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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 WEEDING FREQUENCY ON YIELD AND YIELD COMPONENTS OF DURUM WHEAT (*Triticum turgidum* L. var. *durum)* VARIETIES IN JANAMORA DISTRICT, NORTH GONDAR ZONE

MSc THESIS

HAILE MOLLA AYALEW

MAY 2026

ADDIS ABABA, ETHIOPIA

EFFECT OF WEEDING FREQUENCY ON YIELD AND YIELD COMPONENTS OF DURUM WHEAT (*Triticum turgidum* L. var. *durum)* VARIETIES IN JANAMORA DISTRICT, NORTH GONDAR ZONE

A THESIS SUBMITTED TO FEDERAL TECHNICAL AND VOCATIONAL TRAINING INSTITUTE, FACULTY OF AGRICULTURE AND AGRO-PROCESSING TECHNOLOGY

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP PRODUCTION TECHNOLOGY

BY

HAILE MOLLA AYALEW

ADVISOR: HABTAMU ASHAGRE (ASSOC. PROF)

MAY 2026

ADDIS ABABA, ETHIOPIA

DECLARATION

I hereby declare that the work which is presented in this thesis entitled "Effect of Weeding Frequency on Yield and Yield Components of Durum Wheat (*Triticum turgidum* L. var. *durum)* Varieties in Janamora District, North Gondar Zone" is my original work carried out under the supervision of Habtamu Ashagre (Assoc.Prof). It has not been presented for a degree at any other university, and all sources of materials used for this thesis are duly acknowledged.

Name of candidate signature date

Haile Molla Ayalew  04/04/2026

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Name of advisor signature date

Habtamu Ashagre (Assoc. Prof.)  04/4/2026

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This is to certify that the research entitled "Effect of Weeding Frequency on Yield and Yield Component of Durum Wheat (*Triticum turgidum* L. var. *durum)* Varieties in Janamora District, North Gondar Zone" submitted in partial fulfillment of the requirements for the Degree of Masters of Science in Crop Production Technology in the department Fruit and Vegetable Processing Technology, and has been carried out by Haile Molla Ayalew ID No TTMR 313/16 under my supervision. Therefore, I recommend that the candidate has fulfilled the requirements and hence can submit the thesis to the department for defense.

Habtamu Ashagre (Assoc. Prof.)	_____	04/4/2026
Name of advisor	Signature	Date

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CERTIFICATION SHEET

As thesis research advisor, I hereby certify that I have read and assessed the thesis prepared by Haile Molla Ayalew ID. No TTMR313/16 under my guidance, which is "Effect of Weeding Frequency on Yield and Yield Components of Durum Wheat (*Triticum turgidum* L. var. *durum)* Varieties in Janamora District, North Gondar Zone"**.** I recommend that the thesis be submitted as it fulfills the requirements for the degree of Master of Science in Crop Production Technology.

Habtamu Ashagre (Assoc. Prof.)	_____	_____
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As members of the Board of Examiners of the M.Sc. Thesis open defense examination, we certify that we have read and evaluated the thesis prepared by Haile Molla Ayalew and examined the candidate. We recommend that the thesis be accepted as it fulfills the requirements for the Degree of Master of Science in Crop Production Technology.

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External Examiner	Signature	Date

DEDICATION

This thesis manuscript is dedicated to my beloved spouse, Weletetinsae Shumet, for her prayers, encouragement, and partnership in the success of my life, and my baby, Bemnet Haile.

BIOGRAPHICAL SKETCH

The author was born on the 22nd of December 1995 G.C at Derasgie kebele in Janamora woreda, North Gondar Zone of Amhara Regional State, Ethiopia, from his father Molla Ayalew and his mother Meaza G/Meskel. He attended his elementary education at Mekane Birhan Primary School from 2002 to 2009 and High School and Preparatory School at Mekane Birhan Secondary and Preparatory School from 2010 to 2013 G.C. After passing the Ethiopian Higher Education Entrance Certificate Examination (EHEECE), he joined Debre Tabor University, College of Agriculture in 2014 and graduated with a Bachelor of Science (BSc) degree in Plant Science in July 2017 G.C.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
DARC	Debrezeyit Agricultural Research Center
HI	Harvest Index
MRR	Marginal Rate of Return
NB	Net Benefit
t/ha	tone per hectare
RCBD	Randomized Complete Block Design
RYL	Relative Yield Loss
Tukey HSD	Tukey Honest Significant Difference
TVC	Total Variable Cost
WCE	Weed Control Efficiency
WI	Weed Index

Effect of Weeding Frequency on Yield and Yield Component of Durum Wheat (*Triticum turgidum* L. var. *durum)* Varieties in Janamora District, North Gondar Zone

ABSTRACT

Durum wheat (Triticum turgidum L. var. durum) production in the highlands of Ethiopia is significantly constrained by weed competition. Therefore a field experiment was conducted in Janamora District, North Gondar Zone, during the 2025 main cropping season to determine the optimum weeding frequency for enhancing the productivity of durum wheat varieties. The treatments consisted of a factorial combination of four durum wheat varieties (Utuba, Seftu, Jihur, Abedadary (local)) and five weeding frequencies (one weeding (30 DAS), two weeding (30 & 50 DAS), three weeding (30, 50 & 70 DAS), weedy check, and weed free check). The experiment was laid out in a Randomized Complete Block Design (RCBD) in factorial combination with three replications. The experimental site was infested with diverse weed flora, primarily dominated by Spergula arvensis and Galinsoga parviflora. Results revealed that weeding frequency, variety, and their interaction had a highly significant (P< 0.01) effect on crop phenology, growth, and grain yield. The highest biomass (16.13 t/ha) was obtained from Utuba with three weedings. A significant interaction indicated that while the improved varieties Utuba and Jihur maximized yield under weed-free conditions (6.06 t/ha and 6.05 t/ha, respectively), the local cultivar Abedadary demonstrated superior competitive ability and yield stability under weedy conditions. The highest relative yield loss (58.17-59.4%) was recorded from all improved varieties, while the lowest yield loss (47.7 and 5.2%) was recorded on the Abedadary cultivar with weedy and twice-weeding treatment, respectively. The highest net benefit of ETB 386612/ha, with a marginal rate of return 198.8%, was obtained from the Utuba variety combined with twice hand weeding. Therefore, the use of the Utuba variety with twice hand weeding was found profitable, and recommended for durum wheat production in the Janamora district. This study was conducted during a single growing season at one location, hand weeding was the only weed control method tested; a study should be conducted for broader recommendation.

