had a significant effect on anthesis and plant height. Soil analysis revealed that Dabat had more clay content, organic carbon content, total nitrogen, and cation exchange capacity compared to Debark, where the silt content and soil erosion were higher. Both areas had acidic soils with low electrical conductivity. Late sowing greatly affected the wheat yield negatively. This demonstrates the need for variety-specific planting times in North Gondar.

1. INTRODUCTION

One of the most significant cereals produced around the world is wheat (*Triticum aestivum L.).* It is very important in providing food security and sustenance. In the world, wheat represents one-fifth of the calorific value and protein intake of humans. It remains a very essential staple in developed and developing worlds (Curtis & Halford, 2014). Wheat production is very important to food security and agricultural development in Ethiopia. Wheat yield depends on various factors such as environmental parameters and farming practices, which include temperature, rainfall, soil fertility, planting dates, and varietal attributes (Porter & Gawith, 1999)

Sowing time and variety selection are important components of wheat crop management because they influence crop phenology, growth, development, and grain yield under different environmental conditions. Appropriate sowing time enables wheat to utilize favorable temperature, soil moisture, and radiation conditions during different growth stages, while selecting well-adapted varieties can improve crop performance and yield under specific production environments (Tamiru *et al*., 2023)

The date of planting is one of the most significant agronomic factors that influence wheat productivity because it will determine the environmental conditions under which the crop grows. Planting date influences the environmental conditions such as soil moisture and temperature, among others under which the crop will grow and develop(Tamiru *et al*., 2023). Wheat which is planted within the proper time will make use of proper moisture and temperature conditions, but when planted too early or too late, it

will be subjected to conditions that might not be suitable, thus resulting in reduced growth and yield. It is thus essential to identify the proper planting period of wheat(Desta *et al*., 2020)

These differences in growth duration, maturity, yield capacity, adaptation, and environmental response exist among different varieties of wheat. These differences can impact phenology, growth, biomass production, grain development, and ultimately grain yield of crops. Therefore, it is possible that a variety which yields good performance under one particular environment or planting season might not yield similar results under another particular environment or planting season. Research conducted in the field in Ethiopia showed that different wheat varieties vary with respect to phenology, grain filling period, and yield (Tamiru *et al*., 2023). The same vein, investigations on varieties of wheat in Ethiopia have emphasized the need for testing variety performance in different environments since genotypic reactions may be environment-specific (Gudina et al., 2026). Therefore, evaluating different varieties under different sowing dates is important for understanding varietal adaptation and identifying suitable production options for specific agro-ecological conditions(Gudina et al., 2026).

It is crucial to consider the interaction of sowing date and wheat variety in the process of varietal evaluation, since the reaction of various varieties may be different for changes in sowing date. The performance of a variety depends on the combination of the genotype of the variety and environment. Therefore, it is possible to assess the adaptation and yield reaction of varieties at various sowing dates(Desta *et al*., 2020). Response magnitudes and directions can also be varied at different sites due to variations in temperature, rainfall, soil attributes, and other agro ecological factors. It is therefore imperative that the impact of sowing date and variety is assessed in different representative production environments for making site-specific recommendations for wheat management (Gudina et al., 2026).

In addition to yield, agronomic and agricultural practices have the potential to affect the physicochemical properties of soils and nutrient availability and soil properties concerning crop production. There is an uptake of nutrients by wheat from the soil. Crop residues, roots, and organic matter additions have the potential to add carbon and nutrients. Nitrogen and phosphorus deficiency have been cited as major limiting factors regarding soil fertility for wheat production in Ethiopia. Thus, analysis of soil characteristics before and after cultivation of crops will be beneficial for the identification of soil fertility associated with wheat production.

Ethiopia is among the largest producers of wheat in Sub-Saharan Africa and the commodity is also a food and cash crop that plays a significant role in the agricultural production of the country. There are a number of challenges that affect wheat production in the country, including poor soil fertility status, poor nutrient management practices, variable environmental conditions, and lack of proper production technology and varieties (Anteneh & Asrat, 2020). These constraints have special relevance in the Ethiopian highlands, where wheat forms an important part of the small-scale agriculture system and soil fertility management is an important factor in crop productivity. In north-west Ethiopia, recent research work has highlighted soil fertility depletion as one of the constraints to sustainable wheat production(Debebe et al., 2026)

The North Gondar Zone consists of agro ecological diverse areas in terms of variability in elevation, temperature, rainfall, soil, and crop growing conditions. Variability of this kind could affect the growth and productivity of wheat and lead to differential reactions of wheat varieties to the timing of planting. Despite the widespread cultivation of wheat in this zone, locally available research data regarding the effect of sowing date and varieties, especially in combination, on grain yields, is scarce. Consequently, farmers could be lacking adequate location-specific information for deciding on suitable planting seasons and varieties.

In addition to that, continuous cropping and nutrient withdrawal could influence soil fertility, and variations in plant growth and residue generation could affect the selected soil physicochemical properties. Unfortunately, information about the pre and post-production soil physicochemical property status in the study area in relation to wheat production for different sowing dates and varieties is not available. As a result of that, evaluation of the effect of wheat productivity along with the variation of soil physicochemical properties under different production practices would be difficult. Consequently, a field experiment was conducted at Dab at and Debark experimental sites, North Gondar Zone, Ethiopia.

2. MATERIALS AND METHODOLOGY

2.1. Description of the Study Area

The study was carried out in North Gondar Zone, Amhara Region, Northwestern Ethiopia. There is great variation in terrain in this zone, comprising highland plateau, mountain, and valley land types, at altitudes of 1,500 to more than 4,000 meters above sea level. This region usually has a cool highland climate with an average annual temperature of 10–16°C and a high annual rainfall of up to 1,200 mm in the highlands. Rain usually occurs during the rainy months of June to September. Such climatic conditions make it possible for the cultivation of wheat, barley, pulse crops, and others.

Purposeful sampling was done in Dabat and Debark districts as they represent significant highland regions known for wheat production where variations exist in altitude, topography, soil properties, and environment. Rabat district represents highland and mountainous topography, whereas Debark district is found in the higher, rugged, and cooler Simian highlands. Differences in these two regions provide an ideal ground to assess the impacts of sowing dates and wheat cultivars on grain yields and selected physiochemical properties of soil.

2.1.1 Agro-Ecological Conditions of North Gondar Zone

Agro ecological features in the North Gondar Zone vary depending on differences in altitude, topography, climate, and rainfall. The agro ecological zones include Dega (highland), Woina Dega (midland), and Kolla (lowland). Highlands, which are above 2,500 m above sea level, are comparatively cooler, and the crops grown in this zone include wheat, barley, and pulses. Midland areas, which are approximately 1,500–2,500 m above sea level, are warmer, and the crops produced include wheat, eff, maize, sorghum,

and pulses. Lowlands, which are below 1,500 m above sea level, are relatively warmer with lower rainfall and produce drought-resistant crops like sorghum, millet, and oilseeds. Diverse types of soils exist within the zone, with Nitinols being common in the highlands and other types of soils in the lowlands. Fertility exhaustion and soil erosion, especially on slopes, are some of the factors that constrain crop production. Variability in agro ecological conditions creates varied production environments to test wheat varieties and planting dates.

2.1.2 Location and Agro climatic Conditions of Dabat District

The Dabat experimental site is located at approximately 12°59'03" N latitude and 37°45'54" E longitude in Dabat District, North Gondar Zone. The district is characterized by highland and mountainous terrain, with elevations of approximately 2,500–3,000 m above sea level. It has a cool climate, with temperatures generally ranging from about 10–20°C, and receives approximately 800–1,200 mm of annual rainfall, most of which occurs during the June–September rainy season. These conditions are favorable for cool-season crops, particularly wheat and barley. Wheat, barley, and teff are among the major cereal crops cultivated in the district, while pulses and vegetables are also produced. The combination of high elevation, cool temperatures, seasonal rainfall, and variable topography makes Dabat an important environment for evaluating the effects of sowing date and wheat variety on grain yield.