***Keywords**: Durum wheat, Economic analysis, Grain yield, weed competition, Weeding frequency.*

1. INTRODUCTION

1.1 Background

Wheat (*Triticum spp*.) is one of the cereal crops that is produced and traded on a global scale, accounting for 15% of the worldwide area dedicated to cereal cultivation (Alemu et al., 2020). In Ethiopia, two main varieties of wheat are cultivated: bread wheat (*Triticum aestivum*) and durum wheat (*Triticum turgidum* L. var *durum*). Durum wheat accounts for 40% of production, and bread wheat the remaining 60% (Anteneh & Asrat, 2020). As a key staple crop, durum wheat plays an essential role in the nation's food security and agricultural economy (Melash, 2025). Durum wheat serves as a fundamental food source, supplying vital carbohydrates and nutrients (FAO, 2023). In the Amhara region including the N/Gondar, Janamora district, it is used to make various traditional and culturally significant foods, including 'injera' (a type of thin flatbread), 'dabo' (Ethiopian bread), 'nifro' (boiled whole grain), 'kolo' (roasted grain), and Tela (local beer) (Ketema & Megento, 2021). Durum wheat is crucial for food security, especially in urban settings, where it serves as a main source of calories (Wasihun & Desu, 2021).

Durum wheat (*Triticum turgidum* L. var. *durum)* is a significant cereal primarily cultivated in the Ethiopian highlands, located between 6 and 16° N latitude and 35 and 42° E longitude, at elevations of 1500 to 2800 meters above sea level (Hailu et al., 2022). The optimal temperature for the growth of durum wheat falls between 15°C and 25°C, with rainfall ranging from 400 to 600 mm, ideally distributed evenly throughout the growing season (Sall et al., 2019). It can be grown in a variety of soil conditions, but it thrives best in fertile, well-drained clay loam soils with a pH level between 6.0 and 7.5 (Hailu et al., 2015). The highland areas of Ethiopia, particularly the Oromia, Amhara, and Tigray regions, are where durum wheat is primarily grown (Lemma, 2022). In Ethiopia, durum wheat is cultivated in rain-fed production systems, and from the total wheat cultivated areas of 1,605,654, only 561,979 hectares of land are covered by durum wheat (Tadesse et al., 2022). Mengist et al. (2021) indicate that the durum wheat productivity potential in North Gondar ranges from 3.26 to 3.88 t/ha under optimal production input.

1.2 Statement of the problem

The national average yield of durum wheat is not more than 2.6 tons/hectare, which is far below the potential yield of the crop, 6-8 tons/hectare (Desta, 2022). Several factors contribute to the reduced yields of durum wheat, including declining soil fertility, weeds, diseases, and insects. The infestation of weeds is a significant challenge to durum wheat production in Ethiopia, particularly during the rainy season. Season-long weed interference can reduce durum wheat yield by a substantial margin (Daba & Sharma, 2018).

Weeds compete with durum wheat for essential resources such as nutrients, water, sunlight, and space, which can weaken the primary crop and ultimately result in reduced yields. Weeds can reduce durum wheat production by 15-70%, and in severe cases, the losses may lead to a total failure (Hussain et al., 2020). Durum wheat varieties may exhibit different levels of tolerance against weeds, influencing their response to weeding frequency (Mengist et al., 2021). Controlling weeds at the critical period of crop-weed competition is economical and efficient (Korav et al., 2018). Integration of improved durum wheat varieties and appropriate weeding frequency has been identified as an economically viable and ecologically safe weed management strategy (Melash et al., 2023).

There is a difference in the time of the critical period of weed competition and weeding frequency among different researchers. According to Terefe et al. (2016), the critical periods for weed competition in durum wheat typically span from 15 to 45 days after sowing (DAS), and they got a higher yield with two times weeding (at 15 and 45 days after sowing). Mengist et al. (2021) also conclude that the critical periods for weed competition in durum wheat are between 20 and 50 days after emergence, and the yield of durum wheat was significantly higher at two weeding frequencies (20 and 50 DAE). Weeding 3 times at 15, 45, and 75 days after emergence is recognized as the most critical period for weed control, are ensuring the highest yields in wheat crops (Hunde et al., 2021). This difference could be due to variety differences, agronomic practices, climate, and geographical differences (location) (Pathak et al., 2024).

Many of farmers in the study area tend to skip weeding before 60 DAE (days after crop emergence) because they believe it provides sufficient feed for their animals. This activity increases the competition between weeds and crops for resources and finally causes high yield loss both in quality and quantity. Moreover, there is a lack of research recommendations on weeding frequency for durum wheat varieties in the study area because of limited access of improved durum wheat varieties (Shibeshi & Kassa, 2021). Therefore, it is crucial to determine the optimal weeding frequency to enhance durum wheat yield in the district, thereby addressing both the scientific uncertainty and detrimental local practices.

1.3. Objectives

General objective

- ✓ To improve the productivity of durum wheat through determining the optimum weeding frequency in Janamora district, North Gondar Ethiopia.

Specific objectives

- ✓ To evaluate the effect of weeding frequencies on phenology, growth, yield and yield components of durum wheat varieties in the study area.
- ✓ To determine the variety with weeding frequency combination that maximizes grain yield and net economic return.

1.4. Significance of the Study

This research generates practical, evidence-based recommendations on the optimal combination of weeding frequency and durum wheat variety in the Janamora district. The findings directly empower smallholder farmers with clear guidelines about weeding frequency to enhance durum wheat productivity. By addressing such key agronomic bottlenecks, the study can contribute to improving farmer livelihoods.

2. LITERATURE REVIEW

2.1. Durum Wheat Production in Ethiopia

Ethiopia is considered a secondary center of origin and diversity for tetraploid wheat species such as *Triticum ethiopicum*, *Triticum dicoccon, Triticum durum Desf., Triticum polonicum L., Triticum pyriamidale Perc, Triticum turgidum L.* and *Triticum compactum Host* (Alemu et al., 2020). The highlands of the central, south-eastern and northwest parts of the country are the main durum wheat-growing areas of Ethiopia (Mitiku, 2022). From the total wheat grown, about 1.6-1.8 million ha annually and with an estimated 5 million farming households (Hodson et al., 2020), durum wheat covers 20% of the area production (Nagassa et al., 2019).

GebreMariam et al. (2024) revealed that in Ethiopia, durum wheat is mostly cultivated in rain-fed production systems, and from the total wheat cultivated areas of 1,605,654, only 561,979 hectares of land is covered by durum wheat. Desta (2022) concluded that the average yield of durum wheat is not more than 2.6 t/ha at the national level, which is far below the potential yield of the crop, 6-8 t/ha. The research conducted by Yigrem et al. (2021) indicates that the durum wheat productivity potential in North Gondar ranges from 3.26 t/ha to 3.88 t/ha under optimal use of production inputs.

2.2. Importance of Durum Wheat

Durum wheat is globally recognized mainly for pasta; the grain has properties that make it ideal for such products; however, industrial processing is not widely practiced in Ethiopia (Tesfaye, 2021). Durum wheat serves as a fundamental food source, supplying vital carbohydrates and nutrients (FAO, 2023). In the Amhara region including the North Gondar, Janamora district it is used to making various traditional and culturally significant foods, such as 'Injera' (a type of thin flatbread), 'dabo' (Ethiopian bread), 'nifro' (boiled whole grain), 'kolo' (roasted grain), and Tela (local beer) (Ketema & Megento, 2021). Durum wheat is crucial for food security, especially in urban settings, where it serves as a main source of calories (Bati, 2024).

Farmers frequently show preferences for certain characteristics in durum wheat, such as larger grain size, a visually appealing amber color, early maturation to accommodate the short rainy seasons, sturdy straw to minimize lodging, straw that can be consumed by livestock, good overall food quality, and high marketability to guarantee income generation (Gezahegn et al., 2022). Additionally, durum wheat is notable for its nutritional profile, which includes valuable protein and micronutrient content (Melash et al., 2023).

The landraces of durum wheat found in Ethiopia have developed to adapt well to the local environment, often showing stable yields and built-in resistance to both biotic challenges like diseases and insect pests, as well as abiotic challenges such as drought, especially in low-input farming systems (Gashaw et al., 2022). This natural resilience, along with the considerable genetic diversity present in Ethiopian durum wheat landraces, offers a significant asset for future wheat enhancement initiatives focused on increasing yield and stress resistance (Melash et al., 2023).

2.3. Definition and Characteristics of Weeds

Weeds are defined as any plants that disrupt human interests and the ecosystem (Mendes & Alberto da Silva, 2022). In a wheat field setting, a weed refers to any plant species, aside from the cultivated wheat (*Triticum spps*), that grows in the field and hinders the goals of wheat production. Consequently, the classification of a plant as a "weed" depends on the context; a plant regarded as a weed in a wheat field may be valued in another setting (Hendriks, 2023). Weeds that flourish and pose substantial issues in wheat fields typically exhibit a combination of traits that allow them to establish, and compete effectively within the wheat cropping system.

These characteristics encompass: Successful wheat weeds exhibit synchronized life cycles with the crop (Travlos et al., 2025), strong competitive capabilities for resources like light and nutrients (Koskey et al., 2022), and robust reproductive strategies including abundant seed production (Radosevich et al., 2017) coupled with seed dormancy and longevity that ensure persistence in the soil seed bank (Korres et al., 2018). These weeds further adapt to farming practices, sometimes through morphological similarities to wheat, and critically,

many key species (e.g., *Lolium* spp., *Avena fatua*) have developed herbicide resistance (Hulme, 2022), while some also employ allelopathy to inhibit wheat growth (Jabran et al., 2015), collectively making their management challenging.

2.4. Major Weeds of Durum Wheat

Durum wheat field infested by a variety of weed species belonging to different families (Regassa, 2024). Mengist et al. (2025) reported that many types of weed species have been found to infest wheat crops. Some of them are *Avena fatua, Hypochoeris radicata, Polygonium nepalense, Galinsoga parviflora, Gallium spurium, Medicago polymorpha, Oxalis latifola, Spergula arvensis, Guizotia scabra, Galium hamatum L., Cynodon dactylon, Cynodon nlemfuensis, Cyprus rotundas, Eleusine indica L. Gaertn, Phalaris paradoxa L., Spergula arvensis L., Tagetes minuta L. and Bidens pilosa*. Out of the total weeds present in the durum wheat field, 27.3% were broadleaved while 72.7% were grasses. *Avena fatua, Phalaris paradoxa, Polygonum nepalense,* and *Galinsoga parviflora* are the dominant weed species grown in durum wheat fields in the central and northern highland parts of Ethiopia (Tesfaye, 2021).

2.5. Effect of Weeding Frequency on Weed characteristics

2.5.1 Weed flora composition

The composition and relative abundance of weed species found in agricultural areas are referred to as weed flora. The timing and frequency of disturbance have a significant impact on the composition of weed flora in wheat fields (Marifatul et al., 2023). Research conducted in Bedesa, Oromia, showed that grasses contributed 24.3% of the relative weed density, whereas broadleaf weeds accounted for 74.6% (Kebede & Kindie, 2024). The competitiveness of broadleaf species un9der Ethiopia's diverse environmental circumstances and traditional crop management practices is shown in this composition pattern (Tesfaye et al., 2025).

Broadleaf weeds like *Galinsoga parviflora* and *Chenopodium album*, as well as grass weeds like *Phalaris minor* and *Avena fatua* (wild oats), usually dominate the flora in Ethiopian

wheat-growing regions like the Arsi and Guji zones (Misgana et al., 2025). By preventing these dominating species from reaching reproductive maturity, frequent weeding (three or more times) lowers the "soil seed bank" for future seasons. On the other hand, low-frequency weeding frequently causes the flora to change, with late-emerging plants taking over (Hunde et al., 2021).

2.5.2. Weed density

Weeding frequency has a direct effect on weed density, which is the quantity of weed plants per unit area. When compared to unweeded (weedy check) plots, weeding frequencies such as one hand weeding, two-hand weeding, or total weed-free conditions dramatically lower weed density (Mengist et al., 2021). Weed density levels significantly decreased under fully weed-free regimes, improving the crop's access to nutrients and overall growth (Kebede & Kindie, 2024). Increasing weeding frequency from one time to three times decreased weed density by more than 70% in comparison to a weedy check (Ayana et al., 2021).