2.1.3 Location and Agro-climatic Conditions of Debark District

Debark experimental farm lies in Debark district of North Gondar Zone, with geographical coordinates of about 13.156° N latitude and 37.897° E longitude. Debark district is in the highland area of north Ethiopia, which has rough topography that belongs to Simien highlands. Elevation varies from about 2,500 to 4,000 m above sea level, which provides a cool environment for growth. Average annual rainfall falls within 900–1,500 mm and is mainly concentrated in June – September period, when temperature changes according to altitude conditions and supports the cultivation of wheat, barley, and pulses, particularly faba bean. Agriculture is mainly rain-fed and smallholder-based, while steep slopes increase the risk of soil erosion. The high elevation and cool growing environment make Debark an appropriate site for evaluating wheat varietal performance under different sowing dates.

2.2 Experimental Materials and Treatments

The field experiment was conducted during the 2025 main cropping season at Dabat and Debark experimental sites to evaluate the effects of three sowing dates and three wheat varieties on grain yield and selected soil physicochemical properties. The treatments consisted of three sowing dates and three wheat varieties arranged in a factorial combination. At Dabat, sowing was conducted on June 25, July 9, and July 26, 2025, while at Debark the corresponding sowing dates were June 25, July 10, and July 27, 2025. The three varieties were designated V1, V2, and V3 according to the experimental records. The experiment therefore consisted of nine treatment combinations at each site.

2.3. Field Experimental Design and Experimental Layout

The experiment was conducted using RCBD, that is, Randomized Complete Block Design, in which three replications were performed at each location of the experiment. Treatments included three different varieties of wheat with three sowing dates, making a total of nine treatments per replication, and hence, 27 experimental plots in each location. The sowing dates were considered for early, normal, and late sowing conditions.

The experimental plots size was 2.0 m x 2.5 m (5 m^2), and they comprised 10 rows with row-to-row spacing of 20 cm. Spacing of 1 m was provided between replicates for better field management and avoiding any interference between blocks. Two outermost rows on each side of each replicate were not included in data collection and were considered as border rows. So, agronomic and yield data were recorded only for the net plot size. Randomization of treatment combinations was carried out in each replicate. The results of the grain yields from the net plots were analyzed through analysis of variance (ANOVA) in the SAS version 9.4 statistical package. If there was a significant effect of the treatment, then comparisons of means were done through the Least Significant Difference (LSD) test at 5%.

2.4. Soil Sampling Design and Laboratory Analysis

Several subsamples were obtained before planting in a systematic manner in all experimental fields, excluding edges of plots and any other irregular areas. The subsamples were well-mixed to obtain a representative composite sample for each experimental area. Soil samples were taken after harvesting from the experimental plots from the same 0–20 cm soil depth. In each replication, soil subsamples from the corresponding experimental plots were mixed together to create one composite sample for each replication. Composite sampling was used to get a representative sample of soil while minimizing spatial variation within the unit, following the recommended sampling and composite sampling techniques for soil (Abera et al., 2020).

2.5. Statistical Analysis of Field Experiment Data

The impacts of seeding date, wheat cultivar, and the interaction of these two variables on the yield of wheat grains were assessed through an analysis of variance (ANOVA). This analysis was conducted through the GLM procedure of Statistical Analysis System (SAS) software, version 9.4. Data were analyzed individually for the Dab at and Debark experimental plots. Comparison of treatment means was done using the Least Significant Difference (LSD) test at the 5% level of significance ($p < 0.05$) where the ANOVA showed significant differences among treatments. Significance was established at $p < 0.05$ while highly significant differences were noted when $p < 0.01$. Physical and chemical characteristics of soil before the cultivation process and after the harvest period were analyzed in order to know the changes in the soil during the experimentation period. The parameters were the following: pH, EC, OC, TN and CEC.

3. RESULT AND DISCUSSION

3.1. The initial and Post-Harvest Soil properties in the study area

The properties of the soils before planting were different for the two experimental sites of Dabat and Debark (Table 1). The Dab at site had more clay percentage (55%) than Debark (31%), but Debark had a higher silt percentage (61%) compared to Dabat (33%). The sand percentages for Dabat and Debark were 12% and 8%, respectively (clay textural class and silty clay loam, respectively), according to (Hazelton & Murphy, 2007.)

At Dabat soil showed higher levels of organic carbon (1.64%), total nitrogen (0.294%) and Cation Exchange Capacity (CEC, 10.95 cmol(+) kg-1) as compared to that in the Debark soil (organic carbon, 1.32%; total nitrogen, 0.238%; CEC, 7.18 cool(+) kg^{-1}). Based on (Dent et al., 2020.)), the organic carbon and CEC levels at both sites would be considered low while the total nitrogen level is considered medium. The soil pH was 5.70 for Dab at and 5.60 for Debark; both were moderately acidic soils based on Tadesse et al. (1991). The electrical conductivity (EC) values were 0.04 and 0.06 dSm^{-1} for Dab at and Debark, respectively, which are non-saline soils (Dent et al., 2020).

Table 1
initial soil physicochemical characteristics of the Dabat and Debark experimental sites

Parameter	Dabat experiment site		Debark experiment site		Reference
	Content	Rating	Content	Rating	
Clay (%)	55		31		
Silt (%)	33		61		
Sand (%)	12	Clay textural class	8	Silty Clay Loam	(Hazelton & Murphy,2007)
EC (dSm^{-1})	0.04	Non-saline	0.06	None- saline	(Dent et al., 2020)
CEC(cmol(+) kg^{-1})	10.95	Low to medium	7.18	Low to medium	(Dent et al., 2020)
Soil pH	5.70	Moderately acid	5.60	Moderately acidic	(Desta et al., 2020)
(OC) (%)	1.64	low	1.32	low	(Dent et al., 2020)
(TN) (%)	0.294	medium	0.238	medium	(Dent et al., 2020)

Note: EC = Electrical Conductivity; CEC = Cation Exchange Capacity; pH = Soil Reaction; OC = Organic Carbon; TN = Total Nitrogen.

Post-harvest soil characteristics differed among the nine combinations of sowing date × variety treatments at Dabat (Table below 2). The pH value was between 4.92 and 5.04, meaning that all treatment combinations were strongly to moderately acidic after harvest using the criteria defined by

(Desta *et al*., 2020). The electrical conductivity value was between 0.0246 and 0.0447 dS m^{-1}, which shows low concentrations of soluble salts and non-salinization of the soils (Dent et al., 2020). Organic carbon content was between 0.936 and 1.872%, which is rated as low according to (Dent et al., 2020), while total nitrogen was between 0.196 and 0.252%, which is rated as low to medium (Dent et al., 2020).

All the treatment combinations, the highest amount of organic carbon (1.872%) was observed in D3V1, while the lowest amount of organic carbon (0.936%) was observed in D1V1. Of all the treatment combinations, the highest soil pH was observed in D2V2 (5.04), while the lowest soil pH was observed in D1V3 (4.92). Of all the treatment combinations, the lowest electrical conductivity was observed in D2V1 (0.0246 dS m^{-1}), while the highest electrical conductivity was observed in D3V3 (0.0447 dS m^{-1}).

Table 2
Post-harvest soil physicochemical properties in different treatment combination at Dabat

Treatment	pH	EC	OC (%)	TN (%)	CEC (cmol(+) kg^{-1})
D1V1	5.00	0.0279	0.936	0.238	22.00
D1V2	5.00	0.0324	1.014	0.196	28.40
D1V3	4.92	0.0252	1.638	0.210	27.20
D2V1	5.02	0.0246	1.599	0.217	24.40
D2V2	5.04	0.0278	1.404	0.224	26.00
D2V3	5.00	0.0257	1.794	0.217	23.60
D3V1	4.94	0.0258	1.872	0.252	24.40
D3V2	5.00	0.0270	1.638	0.224	20.00
D3V3	5.00	0.0447	1.833	0.217	18.00

Notice: D1: first sowing date, D2: second sowing date, D3: third sowing date and V1: wheat variety 1, V2: wheat variety 2, V3: wheat variety 3

The post-harvest soil properties at Debark exhibited some variations among the nine different treatments used. The soil had a pH range that was between 4.96 (strongly acidic) for treatment D3V3 and 5.07 (moderately acidic) for treatments D1V1 and D3V1 as stated by (Desta et al., 2020). EC values of the different treatments were found to be within the limits of non-saline condition plots(Desta *et al*., 2020), where D1V3 showed the minimum value of 0.0210 dS m^{-1} while D1V1 registered the maximum value of 0.0446 dS m^{-1}. Organic carbon content of the different treatments was within a range of 1.794% in D3V3 to a medium value of 2.418% in D1V2 (Desta *et al*., 2020)

The total nitrogen content of all treatments was also within the medium range (Dent et al., 2020), with a minimum of 0.238% in D2V3 up to 0.294% in treatments D1V3, D2V1, and D3V1. Lastly, the Cation Exchange Capacity (CEC) was within high to very high ratings (Dent et al., 2020) from 37.20 cmol (+) kg^{-1} in treatments D1V1, D2V1, and D3V1 to a maximum of 41.20 cmol (+) kg^{-1} in D2V2.