Enhanced durum wheat cultivars that are often weeded typically have lower weed densities than both local types in weedy environments and improved varieties in poorly weeded plots (Chaudhary et al., 2022). Weed density under improved cultivars with weed-free treatments was as low as 22.78 weed plants/m^2 in the field trial carried out in Ethiopia's North Gondar Zone, as opposed to nearly 50 plants/m^2 under unweeded control plots (Mengist et al., 2021).

2.5.3. Weed fresh and dry biomass

The competitive effect of weeds is reflected in weed biomass, which is quantified at harvest as fresh or dry weight. Because biomass represents the overall competitive impact weeds apply during crop development phases, reducing weed biomass is crucial (Little et al., 2021). In durum wheat, weed biomass reduction concurrently promotes more crop growth, tillering, and yield components while reducing competition for resources (such as light, water, and nutrients) (Beres et al., 2020). Weed biomass buildup is greatly reduced by frequent weeding. Complete weed-free plots consistently yielded the lowest weed dry biomass values (e.g., 3.89-4.64 g/m^2), but unweeded plots had much higher biomass (18-24 g/m^2) at harvest (Kebede & Kindie, 2024). Dry biomass is a more critical indicator of nutrient depletion than

density alone. Studies on durum wheat varieties like Mangudo and Utuba in Ethiopia demonstrated that a weed-free treatment reduced weed dry biomass by up to 84% compared to weedy plots (Mengist et al., 2021).

2.5.4. Weed control efficiency

The effectiveness of weed management techniques in comparison to an uncontrolled (weedy) environment is measured by a statistic called weed control efficiency (WCE) (Monteiro & Santos, 2022). A WCE of 80-95% is usually attained by high weeding frequency (2–3 times) (Kumar et al., 2025). Weeding between 20 and 50 days after emergence (DAE) frequently results in the maximum WCE (Kebede & Kindie, 2024). Unweeded control plots had a WCE of 0%, whereas the combination of better wheat varieties with fully weed-free plots had the highest reported WCE (84.06%). These findings demonstrate that intensifying manual weeding practices significantly suppresses weed growth and maximizes competitive advantage for the crop (Mengist et al., 2021).

2.5.5. Weed index

The weed index serves as an indicator of yield loss attributed to weed competition (Horvath et al., 2023). A significant portion of the decline in grain output is caused by weed interference; better management and reduced weed biomass are associated with higher yield performance (Aljuaid et al., 2021). In Ethiopia, uncontrolled wheat fields can have a WI of up to 65-80%, which means that 80% of the potential production is wasted. Increasing weeding frequency can reduce this index down to below 10%, essentially overcoming the yield difference (Kebede & Kindie, 2024).

2.6. Effect of Weeding Frequency on Phenology and Growth of Durum Wheat

2.6.1. Days to emergence

The 50% emergence date of durum wheat is not much affected by weed intervention (Ayana et al., 2021). This is essentially because the emergence of wheat is predominantly governed by the seed's internal energy stores (endosperm) and the immediate environmental conditions of the seedbed, such as moisture and temperature, rather than external competition (Kebede & Kindie, 2024). The days to 50% emergence were statistically equal across different weed

management levels in experiments on durum wheat types in Ethiopia (Mengist et al., 2021). This is due to the fact that weeds and crops frequently germinate and emerge simultaneously, indicating that the competitive pressure from weeds has not yet increased to the point where the wheat's physical emergence is delayed.

2.6.2. Days to heading

The frequency of weeding significantly influences the days to reach 50% heading. In a study on weed control, durum wheat without any weeding reached early heading at 82.8 days, whereas fields that experienced four weeding events gave the longest heading interval at 90.6 days (Kebede & Kindie, 2024). In comparison to treatments with higher weed infestation, wheat plants under lower weed pressure took a slightly longer time to reach the heading stage (Naruhn et al., 2021). Mekonnen (2022) also revealed that the shortest time (62.00 days) required for 50% heading was observed in weedy check plots.

Most research revealed that, when weeds are eliminated from a durum wheat field, the duration before heading typically extends compared to fields where weeds are allowed to thrive throughout the growing season. This may be because the plants can engage in vegetative growth for a longer duration without disturbance, as resources like moisture and nutrients remain accessible for an extended time without competition from weeds (Shinde et al., 2022)**.**

2.6.3 Days to physiological maturity

Weeding frequency has no significant effect on days to physiological maturity of durum wheat (Kebede & Kindie, 2024). Plots that were not weeded matured earlier because of stress, or at least physiological maturity was slightly delayed as a result of increased weeding frequency (Alemu et al., 2020). In comparison to plots experiencing prolonged weed interference, those with less weed competition can have a somewhat longer development phase, which could postpone maturity by two to seven days (Tolesa et al., 2019). Mekonnen (2022) also said that the delayed maturity (109.00 days) was observed at a weed-free plot.

Research in the central highlands has shown that weeding twice (typically at the tillering and booting stages) significantly delays physiological maturity compared to weedy checks. Varieties with higher tillering capacities tend to compete better with weeds, but they still show a marked increase in days to maturity when kept weed-free (Kumar., et al 2020). When weeds are not controlled, they compete with durum wheat for essential resources like nitrogen, moisture, and light. This competition often induces "forced maturity," where the crop shortens its grain-filling period to ensure seed production under stress (Nigir et al., 2025).

2.6.4 Plant height

Plant height is highly affected by weed competition. Delayed weeding (45–75 DAS) negatively affects plant height (Terefe et al., 2016). Mengist et al. (2021) also noted that the tallest plant height of 76.45 cm was observed in durum wheat grown in completely weed-free plots, whereas the shortest height of 64.72 cm was measured with a single weeding conducted 20 days after emergence.

Kebede & Kindie (2024) revealed that the shortest plants, measuring 69.8 cm, were observed in the weedy control plots, whereas significantly taller plants at 81.4 cm were found when the durum wheat was maintained weed-free throughout the growing season. The decrease in plant height of the durum wheat may have resulted from weeds utilizing the limited light, water, and nutrients for an extended period. The prolonged presence of weeds led to increased competition for the available environmental resources (Hussain et al., 2017).