Table 3
Post-harvest soil physicochemical properties in different treatment combination at Debark

Treatment	PH	EC	OC (%)	TN (%)	CEC(Cmol(+)/kg))
D1V1	5.07	0.0446	1.950	0.280	37.20
D1V2	4.98	0.0326	2.418	0.287	39.60
D1V3	5.02	0.0210	1.950	0.294	39.20
D2V1	5.05	0.0276	2.340	0.294	37.20
D2V2	5.01	0.0246	2.184	0.266	41.20
D2V3	5.06	0.0261	2.340	0.238	40.60
D3V1	5.07	0.0270	2.184	0.294	37.20
D3V2	5.03	0.0264	2.028	0.266	38.60
D3V3	4.96	0.0234	1.794	0.252	38.40

Notice: D1: first sowing date, D2: second sowing date, D3: third sowing date and V1: wheat variety 1, V2: wheat variety 2, V3: wheat variety 3

3.2. Effect of Sowing Date and Variety on Grain Yield in Dabat experiment site

3.2.1. ANOVA result for Phenological, Growth, and yield trait at Dabat Experimental Site

Analysis of variance indicated that days to maturity, total biomass, grain yield, and by-product biomass were influenced significantly by the effect of sowing date at Dabat (Table 4 below). Days to maturity ($p = 0.0008$), total biomass ($p = 0.0001$), grain yield ($p = 0.0003$), and by-product biomass ($p = 0.0002$) had highly significant effects due to differences in sowing dates. However, days to anthesis ($p = 0.6666$) and plant height ($p = 0.1006$) were unaffected by variations in sowing dates. The significant influence of sowing date on days to maturity and yields agrees with (Gezahegn et al., 2022), where differences in sowing date significantly affected maturity, biomass, and grain yield of wheat at Metema and Belesa. Similar results are reported by Desta *et al*. (2020) for growth and grain yield of durum wheat in Ethiopia. Differences in sowing date may affect wheat plants in terms of temperature, moisture, and radiation during crop development, thereby influencing crop growth and productivity.

The nonsignificant influence of sowing date on days to flowering and plant height in the current study is unlike the results by (Tamiru *et al*., 2023), who observed the significance of sowing date in phenology and plant height of wheat in Gonde and Ardayita. This disparity in research findings might be linked to variations in environmental factors such as temperature and moisture availability and variety differences.

Wheat cultivar greatly influenced the traits that were studied at Dabat, although the influence was variable depending on the trait (Table 4 below). Cultivar was significantly influencing days to anthesis (p = 0.0001) and days to maturity (p = 0.0004), which is evidence for large genetic differences in time taken for flowering and maturity. The other traits influenced by cultivar were plant height (p = 0.0499), total biomass (p = 0.0045), grain yield (p = 0.0301), and by-product biomass (p = 0.0047). This might be attributed to genetic differences in developmental time, plant morphology, tillering ability, leaf growth, stem elongation, biomass accumulation, and assimilate distribution.

These results are in line with those by (Alemu et al., 2020), who identified variation in phenology and agronomy traits of 64 durum wheat landraces in Dabat Research Station. Likewise, (Alemu et al., 2020)found variance in bread wheat genotypes at Dabat and Debark stations in North Gondar. This study clearly emphasizes the need for genetic variation for the determination of wheat phenology, growth, and yield in North Gondar conditions. Nonetheless, the size and nature of varietal variance are likely to vary from one environment to another due to genotype-environment interaction and management.

Table 4
Analysis of variance for phonological, growth, biomass, and yield traits of wheat at Dabat

Trait	SD F-value	*p*-value	Variety F-value	*p*-value	SD significance	Variety significance
DTA	0.41	0.6666	29.12	0.0001	ns (p > 0.05)	*** (p < 0.001)
DTM	10.11	0.0008	11.64	0.0004	*** (p < 0.001)	*** (p < 0.001)
Height (cm)	2.55	0.1006	3.45	0.0499	ns (p > 0.05)	* (p < 0.05)
TBM (kg ha^{-1})	15.94	0.0001	6.99	0.0045	*** (p < 0.001)	** (p < 0.01)
Yield (kg ha^{-1})	12.13	0.0003	4.13	0.0301	*** (p < 0.001)	* (p < 0.05)
BP (kg ha^{-1})	13.49	0.0002	6.90	0.0047	*** (p < 0.001)	** (p < 0.01)

Notice

SD = sowing date; DTA = days to anthesis; DTM = days to maturity; TBM = total biomass; BP = by product (straw); ns = not significant; * = p < 0.05; ** = p < 0.01; *** = p < 0.001.

3.2.2 Effect of sowing date on phonological traits at Dabat experiment site

There was no significant effect of sowing date on days to anthesis (F = 0.41, p = 0.6666), but there was a significant effect of sowing date on days to maturity (F = 10.11, p = 0.0008; Table 4). The days to anthesis were quite similar across sowing dates, with 73.44 days for sowing date 2 and 74.44 days for

sowing date 1, while all sowing dates were statistically similar (Table 5). This is consistent with the results reported by (Gezahegn et al., 2022), which indicated that the sowing date had no significant effect on days to heading at Belesa. This is, however, inconsistent with (Tamiru *et al*., 2023), which indicated a significant effect of sowing date on days to heading at Gonde and Ardayita.

On the other hand, days to maturity varied significantly based on the date of sowing. Maturity was attained earliest (110.44 days) in sowing date 2 compared to sowing date 1 (116.78 days) and sowing date 3 (117.44 days); sowing date and sowing date 3 did not differ significantly from each other (Table 5 below). The significant impact of sowing date on maturity is supported by (Tamiru *et al*., 2023) and (Gezahegn et al., 2022), where the authors noted that sowing date could affect wheat maturity. This response could be attributed to the different environmental conditions, such as temperature and moisture, faced by the crops during their developmental phase. Therefore, for the current experimental settings, the sowing date seemed to have more influence on the period of maturity than anthesis.

Table 5
Mean performance of wheat for phonological and growth traits in different SD at Dabat

SD	DTA	DTM	height(cm)	TB (kg ha⁻¹)	Grain yield (kg ha⁻¹)	BP
SD1	74.44	116.78	93.99	7511.1	2911.1	4600.0
SD2	73.44	110.44	98.33	7311.1	2822.2	4488.9a
SD3	74.22	117.44	90.62	3333.3	1344.4	1988.9
LSD (5%)	2.396	3.564	7.095	1731.3	741.14	1179.2

Notice

Means followed by the same letter within a column are not significantly different at the 5% probability level and SD1 = sowing date 1; SD2 = sowing date 2; SD3 = sowing date 3.

3.2.3. Effect of Sowing Date on Growth, Biomass, and Grain Yield

The sowing date highly significantly influenced the total biomass (p = 0.0001; Table 4). The highest total biomass was observed in sowing date 1 (7,511.1 kg ha⁻¹), followed by SD2 (7,311.1 kg ha⁻¹), while the least biomass was obtained in sowing date 3 (3,333.3 kg ha⁻¹) (Table 5). Mean comparison revealed that sowing date 1 and sowing date 2 were statistically alike, while sowing date 3 showed significantly less biomass than sowing date 1 and sowing date 2. This observation supports the findings of (Gezahegn et al., 2022), who stated the highly significant effects of sowing date on the above-ground biomass of wheat at Metema and Belesa, where a notable decline in biomass occurred due to the late sowing date. Likewise, (Desta *et al*., 2020) found significant variations in the above-ground biomass according to the sowing date for durum wheat, where more biomass was obtained at an early sowing date compared to the late sowing date.

The significantly lower biomass production in sowing date 3 is an indication that late planting led to low biomass accumulation at Dabat. Late planting could be attributed to exposing the wheat plants to less favorable conditions, hence limiting their time to accumulate biomass during the vegetative stage. Biomass accumulation in sowing date 1 and sowing date 2 being almost similar implies favorable growth conditions for the crops.

However, sowing date had a great influence on grain yield ($p = 0.0003$; Table 4above). Grain yield was the highest under sowing date 1 (2,911.1 kg ha^{-1}), second-highest under sowing date 2 (2,822.2 kg ha^{-1}), and the lowest under sowing date 3 (1,344.4 kg ha^{-1}) (Table 5 above). The difference between sowing date 1 and sowing date 2 was insignificant, but the difference between sowing date 1 and sowing date 2 and sowing date 3 was significant.

The effect of reduced grain yield under 3 signifies that the delay in sowing was linked with low grain yields at Dabat. The reduction in grain yield was accompanied by a notable reduction in total biomass, signifying that low biomass accumulation under late sowing might have been responsible for low grain yield. Delayed sowing may expose the crop to suboptimal temperatures and moisture for establishment, flowering, and grain filling, resulting in low biomass accumulation and grain yield. The findings of the study are consistent with the results found in the studies of (Gezahegn et al., 2022) and(Desta *et al*., 2020). Genetic differences in the varieties were shown to affect the grain yield ($p = 0.0301$; Table 4 above). But since the means for the varieties could not be separated, it was not possible to rank the varieties.

3.2.4. Effect of Wheat Variety on Phenological and Growth Traits

The wheat variety had a strong impact on days to anthesis, days to maturity, plant height, biomass, grain yield, and byproduct biomass (Table 4 above). This can be seen by the highly significant effect of the variety on days to anthesis and days to maturity which clearly demonstrates the existence of genetic diversity among the test varieties in terms of development time.

The wide variation in total biomass, grain yield, and biomass of by-products is an additional indication of variation among varieties in terms of biomass production and assimilate distribution. This is expected because there are genetic differences among wheat varieties with respect to tillering ability, plant architecture, duration, and potential yield. These findings agree with those reported by (Alemu et al., 2020) about the variation observed among durum wheat landraces evaluated at Dabat Research Station and (Desta *et al*., 2020d) about the variation among bread wheat varieties evaluated at Dabat and Debark. Mean separation between the wheat varieties has not been done in the current study; therefore, the ranking of the varieties as being either better or worse off cannot be done using ANOVA results alone. Mean separation needs to be done to determine whether there are significant differences between the varieties and their relative performances.

3.2.5. Effect of Sowing Date and Wheat Variety on By-Product Biomass

The impact of sowing dates and varieties on the by-product biomass is statistically significant (p = 0.0002, p = 0.0047, respectively; see Table 4 above). Out of the three sowing dates, sowing date 1 had the greatest by-product biomass (4,600.0 kg ha^{-1}), followed by sowing date 2 (4,488.9 kg ha^{-1}), while sowing date 3 recorded the lowest (1,988.9 kg ha^{-1}) (Table 5 above). Sowing date 1 and sowing date 2 were not statistically different, while sowing date 3 was statistically lower than both. The decrease in the amount of by-product biomass in sowing date 3 was consistent with the trend for total biomass and grain yield. This implies that sowing of the crop late reduced biomass and crop growth. There might have been genetic differences in by-product biomass among the varieties.

3.2.6 Effects of Overall Model on Phenology, Growth, and Yield in Dabat

The overall ANOVA model was significant for all attributes evaluated in Dabat (Table 6 below). The model was very significant for days to anthesis, days to maturity, total biomass, grain yield, and biological yield ($p < 0.001$), while plant height was significant at $p < 0.05$. The proportion of variance accounted for by the overall model is 72.9%, 66.4%, 35.3%, 67.6%, 59.6%, and 65.0% for days to anthesis, days to maturity, plant height, total biomass, grain yield, and biological yield, respectively(Table 6 below).

Since the R^2 values of the phenology and biomass are higher compared to those of the height of the plants, the experimental conditions accounted for much of the variation, while other factors might have influenced the variation of the height. On average, the grain yield was 2359.26 kg ha^{-1}, total biomass 6051.85 and biological yield 3692.59 kg ha^{-1} (Table 6 below). Generally, the results obtained support the findings of other studies that suggest that genetic variation and the environment account for the phenological development of wheat, biomass production, and yield (Foulkes et al., 2011). Nevertheless, since the overall model does not provide information on the particular factor causing the variation, the effect of the sowing date, the variety, and the interaction between the two is discussed separately.

Table 6
Summary of ANOVA on Phenology, Growth, and Yield Traits at Dabat

Trait	Model F-value	*p*-value	R^2	Mean	Model significance
DTA	14.77	0.0001	0.729	74.04 days	*** ($p < 0.001$)
DTM	10.87	0.0001	0.664	114.89 days	*** ($p < 0.001$)
Height (cm)	3.00	0.0407	0.353	94.31 cm	* ($p < 0.05$)
TBM (kgha^{-1})	11.46	0.0001	0.676	6051.85	*** ($p < 0.001$)
Yield (kgha^{-1})	8.13	0.0004	0.596	2359.26	*** ($p < 0.001$)
BP (kgha^{-1})	10.19	0.0001	0.650	3692.59	*** ($p < 0.001$)

Notice

DTA = days to anthesis; DTM = days to maturity; TBM = total biomass; BP = by product (straw); * = p < 0.05; ** = p < 0.01; *** = p < 0.001.

3.5.7 Effects Varieties on Wheat Performance at Dabat Experiment Site

There were differences shown by the wheat varieties with respect to phenology, growth, biomass and yield parameters at the experimental site of Dabat (Table 7 below). The days to anthesis varied from 69.89 days for Variety 2 to 78.67 days for Variety 3. While the days to maturity varied from 110.33 to 118.44 days, respectively. The days to anthesis for Variety 1 were 73.56 days and for days to maturity was 115.89 days.

According to Table 7 below, the variety with the highest plant height mean was Variety 3 (97.08 cm), followed by Variety 1 (96.73 cm), while the variety with the lowest plant height mean was Variety 2 (89.13 cm). In the same way, the total biomass of Variety 3 was highest (7,155.56 kg ha^{-1}), followed by Variety 1 (6,733.33 $kgha^{-1}$), while the lowest biomass was recorded in Variety 2 (4,266.67 kg ha^{-1}). As for the grain yield, the highest yield was obtained in Variety 1 (2,666.67 kg ha^{-1}), followed by Variety 3 (2,644.44 kg ha^{-1}), while the lowest grain yield was recorded in Variety 2 (1,766.67 kg ha^{-1}). The biological yield was observed to be similar with Variety 3 showing the maximum value of 4,511.11 $kgha^{-1}$ and Variety 1 and Variety 2 having values of 4,066.67 kg/ha and 2,500.00 kg/ha respectively.

In the case of relatively higher biomass and grain-yield levels of Varieties 1 and 3 than Variety 2 (Table 7 below), there appear to be differences in productivity of the tested genotypes in the Dabat area. It is important to understand that the descriptive means in Table 7 cannot alone be taken as being statistically significant. The statistical significance of any difference among varieties needs to be assessed from the ANOVA table and mean separation outcomes. In the current study, variety was significant in influencing days to anthesis, days to maturity, plant height, biomass, grain yield, and biological yield.

The coefficients of variation in Table 7 were relatively high for biomass and grain yield (35.83–56.40%), indicating considerable variability among observations. However, because the experiment was conducted at a single site and season, this variability cannot be directly attributed to variety × environment interaction. Multi-environment testing across locations and seasons is therefore needed to confirm varietal performance.