2.6.5 Spike length

The length of durum wheat spikes is highly affected by weed infestation. The highest spike length performance is observed under weed-free conditions (Mengist et al., 2021). Mulatu et al. (2024) also revealed that the spike length varies between 6.8 cm and 9.67 cm, as observed in weedy and weed-free plots, respectively. Kebede & Kindie (2024) noted that plants that were maintained without weeds throughout the growing season resulted in the longest spikes, measuring 6.5 cm, whereas those that were left unweeded had shorter spikes at 4.84 cm.

Hunde et al. (2021) also revealed that the longest spike length (8.37 cm) was recorded from three hand weedings, and the shortest spike length of 3.07 cm was recorded from zero weeding. The increase in spike length with increasing weeding frequency may be attributed to the adequate availability of growth resources that support cell elongation for spike development (Mekonnen, 2022).

2.7 Effect of Weeding Frequency on Yield and Yield-Related Components of Durum Wheat

2.7.1 Tillering

Weeds compete with crops for various resources. This competition occurs when neighboring plants draw from the same resources, and the effectiveness of this competition is heavily determined by a plant's capability to obtain those resources (Melash et al., 2023). Tiller number is highly affected by weeding frequency. A notably greater quantity of total tillers was observed in durum wheat grown in completely weed-free conditions, yielding 4.33 total productive tillers. The count of total productive tillers is greatly influenced by the frequency and timing of weeding (Mengist et al., 2021).

Durum wheat with two weeding times had the highest number of productive tillers per plant (6.8), whereas the weedy control had the lowest number of productive tillers per plant (2.8) (Kebede & Kindie, 2024). When weeds emerge earlier than the crop, the competition becomes severe, and losses in yield are primarily due to reduction in tillering (Misganaw & Ayalew, 2020). Three times and two times weeding recorded the highest number of productive tillers per plant, whereas the lowest number of productive tillers was observed in the weedy check (Ayana et al., 2021). The number of fertile tillers increased with the increasing in weeding frequency due to reduced intra plant competition (Mekonnen, 2022).

2.7.2. Above-ground biomass

Weeding frequency also affects the total above ground biomass of durum wheat. The highest above-ground biomass yield (9800 kg/ha) is recorded at plots kept weed-free, and the lowest above-ground biomass yield (7900 kg/ha) is recorded in weedy check plots (Kebede & Kindie, 2024). According to Feyissa, et al. (2020), there was a considerable increase in

above-ground biomass or biological yield when the frequency of weeding was raised from zero to one and from one to two weedings.

Ayana et al. (2021) also noted that the highest (3878 kg/ha) biological yield was obtained from three times weeded and the lowest (1500 kg/ha) biological yield was obtained from weedy check. Compared to shorter weed-free periods or no weeding, maintaining weed-free conditions for longer periods of time, achieved through optimal weeding frequency, significantly increases vegetative growth and total biomass (Tolesa et al., 2019).

2.7.3. Grain yield

Among the various factors that negatively impact wheat crop yield, weed infestation stands out as the most detrimental but less noticeable. Weeds can reduce wheat production by 15-70%, and in severe cases, the losses may lead to a total crop failure (Hussain et al., 2017). The reduction in wheat yield caused by weed infestations ranges from 10% to 65%, depending on the type of weeds present, their density, and the surrounding environmental factors (Misgana et al., 2025).

Weeds can diminish grain yield in wheat crops by approximately 40-50% (Melash et al., 2023). Performing weed removal in the fields twice can lessen weed competition and result in higher grain yields compared to weeding just once. Durum wheat grown in plots free of weeds and maintained with weeding at 20 and 50 DAE showed significantly greater yields in comparison to plots with weed competition (Mengist et al., 2021). Grain yield is highly affected by weeding frequency. Plots with weed-free conditions resulted in the highest grain yield (5380 kg/ha), and the smallest grain yield (2479.17 kg/ha) was recorded from control plots (weedy check) (Kebede & Kindie, 2024). Keeping wheat fields free from weed competition (increasing weeding frequency) allows the crop to utilize the available resources and increases the final grain yield (Hunde et al., 2021).

2.7.4. Thousand Seed weight

Field research has shown that increasing the number of weedings (hand-weeded two or three times during the season) often results in a significantly higher seed weight compared to a single weeding or no weeding (Hunde et al., 2021). Improved durum wheat varieties with

stronger competitive ability or better nutrient use efficiency often show greater increases in seed weight under frequent weeding compared to local or less vigorous varieties (Beres et al., 2020). Mengist et al. (2021) noted that the highest thousand-grain weight was recorded in weed-free plots (44.56 g), whereas the minimum thousand-grain weight was observed in the weedy check plot (31.09 g).

The higher thousand-seed weight (46.26 g) was recorded at a frequency of three times weeding, and the lowest (37.56 g) was recorded from the weedy check (Ayana et al., 2021). A variety with inherent stress tolerance and efficient grain-filling can better capitalize on resource availability created by rigorous weeding, leading to improved seed weight (Okbagabir et al., 2024)**.** Weed-free plots or enhanced weed control resulted in higher seed weight than plots with minimal or no weed control, which suggests that frequent weed management enhances kernel weight by alleviating competition (Mengist et al., 2021).

2.7.5. Harvest Index

The Harvest index represents the efficiency of a plant in partitioning photosynthates into grain versus straw. In wheat, weeding frequency directly impacts this ratio by determining the level of inter-species competition for light and nutrients (Asadi et al., 2020). Recent studies in Ethiopia indicate that harvest index is significantly lower in "weedy check" plots compared to plots weeded two or three times (Mengist et al., 2021). Harvest index can improve from 0.28 (unweeded) to 0.42 (twice-weeded), demonstrating that timely weed removal is essential for achieving the biological potential of the crop (Misgana et al., 2025).

Mekonnen (2022) also noted that the highest uppermost harvest index was recorded with the weed-free check (41.57%), followed by one hand weeding (40.32%) at 30 DAE. Research conducted by Ayana et al. (2021) revealed that the highest harvest index was obtained from three times weeding (42.14%), while the lowest harvest index was 19.24% with two times weeding. The lowest harvest index in weedy condition attributed to weeds outcompeting wheat for nitrogen during the grain-filling stage, which forces the wheat plant to invest more energy into vegetative survival rather than grain development (Misgana et al., 2025).

2.7.6 Relative Yield Loss

Relative Yield Loss is the percentage of yield reduction caused by weed competition compared to a weed-free control. This metric is the most direct indicator of the economic damage caused by weeds (Horvath et al., 2023). In the Ethiopian highlands, the relative yield loss in durum wheat can reach staggering levels of 45% to 75% when no weeding is performed (Hunde et al., 2021).