Table 7
Descriptive Statistics for Each wheat variety in Dabat Site Experiment

Trait	Variety 1	Variety 2	Variety 3
DTA	73.56 ± 3.71 (64–77; CV = 5.05%)	69.89 ± 1.76 (68–73;CV = 2.52%)	78.67 ± 5.10 (78–79;CV = 4.31%)
DTM	115.89 ± 1.83 (113–118; CV = 1.58%)	110.33 ± 6.38 (102–116; CV = 5.79%)	118.44 ± 5.30 (110–123; CV = 5.46%)
height(cm)	96.73 ± 11.32 (80.4 = 112.2; CV = 11.70%)	89.13 ± 4.72 (80.2–95.2; CV = 5.29%)	97.08 ± 2.42 (92.0-107.0; CV = 33.88%)
TBM($kgha^{-1}$)	6733.33 ± 3074.09 (1800–10400; CV = 45.65%)	4266.67 ± 2406.24 (1200–8000; CV = 56.40%)	7155.56 ± 2424.41 (3800–11600; CV = 35.83%)
Yield ($kgha^{-1}$)	2666.67 ± 1356.47 (800–4600; CV = 50.87%)	1766.67 ± 764.85 (600–3000; CV = 43.29%)	2644.44 ± 947.51 (1400–4200; CV = 35.83%)
BP($kgha^{-1}$)	4066.67 ± 1910.50 (1000–6400; CV = 46.98%)	2500.00 ± 1721.92 (200–5000; CV = 68.88%)	4511.11 ± 1513.64 (2400–7400; CV = 33.55%)

Notice

mean ± SD; values in parentheses represent the minimum–maximum range and CV=coefficient of variation; DTA=days to anthesis; DTM=days to maturity; TBM= total biomass; BP = by product.

2.5.8 Effect of Sowing Date on Wheat Performance at Dabat Experiment Site

Descriptive statistics provided in Table 8 indicate obvious variations between sowing dates in relation to wheat performance at Dabat. The number of days required for anthesis was quite similar regardless of the sowing date, which ranged from 73.44 days in sowing date 2 to 74.44 days in sowing date 1. Conversely, the minimum and maximum numbers of days required for maturity were recorded in sowing date 2 (110.44 days) and sowing date 3 (117.44 days), respectively. In the same way, plant height was the highest in sowing date 2 (98.33 cm) and sowing date 1 (93.99 cm), while the lowest was obtained in sowing date 3 (90.62 cm).

There was a great variation in biomass and yield (Table 8 below). Biomass was maximum in sowing date 1 (7,511.11 kg ha^{-1}) and sowing date 2 (7,311.11 kg ha^{-1}); however, the biomass of sowing date 3 was

lower (3,333.33 kg ha⁻¹). Grain yield was also the highest in sowing date 1 (2,911.11 kg ha⁻¹) and sowing date 2 (2,822.22 kg ha⁻¹) and was lower in sowing date 3 (1,344.44 kg ha⁻¹). The biological yield followed the same trend; sowing date 1 had 4,600.00 kg ha⁻¹, while sowing date 2 had 4,488.89 kg ha⁻¹ and sowing date 3 had 1,988.89 kg ha⁻¹. From the results, delayed sowing led to poor biomass and grain yield at Dabat.

The poor performance in sowing date 3 might be a result of a relatively unfavorable environment for the growth of crops, leading to lower biomass production and grain filling. In similar research conducted in Ethiopia, it has been observed that the delay in planting results in decreased yield of wheat. The high CV values in sowing date 3 for biomass, grain yield, and biological yield (54.08%, 44.49%, and 60.78%, respectively) (Table 8 below) show great variation.

Table 8
Descriptive Statistics by sowing date at Dabat experiment site

Trait	Sowing date 1	Sowing date 2	Sowing date 3
DTA	74.44 ± 4.28	73.44 ± 4.53	74.22 ± 4.63
	(68–79; CV = 5.74%)	(64–78; CV = 6.17%)	(Min: 68–79; CV = 6.24%)
DTM	116.78 ± 4.84	110.44 ± 7.06	117.44 ± 1.42
	(113–123; CV = 4.15%)	(102–120; CV = 6.39%)	(116–119; CV = 1.21%)
height(cm)	93.99 ± 8.85	98.33 ± 6.18	90.62 ± 8.58
	(80.6- 112.2; CV = 9.42%)	(89.8–107.0, CV: 6.29%)	(80.2–107.0; CV = 9.47%)
TBM(kgha-1)	7511.11 ± 2919.09	7311.11 ± 1526.80	3333.33 ± 1802.78
	(2000–11600; CV = 38.86%)	(5400–9800; CV = 20.88%)	(1200–6000; CV = 54.08%)
Yield (kgha^{-1})	2911.11 ± 970.11	2822.22 ± 935.12	1344.44 ± 598.15
	(1800–4200; CV = 33.32%)	(2000–4600; CV = 33.13%)	(600–2200; CV = 44.49%)
BP(kgha-1)	4600.00 ± 2095.23	4488.89 ± 813.09	1988.89 ± 1208.76
	(200–7400; CV = 45.55%)	(3400–5800; CV = 18.11%)	(600–3800; CV = 60.78%)

Notice

mean ± SD; values in parentheses represent the minimum–maximum range and CV=coefficient of variation; DTA=days to anthesis; DTM=days to maturity; TBM= total biomass; BP = by product.

3.3. Effects of Sowing Date and Wheat Variety on Wheat at Debark

3.3.1. Results of Analysis of Variance for Phenological, Growth, Biomass and Yield Traits

Analysis of variance indicated that the date of planting was significantly influenced several traits in wheat at the Debark experiment station (Table 9 below). Date of planting was not significantly influenced days to anthesis ($F = 1.56$, $p = 0.2326$), but was significantly influenced days to maturity ($F = 28.78$, $p < 0.0001$), plant height ($F = 20.73$, $p < 0.0001$), total biomass ($F = 17.88$, $p < 0.0001$), grain yield ($F = 6.73$, $p = 0.0052$), and biomass of by-products ($F = 11.82$, $p = 0.0003$). Therefore, the date of planting was more influential in maturity, vegetative growth, biomass production and grain yield than anthesis at Debark.

Wheat variety significantly affected days to anthesis ($F = 28.30$, $p < 0.0001$) and plant height ($F = 14.22$, $p = 0.0001$), but did not significantly affect days to maturity ($F = 2.35$, $p = 0.1184$), total biomass ($F = 0.76$, $p = 0.4790$), grain yield ($F = 0.56$, $p = 0.5799$), or by-product biomass ($F = 0.92$, $p = 0.4146$). These results indicate that the tested varieties differed mainly in phenological development and plant stature rather than in biomass and grain yield under the Debark conditions.

The substantial influence of planting date on biomass production and grain yield supports findings (Gezahegn et al., 2022), in which a significant influence of planting date was noted on the wheat yield and above-ground biomass at Metema and Belesa. In their research, a delayed planting date decreased biomass and grain yields because the crops had been exposed to relatively higher temperatures and increased development rate. The same findings were noted by (Desta *et al*., 2020), who found a significant influence of planting date on the growth and yield of durum wheat in Ethiopia.

Days to anthesis and plant height show a significant varietal effect. Studies carried out in Ethiopia have indicated significant variability between wheat varieties in terms of days to heading and maturity, plant height, biomass production, and grain yield. The lack of significant differences among varieties of terms of grain yield and biomass in the Debark experiment can be explained by the similarities in the level of productivity of the three varieties.