The relative yield loss decreases sharply as weeding frequency increases. For instance, a single weeding at 25–30 days after sowing (DAS) can reduce relative yield loss to 25%, while two weedings (at 25 and 50 DAS) can bring relative yield loss down to less than 10% (Misgana et al., 2025). Mengist et al. (2025) also noted that the maximum relative grain yield loss of 45.24% was obtained from local wheat with weedy check/control plots, while the minimum relative grain yield loss (1.74%) was obtained from Utuba durum wheat variety with weed-free check. Generally, weeding frequency and relative yield loss have an inverse relationship (relative yield loss decreases with increased weeding frequency and vice versa) (Mekonnen, 2022).

2.8. Critical Period of Crop-Weed Competition in Durum Wheat

Critical period of crop-weed competition (CPC) represents the time interval between two separately measured components (Misgana et al., 2025). Those components are the maximum weed-infested period, or the length of time that weeds that have emerged with the crop can remain before they begin to interfere with crop growth. The minimum weed-free period is the length of time a crop must be weed-free after planting in order to prevent yield loss (Mekonnen, 2022).

Competition can happen intra-specifically, including plants of the same species, whether they are weeds or crops, or interspecifically, involving distinct species of weeds or crops (Melash et al., 2023). It is commonly accepted that the first third to half of a crop's life cycle is the important time for weed and crop competition. As a result, weeds that appear before or after this period usually do not significantly lower yields (Misganaw & Ayalew, 2020). The key

times for weed competition in durum wheat usually occur between 15 and 45 days after sowing (DAS) (Terefe et al., 2016).

According to Melash et al. (2023), the crucial time for durum wheat to compete with weeds is between 30 and 60 days following sowing. The yield acquired by weeding during the crucial time of weed competition is therefore quite different to that obtained by cultivating without weeds throughout the duration of the growth season (Mondal, 2022). Generally, the most critical time of weed-crop competition of durum wheat suggested by different researchers is 20-70 days after sowing.

2.9. Timing and Frequency of Weeding on Durum Wheat Field

Hand weeding conducted twice at 15 and 30 days post-emergence was found to be the most effective method for decreasing weed dry matter accumulation in wheat (Kumar et al., 2025). According to Mondal (2022), hand weeding significantly diminished the presence of perennial grasses and sedges in durum wheat. Melash et al. (2023) noted that performing weeding twice (30 and 60 days after emergence) substantially lowered weed infestation. Weeding at 15, 45, and 75 days after emergence is recognized as the most critical period for weed control, ensuring the highest yields in wheat crops (Kebede & Kindie, 2024).

According to Terefe et al. (2016), who conducted their research in the Jima area, conclude that the critical periods for weed competition in wheat typically span from 15 to 45 days after sowing (DAS), and he got higher yield with two times weeding (at 15 and 45 days after sowing). Mengist et al. (2021) also conclude that the critical periods for weed competition in wheat are between 20 and 50 days after emergence, and the yield of durum wheat was significantly higher at two weeding frequencies (20 and 50 DAE).

Dawit (2019) also revealed that there is no significant yield variation in durum wheat under two times weeding at 15 and 30 days after emergence (DAE) and one weeding 21 days after emergence (DAE) and he recommends one time weeding. Weeding three times at 15, 45, and 75 days after emergence is recognized as the most critical period for weed control, ensuring the highest yields in wheat crops (Kebede & Kindie, 2024).

2.10 Effect of Varietal Difference on Yield and yield component of Durum Wheat

Recent studies indicate that high-yielding durum wheat varieties exhibit superior morphological traits compared to low-yielding cultivars. The differences in grain yield among the genotypes can be attributed to variations in key yield components such as tiller number, spike length, and thousand seed weight (Eskezia et al., 2026). In a study conducted in the central highlands of Ethiopia, Alemu et al. (2020) observed that varietal differences accounted for significant variations in tillering capacity and spike characteristics. Shibeshi & Kassa, (2021) found that spike length in durum wheat varieties ranged from 5.5 cm to 9.5 cm. For instance, varieties with longer spikes and a higher number of effective tillers consistently yielded 1.5 to 2.2 tons ha^{-1} more than their counterparts under similar management conditions. Modern cultivars, significant variations were recorded for tillering, indicating that some varieties possess a superior genetic ability to utilize available resources for productive tillers (Mmbando, 2025).

Legesse et al. (2019), who tested different durum wheat varieties, suggested that durum wheat varieties have difference on plant height, spike length seed weight, biomass yield, and grain yield. Improved varieties with higher tillering capacity often require more stringent weed management to prevent shading and nutrient competition during the early growth stages, as their rapid biomass accumulation makes them more sensitive to initial weed density (Misganaw & Ayalew, 2020). Spike length is often more genetically stable than tillering but still varies by variety. In recent evaluations, spike length showed highly significant differences among genotypes, contributing directly to the number of spikelets and grains per spike (Mmbando, 2025).

Different varieties have shown distinct growth patterns in height and maturity. The ultimate expression of varietal difference is found in grain yield, which is a product of the interaction between the genotype's potential and the environment. In trials conducted across diverse districts grain yields varied dramatically between varieties (Mmbando, 2025). Under optimized management and participatory up-scaling, some modern varieties have reached

yields as high as 7 t/ha (Melash et al., 2023). According to Shibeshi & Kassa, (2021), improved durum wheat varieties under optimal management exhibit above-ground biomass production ranging from 9.5 to 13.2 t/ha, whereas older or local varieties often struggle to exceed 8.0 t/ha. The researchers noted that this superiority in biomass is largely due to higher leaf area duration and extended vegetative growth periods in modern cultivars.

Thousand seed weight, a critical quality and yield component, also shows distinct genetic variation. Research by Lemma et al. (2021) revealed that improved durum wheat varieties reach thousand seed weight values of 48–56 g, compared to 35–42 g for traditional landraces. This genetic advantage in seed filling directly correlates with grain yield. In the same study, the grain yield for high-performing varieties ranged between 3.8 and 4.9 t/ha, while local landraces yielded significantly lower, often falling below 2.5 t/ha. Furthermore, the harvest index remains a key indicator of breeding success. A study conducted by Ararsa et al. (2025) in the Oromia region found that newer, semi-dwarf durum wheat varieties achieved a harvest index of 42% to 48%. In contrast, traditional varieties often displayed an harvest index of 30% to 35%, indicating that a greater proportion of resources was being diverted to straw rather than grain.

2.11 Interaction Effect of Variety and Weeding Frequency on Yield and Yield Component of Durum Wheat

The interaction between variety and weeding frequency is a critical determinant of durum wheat productivity in Ethiopia. Studies by GebreMariam et al. (2024) in the Arsi zone demonstrated that the interaction between high-yielding varieties and frequent weeding (two to three weeding) resulted in a substantial increase in tillering capacity. They reported that improved cultivars subjected to three weeding sessions produced 5 total tillers and 4 effective tillers per plant, whereas the same varieties under weedy conditions dropped to three total tillers and two effective tillers. Interestingly, local landraces showed a smaller marginal increase, suggesting that improved varieties are more sensitive to the early-season competition for nutrients and solar radiation.

Legesse et al. (2019) revealed that the interaction of durum wheat varieties with three-time weeding produced an above-ground biomass of 14.5 t/ha, while the unweeded plots of the same varieties yielded only 8.2 t/ha. Biological yield is maximized when a high-tillering variety is paired with a frequent weeding regime (Atumo et al., 2022). Similarly, the thousand-seed weight showed significant synergistic responses: improved varieties under weed-free conditions achieved weights of 52 g, compared to 38 g in the control plots, a shift that directly affected the final harvest index. Eskezia et al. (2026) revealed that the interaction effect on spike length was statistically significant, where optimal weeding frequency enabled improved varieties to produce spikes of 9.8 cm compared to 6.2 cm in unweeded conditions.

The interaction between genotype and weed management significantly dictates the economic efficiency of durum wheat production. Amare, (2014) reported that the improved varieties yielded as high as 5.2 t/ha under three-time weeding, but this value plummeted to 2.4 t/ha under zero-weeding conditions a reduction of over 50%. Conversely, local cultivars showed less dramatic fluctuations, reflecting a more stable but lower yield ceiling. Addisu et al. (2023) noted that the interaction effect on the harvest index followed a similar pattern; improved varieties achieved harvest index of 46% when weeded thrice, compared to 32% in unweeded plots, indicating that weeds severely disrupt the translocation of assimilates to the grain in modern, high-yielding genotypes.

Similarly, research by Negash & Tegenu (2025) in the North Shewa zone highlighted that when weeding was delayed or absent, the harvest index of semi-dwarf durum wheat varieties dropped significantly (from 45% down to 28%) because the weeds outcompeted the wheat for nitrogen and moisture during the critical grain-filling phase. In contrast, the most frequent weeding regime (three times) allowed these varieties to maximize their grain yield, consistently surpassing 4.5 t/ha and maintaining an harvest index above 43%.

By shading out weeds, varieties with quick canopy closure, a higher leaf area index, and rapid early development can suppress them more successfully. These types may fare better when weeding occurs less frequently (Addisu et al., 2023). Because they are less able to

handle weed pressure on their own, less competitive varieties typically exhibit a more noticeable positive response to increased weeding frequency (Kumar et al., 2022).

Durum wheat yield varied from 3.47 t/ha at one weeding up to 4.99 t/ha at four weedings (Kebede & Kindie, 2024). Different durum wheat varieties may exhibit varying levels of tolerance or competitiveness against weeds, influencing their response to weeding frequency (Mondal, 2022). Mangudo gives 3.766 t/ha, Utuba also gives 3.633 t/ha, and the local variety gives 3.266 t/ha at two times weeding at 20 and 50 days after emergence. The study observed that the improved variety Mangudo, when kept weed-free, showed a greater reduction in weed density and biomass compared to the Utuba variety under the same conditions (Mengist et al., 2021).

3. MATERIALS AND METHODS

3.1 Descriptions of the Study Area

The experiment was carried out in the wheat-producing districts of Janamora within the former North Gondar zone during the 2025 G.C cropping season. The Janamora district is far from Addis Ababa and Gondar by 937 and 215km, respectively. The district is situated in the Amhara Region of Northwestern Ethiopia, spans latitudes from 12° 44′ 21.2″ N - 13° 21′ 19.3″ N and 38° 0′ 0.3″ E - 38° 22′ 40.5″ E. The elevation of the study area ranges from 1238 to 4512 m.a.s.l (Marelign, 2020). The district lies on the southern slopes of the Semen Mountains in the North Gondar Administrative Zone of the Amhara Regional State in northwestern Ethiopia (Siraw et al., 2020).

In terms of climate, the districts belong to an agro-ecological zone classified as 'cool, moist mid-highlands' (Siraw et al., 2020). Rainfall in the districts exhibits a bi-modal distribution, with the primary rainy season lasting from June to mid-September, accounting for approximately 65% of total annual rainfall, while the secondary rainy season occurs from March to May, contributing about 15% of the yearly rainfall, which averages between 600 to 1200 mm annually (Abebaw & Betru, 2019). As per the meteorological records, the mean annual temperature falls between 12.9 and 26.4°C (Lemann et al., 2017). The soil types in the study area predominantly consist of Nitosols (55%), Leptosols (30%), Cambisols (10%), and Vertisols (6%) (Sheleme et al., 2023).