Table 9
The result of ANOVA for the effect of sowing date and varieties on growth and yield trait of wheat at Debark

Trait	SD F-value	p-value	Variety F-value	p-value	SD significance	Variety significance
DTA	1.56	0.2326	28.30	0.0001	NS	***
DTM	28.78	0.0001	2.35	0.1184	***	NS
yield (kg ha^{-1})	6.73	0.0052	0.56	0.5799	**	NS
height (cm)	20.73	0.0001	14.22	0.0001	***	***
TBM(kg ha^{-1})	17.88	0.0001	0.76	0.4790	***	NS
BP (kg ha^{-1})	11.82	0.0003	0.92	0.4146	***	NS

3.3.2. Effect of Sowing Date on Phenological Traits at Debark Experiment Site

Date of sowing did not significantly influence days to anthesis at Debark ($F = 1.56$, $p = 0.2326$), even though the mean value was slightly reduced from 76.33 days on sowing date 1 to 74.11 days on sowing date 3 (Table 10). All the three sowing dates showed statistical similarity. This means that anthesis was relatively constant with sowing dates in the experiment. In contrast, planting date significantly influenced the number of days to maturity ($F = 28.78$, $p < 0.0001$). It was found that the crop reached maturity significantly earlier when planted using planting date 3 (101.67 days) than when planted using planting date 1 (122.67 days) and planting date 2 (121.00 days). Planting dates 1 and 2 were statistically not different from each other.

Maturity that occurs early as a result of sowing date 3 is agronomically significant since there will be changes in temperature and moisture levels that might affect the reproductive growth of the wheat. Temperatures that are high in late growth stages can lead to faster phenology development. This means there will be little time left for accumulation of biomass and grain filling. According to (Gezahegn et al., 2022), delay in sowing may lead to faster crop development and low wheat yield due to less favorable temperature levels.

Sowing date significantly affected plant height at Debark ($P < 0.0001$). Plants of sowing date 2 (101.71 cm) were the tallest among the three different sowing dates, while those of sowing date 1 (99.16 cm) were taller than plants of sowing date 3 (85.68 cm) (Table 10 below). The decrease in plant height in late sowing is due to the delay in the growth stage of the plants. The total biomass was equally significantly affected by sowing dates ($p < 0.0001$). Sowing date 2 indicates the highest biomass of 8,355.6 kg ha^{-1}, while the second highest was at sowing date 1 of 7,244.4 kg ha^{-1}, while the third one had 4,333.3 kg ha-

¹(Table 10 below). The first two sowing dates had no significant difference between each other but were significantly different from the third one.

Where there was a decrease in biomass in sowing date 3, there was a decrease in grain yield. In sowing date 2, the grain yield was 2,422.2kgha^{-1}, while in sowing date 1; the grain yield was 2,311.1 kgha^{-1}as compared to 1,344.4 kg/ha in sowing date 3. Therefore, there was a decrease in the grain yield of 44.5% in case of late sowing as compared to sowing date 2.

The current observation is in line with (Gezahegn et al., 2022), who found that the delays in wheat sowing had significant impacts on the yield and biomass produced in Metema and Belesa. These cause increased phenological development as well as reduced photosynthetic production and grain filling. Similarly, (Desta *et al*., 2020) showed that the sowing date influenced the growth and yield of durum wheat. While the notable drop in grain yield as a result of sowing date 3 treatments was also seen in lower total and by-product biomass due to late planting.

3.3.3 Effect of sowing date and variety on wheat by-product biomass

The effect of the sowing date on the by-product biomass was significant (p = 0.0003) at Debark, but the effect on the wheat variety was insignificant (p = 0.4146) (Table 9 above). The biomass of by-products was higher in sowing date 2 (5,933.3 kg ha⁻¹) and lower in sowing date 3 (2,988.9 kg ha⁻¹), where sowing date and sowing date 2 showed similarity. This could be due to low growth time for the crop. Similarly (Desta *et al*., 2020) and (Tamiru *et al*., 2023).

Table 10
Mean performances of wheat growth and yield attributes for sowing date at Debark

SD	DTA	DTM	Yield (kg ha⁻¹)	Height(cm)	TBM (kg ha⁻¹)	BP (kg ha⁻¹)
SD1	76.33	122.67	2311.1	99.16	7244.4	4933.3
SD2	75.11	121.00	2422.2	101.71	8355.6	5933.3
SD3	74.11	101.67	1344.4	85.68	4333.3	2988.9
LSD (5%)	2.614	6.381	670.28	5.549	1440.7	1277.4

Notice

Means followed by the same letter within a column are not significantly different at the 5% probability level and SD1 = sowing date 1; SD2 = sowing date 2; SD3 = sowing date 3.

3.3.4. Effects of wheat varieties on phenological and growth characteristics

Wheat variety had an impact on days to anthesis and plant height in Debark. The average days to anthesis were from 70.22 days for Variety 2 and 79.67 days for Variety 3, while Variety 1 recorded an average day to anthesis of 75.67 days (Table 11). Mean separation revealed that there were significant differences between the three varieties of anthesis, where Variety 2 was the earliest and Variety 3 was the latest.

Variety too played an important role in influencing plant height. Variety 1 produced the tallest plants with a mean height of 99.76 cm, followed by Variety 3 with 99.51 cm, while Variety 2 produced the shortest plants with an average height of 87.28 cm. Such variations indicate that different varieties tested in the experiment differed in their developmental rates as well as plant structure.

Nevertheless, there were no differences between varieties of relation to their effect on total biomass, grain yield, or by-product biomass. Although Variety 3 had the highest grain yield with a figure of 2,222.2 kg ha^{-1}, followed by Variety 2 which produced 1,944.4 kg ha^{-1} and Variety 1 with a yield of 1,911.1 kg ha^{-1}, the numerical difference cannot be taken as statistically significant since the p value of the ANOVA is 0.5799(Table 11 below). The differences in flowering time and plant height found among the varieties agree with past research done on wheat in Ethiopia, which found genetic variability among traits like flowering time and plant morphology. The lack of varietal differences in grain yield and biomass production suggests that the three varieties were equally productive at Debark.

11. Mean Comparison of Yield Traits in Response to Wheat varieties at Debark

Variety	DTA	DTM	height (cm)	TBM (kg ha^{-1})	Grain yield(kg ha^{-1})	BP (kg ha^{-1})
Var1	75.67	111.67	99.76	6955.6	1911.1	5044.4
Var2	70.22	115.33	87.28	6155.6	1944.4	4211.1
Var3	79.67	118.33	99.51	6822.2	2222.2	4600.0

Notice: Note: Means followed by the same letter within a column are not significantly different at the 5% probability level and var1 = varaiety1; var2 = variety 2; var3 = variety 3.

3.3.5. Overall model performance for phenology, growth, and yield at Debark
The overall general linear model test was significant for all traits examined at Debark (see Table 12 below). The model was highly significant for days to anthesis, days to maturity, plant height, total biomass, and byproduct biomass ($p < 0.001$), while the significance level for grain yield was $p = 0.0201$.

This model accounted for 73.1% of the variance in days to anthesis, 73.9% of the variance in days to maturity, 76.1% of the variance in plant height, 62.9% of the variance in total biomass, 39.8% of the variance in grain yield, and 53.7% of the variance in by-product biomass. The relatively high R^2 values of the phenotypic parameters and plant height show that the experimental factors accounted for a

relatively high percentage of variance in the phenotypic parameters. The relatively low R^2 value of grain yield shows that a relatively high percentage of yield variance was explained by factors other than those included in the model.

The average grain yield recorded was 2,025.93 kg ha^{-1}, whereas the average total biomass production and the average by-product biomass were 6,644.44 kg ha^{-1} and 4,618.52 kg ha^{-1}, respectively. The outcomes indicate that the environment and management practices, especially planting date, were very significant determinants of wheat performance in Debark.

Table 12
Model fit statistics for growth and yield traits at Debark

Trait	F-value	p-value	R^2	Root MSE	Overall mean	Significance level
DTA	14.93	0.0001	0.731	2.67	75.19 days	*** (p < 0.001)
DTM	15.57	0.0001	0.739	6.53	115.11 days	*** (p < 0.001)
Grain yield (kg ha^{-1})	3.64	0.0201	0.398	685.61	2025.93 kg ha^{-1}	* (p < 0.05)
Plant height (cm)	17.48	0.0001	0.761	5.68	95.51 cm	*** (p < 0.001)
TBM (kg ha^{-1})	9.32	0.0001	0.629	1473.68	6644.44 kg ha^{-1}	*** (p < 0.001)
BP (kg ha^{-1})	6.37	0.0015	0.537	1306.61	4618.52 kg ha^{-1}	** (p < 0.01)

Notice

DTA = days to anthesis; DTM = days to maturity; TBM = total biomass; BP = by product (straw); * = p < 0.05; ** = p < 0.01; *** = p < 0.001.

3.3.6 Descriptive statistics by sowing date at Debark

The descriptive statistical analysis indicated that there were distinct differences in growth and yield performances of wheat between different sowing dates at Debark trial site. Days to anthesis did not show much variation between different sowing dates and the average number of days to anthesis was 76.33, 75.11, and 74.11 days for sowing date 1, sowing date 2, and sowing date 3, respectively. On the other hand, days to maturity was highly variable, as sowing date 1 and sowing date 2 reached maturity at 122.67 and 121.00 days, respectively, while sowing date 3 matured at 101.67 days. Similarly, grain yield was higher for sowing date 2 (2422.22 kg ha^{-1}) and sowing date 1 (2311.11 kg ha^{-1}) compared to sowing date 3 (1344.44 kg ha^{-1}). The plant height of sowing date 1 and sowing date 2 (99.16 and 101.71 cm, respectively) was also higher than that of sowing date 3 (85.68 cm). Similarly, total biomass was also higher for sowing date 1 (8355.56 kg ha^{-1}) and sowing date 2 (7244.44 kg ha^{-1}) compared to sowing date 3 (4333.33 kg ha^{-1}) under sowing date 3 to 7244.44 and under sowing date 1 and sowing date 2 to 8355.56 kg ha^{-1}, respectively.

This reduction in growth of the recently planted crops is in line with the overall impact of delayed sowing on wheat production. Delayed planting may decrease the growth cycle of the crop as well as reduce the growth in terms of temperature and radiation, which will consequently lead to decreased plant height as well as decreased biomass production. The influence of the sowing date on wheat growth cycle and yield has been observed in the case of Ethiopia. According to (Tamiru *et al*., 2023), significant differences in maturity and yield have been observed according to the sowing date.

However, such descriptive differences need to be understood in conjunction with the ANOVA values. Grain yield at Debark was not significantly affected by the sowing date ($p = 0.5772$), despite the numeric difference of mean values. Hence, sowing date 2 cannot be stated to be statistically better than sowing date 1. On the other hand, the statistical effect of sowing date on the number of days to maturity and plant height shows the reason behind the distinct difference between earlier sowing dates and sowing date 3. Large values of coefficient of variation for sowing 3 grain yield (64.96%) and total biomass (43.66%) show high variation.

Table 13
Descriptive statistics by sowing date at Debark experiment site

Trait	Sowing date 1	Sowing date 2	Sowing date 3
DTA	76.33 ± 3.08	75.11 ± 3.55	74.11 ± 6.94
	(72–80; CV = 4.04%)	(69–79; CV = 4.73%)	(59–80; CV = 9.36%)
DTM	122.67 ± 5.57	121.00 ± 4.50	101.67 ± 9.54
	(118–130; CV = 4.54%)	(115–124; CV = 3.72%)	(91–113; CV = 9.38%)
Height (cm)	99.16 ± 5.07	101.71 ± 12.01	85.68 ± 5.76
	(90.6–106.4; CV = 5.11%)	(77.4–116.4; CV = 11.81%)	(76.4–92.2;CV = 6.72%)
TBM (kg ha^{-1})	7244.44 ± 1271.92	8355.56 ± 1089.85	4333.33 ± 1892.09
	(5400–8800;CV = 17.56%)	(6800–9600; CV = 13.04%)	(1200–7800;CV = 43.66%)
Yield (kg ha^{-1})	2311.11 ± 664.16	2422.22 ± 392.99	1344.44 ± 873.37
	(1400–3400; CV = 28.74%)	(2000–3000; CV = 16.22%)	(400–3400; CV = 64.96%)
BP (kg ha^{-1})	4933.33 ± 692.82	5933.33 ± 1014.89	2988.89 ± 1891.06
	(4000–5800; CV = 14.04%)	(4600–7000; CV = 17.10%)	(400–6400; CV = 63.27%)

Notice

Mean ± SD; values in parentheses represent the minimum–maximum range and CV = coefficient of variation; DTA = days to anthesis; DTM = days to maturity; TBM = total biomass; BP = by-product.

3.3.7 Descriptive Statistics by Wheat Variety at Debark

The descriptive statistics by variety also indicated differences in phenological and growth characteristics among the three wheat varieties. Variety 3 had the longest mean time to anthesis (79.67 days), whereas Variety 2 reached anthesis earliest (70.22 days), with Variety 1 showing an intermediate value (75.67 days). Mean days to maturity ranged from 111.67 days for Variety 1 to 118.33 days for Variety 3. Plant height was relatively similar between Variety 1 (99.76 cm) and Variety 3 (99.51 cm), whereas Variety 2 was shorter (87.28 cm). Mean grain yield ranged from 1911.11 kg ha^{-1} for Variety 1 to 2222.22 kg ha^{-1} for Variety 3. Total biomass also varied numerically among varieties, ranging from 6155.56 kg ha^{-1} for Variety 2 to 6955.56 kg ha^{-1} for Variety 1.

The varietal differences in terms of anthesis and plant height indicate genetic differences associated with the phenological and architectural development of plants. Other investigations on the wheat crop in Ethiopia have shown that varietal differences exist concerning flowering (anthesis) or maturity and plant height. For instance, (Tamiru *et al*., 2023) observed significant varietal differences regarding the time of flowering, maturity, and plant height. Recent research carried out in Ethiopia has shown significant varietal influences on phenology, plant height, biomass accumulation, and grain yield of wheat, although the level of influence varies from one environment to another.

Notably, the differences in the amount of grain yield and biomass observed in Debark cannot be considered significant differences between the varieties. According to the ANOVA results, variety significantly influenced days to anthesis and plant height but not the grain yield ($p = 0.5799$), total biomass ($p = 0.4790$), or by-product biomass ($p = 0.4146$). This means that despite the fact that the highest grain yield was achieved by Variety 3 (2222.22 kg ha^{-1}) (Table 14 below), there is no scientific proof for the claim that it was a better variety in terms of grain yield.

Table 14
Descriptive statistics by wheat variety at Debark experiment site

Trait	Variety 1	Variety 2	Variety 3
DTA	75.67 ± 1.00	70.22 ± 4.60	79.67 ± 0.50
	(75–78; CV = 1.32%)	(59–74; CV = 6.56%)	(79–80; CV = 0.63%)
DTM	111.67 ± 15.60	115.33 ± 2.18	118.33 ± 13.26
	(91–124; CV = 13.97%)	(113–118; CV = 1.89%)	(101–130; CV = 11.20%)
Height (cm)	99.76 ± 10.73	87.28 ± 8.75	99.51 ± 7.99
	(85.8–116.4; CV = 10.76%)	(76.4–97.0; CV = 10.03%)	(87.0–107.8; CV = 8.03%)
TBM (kg ha^{-1})	6955.56 ± 2148.90	6155.56 ± 2271.07	6822.22 ± 2429.91
	(3000–9000; CV = 30.89%)	(1200–8400; CV = 36.89%)	(3800–9600; CV = 35.62%)
Yield (kg ha^{-1})	1911.11 ± 762.31	1944.44 ± 870.50	2222.22 ± 862.81
	(600–3400; CV = 39.89%)	(400–3000; CV = 44.77%)	(800–3400; CV = 38.83%)
BP (kg ha^{-1})	5044.44 ± 1645.53	4211.11 ± 1555.99	4600.00 ± 2147.09
	(2400–6800; CV = 32.62%)	(800–5400; CV = 36.95%)	(400–7000; CV = 46.68%)

Notice

Mean ± SD; values in parentheses represent the minimum–maximum range and CV = coefficient of variation; DTA = days to anthesis; DTM = days to maturity; TBM = total biomass; BP = by-product.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

In the current research, it was observed that wheat growth and yield were affected by the sowing date and variety of wheat differently in the two different study areas. The magnitude and significance of the influence of the factors depended on the trait being evaluated and the environment in which experiments were performed. There, a wheat management strategy should be designed based on local agro-climatic conditions.

At the Dabat study site, sowing time had a significant impact on days to maturity, total biomass, grain yield, and by-product biomass, but had no significant impact on days to anthesis at the study site. Grain yield was significantly decreased for the latest sowing time with grain yield values of 2,911.1, 2,822.2,

and 1,344.4 kg ha^{-1} from the first, second, and third sowing times, respectively. This shows that proper establishment is very critical for maintaining grain yield and biomass production at Dabat. Wheat variety significantly impacted all traits measured in the production, such as phenology, plant height, biomass, grain yield, and by-product biomass. But the performance of the varieties must be considered by taking into account the mean separation with statistical support.

In Debark, the genotypes of wheat differed significantly in terms of various growth and phenological characteristics, such as days to anthesis and plant height. The planting time influenced many growth and phonological characteristics, and a delay in the time of planting was found to result in shorter crop duration, lower plant height, and less biomass production. The maximum biomass and by-product production were obtained at the earlier and intermediate planting times while the lowest value was observed for the latest planting time. It is evident that late planting can limit vegetative growth and biomass production.

The results from the soil test, on the other hand, revealed some significant differences between the two experiments. Dabat had more clay soil and more organic carbon, total nitrogen, and CEC than Debark, implying a high nutrient retention capacity and fertility compared to Debark. The increased levels of silt in Debark can increase its risk of soil erosion. Both locations had acidic soils with low electrical conductivity, implying that soil acidity and nutrient management need to be taken into account when improving wheat productivity.

The results above prove that the right time of sowing, use of suitable varieties of wheat and taking into account specific soil conditions are important factors in sustainable wheat cultivation in North Gondar Zone. The great decrease in yield from delayed sowing emphasizes the importance of sowing wheat during the right season.

4.2. Recommendations

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

- Wheat must be grown during the recommended period since late planting decreases grain yield and biomass yield in Dabat and Debark.
- Use site-specific sowing recommendations, considering local altitude, climate, rainfall, soil conditions, and seasonal onset.
- Select wheat varieties that are suitable for local growing conditions to enhance agricultural productivity.
- Improve site-specific fertility management of soils by adopting effective residue management, use of organic amendments, and proper fertilizer application.
- Address soil acidity with periodic testing of the soil, and where necessary, liming and proper fertilization practices.

- Implement erosion and nutrient loss control measures in Debark through soil and water conservation measures, which will help keep runoff low and preserve soil organic content.
- Carry out multi-seasonal and multi-site experiments to discover fixed planting periods as well as well-adapted varieties of wheat.
- Formulate climate-sensitive sowing guidelines through the integration of seasonal rainfall and temperature forecasts with the results obtained from sowing date experiments.

Declarations

Contribution to sustainable development: The research is contributing towards the United Nations Sustainable Development Goals (SDGs). Specifically, SDG 2 (Zero Hunger) is addressed by identifying the impacts of sowing date and wheat variety on grain yield in different agro-ecological zones of Dabat and Debark, North Gondar, Ethiopia. The results would be useful for informed decision-making on planting period and wheat varieties of order to enhance productivity of wheat and food security in the area. Evaluation of physicochemical characteristics of the soil is also contributing to SDG 12 (Responsible Consumption and Production). Additionally, the results of the research might contribute to SDG 15 (Life on Land). Overall, integration of proper sowing periods, proper wheat varieties, and soil fertility management will contribute towards more productive wheat-based farming systems in Ethiopia.

Field Experiment Permission: The experimental fields in Dabat and Debark districts were rented for the period of the study from the local landowners, and permission was granted by the landowners themselves prior to carrying out the field experiment.

Data availability: The datasets analyzed in the current study are available from the corresponding author on reasonable request.

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Declarations on Ethics, Consent to Participate, and Consent to Publish: Ethics, Consent to Participate, and Consent to Publish declarations: not applicable.

Author Contributions: Bantie Negirew: Conceptualization, investigation, data collection, statistical analysis, writing. **Gashaw Gismu:** methodology, supervision, and review and editing. **Gibir Mihiret:** Investigation, data collection, and software analysis support. **Adamsew Marelign:** Conceptualization, data collection, statistical analysis, and writing original draft preparation.

Conflicts of Interest: The authors declare no conflict of interest.

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Figures

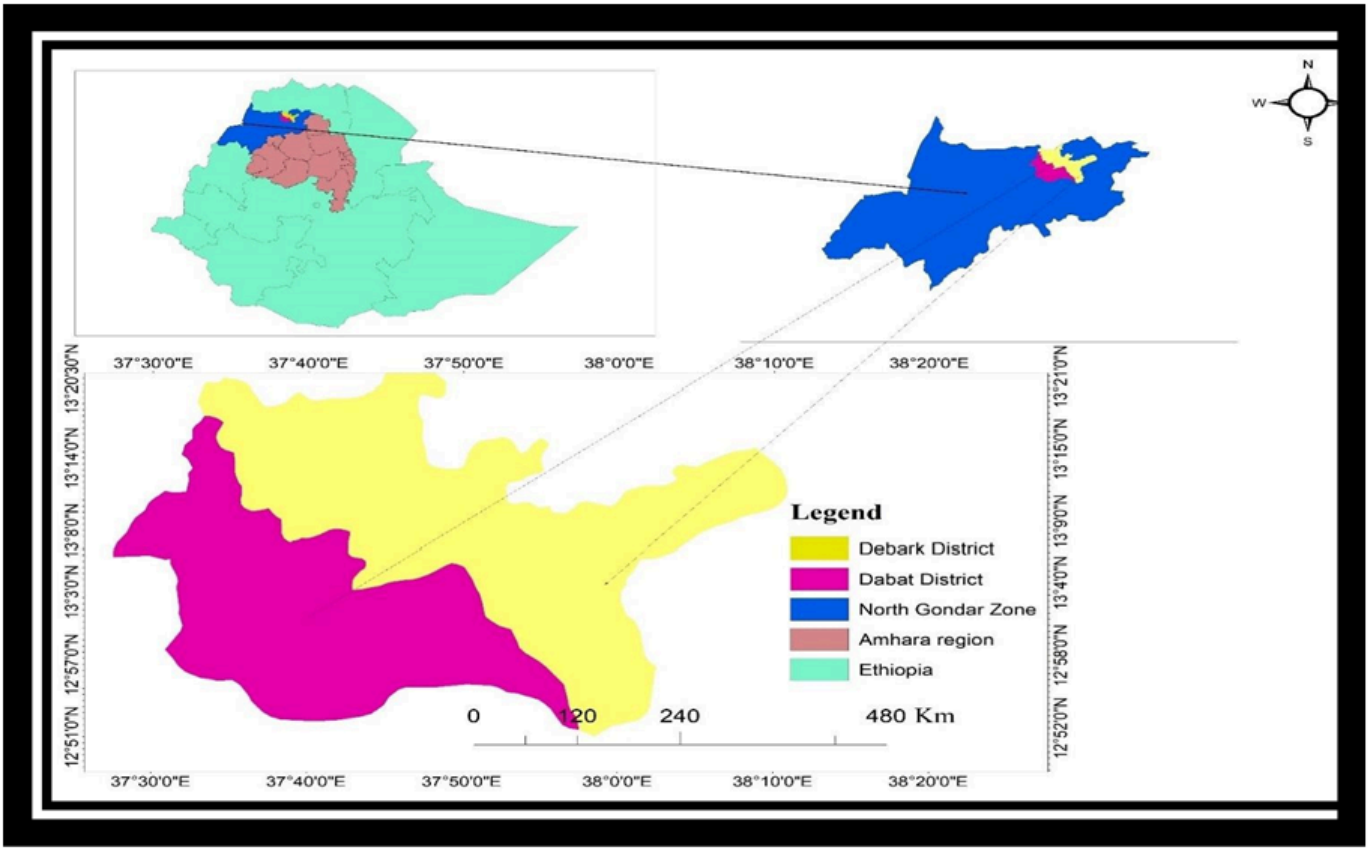


Figure 1

Map of the study area