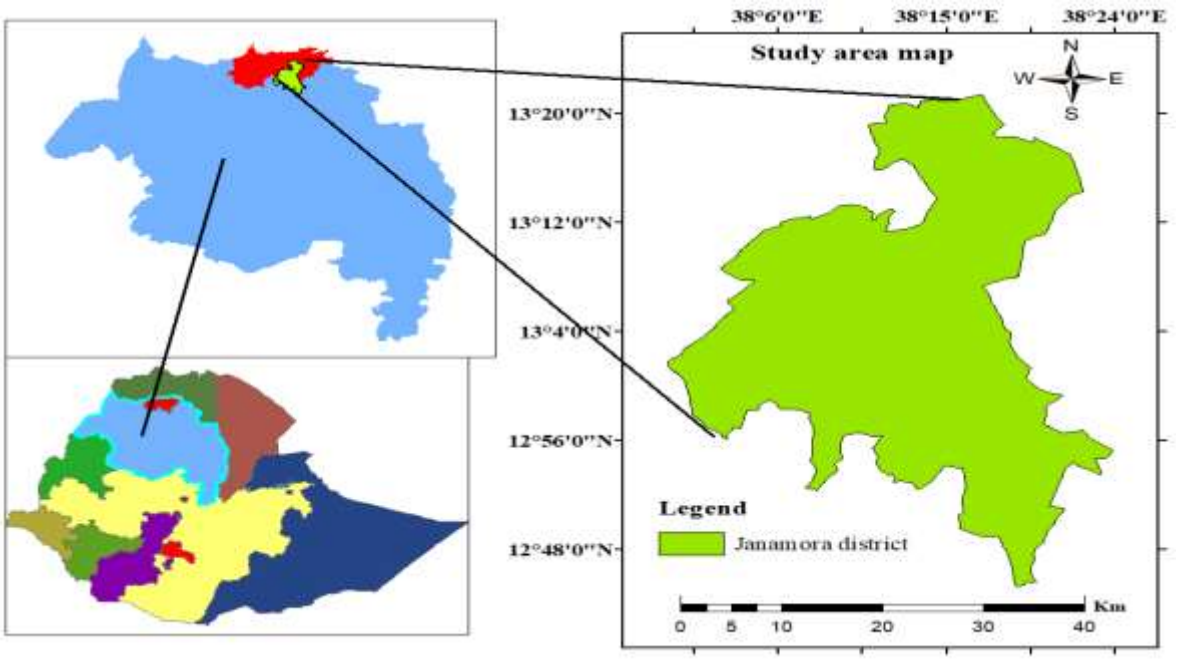


Figure 1: Map of the study area

3.2 Description of Experimental Material

The experimental materials were four durum wheat varieties (Utuba, Seftu, Jihur and one local cultivar). The improved varieties were chosen based on their high-yielding performance. They were released from DZARC (Debrezeyite Agricultural Research Center) and taken from DZARC. The local cultivar named Abedadary was selected based on their wide scale production by the farmers and its yield potential in the study area, purchased from the local market. No research data describes the yield potential of the local cultivar, but farmers noted that it gives a yield of 3-3.5t/ha.

Table 1: General information about the varieties included in the research

Variety name	Year of release	Adaptation (altitude) in m.a.s.l	Rainfall (mm)	Days to maturity	Yield (q/ha)	
					research	Farmer field
Utuba	2015	1800-2700	700-100	105-118	52	40-45
Seftu	2023	1800-2400	800-1200	105-117	55	45-47
Jihur	2024	1800-2400	800-1200	103-116	58	47

Source: MoA (2024)

3.3 Treatments and Experimental Design

The treatment consisted of the combination of four durum wheat varieties (three improved, namely Utuba, Seftu, Jihur, and one local, namely Abedadary) with three weeding frequencies (one hand-weeding at 30 days after crop sowing (DAS), two hand-weeding at 30 and 50 days after crop sowing (DAS), three hand-weeding at 30, 50, and 70 days after crop sowing (DAS), weed-free (WF), and weedy check (WC). The experimental design used was a randomized complete block design with factorial arrangement with three replications. The gross plot size was $6m^2$ (2 m × 3 m), net plot size $4.8m^2$ (1.6 m x 3 m) and the path between plots and blocks was 0.5 m and 1m, respectively.

3.4 Experimental Procedure

The experimental field was prepared uniformly according to local standard practices. This typically involves ploughing twice with oxen and make leveling to create a suitable seedbed. All plots were sown on the same day by calculating the amount of seed needed per plot based on the plot size with an appropriate seed rate (120 kg/ha) (Mengist et al., 2021), preferably at the onset of the main rainy season suitable for durum wheat in the area. The sowing system was drilling with 20 cm row spacing for better management and data collection (Deshmukh & Vidyapeeth, 2019; GebreMariam et al., 2024).

Fertilizers were applied uniformly across all plots based on recommendations for durum wheat. Blended NPSB 100kg/ha (providing 18 kg N, 46 kg P_2O_5, 10 kg S, 0.3 kg B) applied to all at sowing by calculating for each plot size. Similarly, 100 kg/ha urea was also applied (1/3 urea was applied at the time of sowing, while the remaining 1/3 urea was top-dressed at tillering and 1/3 panicle initiation stages) as recommended by Desta & Almayehu (2020). The weeding practice for each treatment was done based on the treatment (DAS). Hand-weeding was done carefully based on treatments for the designated plots. Weed-Free plots were monitored regularly, and any emerging weeds were removed immediately by hand. No Weeding plot was left completely unweeded throughout the growing season. Other necessary agronomic management practices were applied uniformly across all plots as needed.

3.5 Data Collection

3.5.1 Weed parameter

Weed flora: A 0.25 m x 0.25 m quadrat was randomly placed at two locations within each plot, and the weed population was identified by categorizing broadleaved and grasses (Mengist et al., 2021). The species name and the number of individuals of each species were recorded. These data were recorded two times: 30 days after the crops had been sown and 15 days before the anticipated harvest. The weed flora was identified by using the handbook of weed identification (Naidu, 2012) and a mobile app called "Plant Net".

Weed density: The weed density was recorded two times: 30 DAS (days after sowing) and 15 days before harvest (DBH). Measurement was done by using a 0.25 m x 0.25 m quadrat, randomly placed at two locations within each plot (Mengist et al., 2021). Convert the counts to plants per square meter using the quadrat.

$$\text{Weed Density} = \frac{\text{Total number of individual weeds counted in all quadrant}}{\text{Total area of all quadrats } (m^2)}$$

Weed fresh and dry mass: After counting the weeds in each quadrate by separating species-wise, the weeds were uprooted, washed and their weight was measured in electrical balance. Then, after, the weeds were dried at first in the sun and thereafter, in an electric oven for 72 hours, maintaining a constant temperature of 65°C (Mekonnen, 2022). After drying, the weight of the weed was taken by an electronic balance.

Weed Control Efficiency (WCE): It was calculated from weed control treatments in controlling weeds and using the following formula (Wasnik et al., 2022).

$$\text{WCE (\%)} = \frac{DMWut - DMWt}{DMWut} \; X \; 100$$

Where, WCE = Weed control efficiency, WDC = Dry matter of weed from untreated plots or weedy check plots and DMWt = Dry matter of weed from treated plots, or plots in particular treatment.

Weed Index (WI): It is the magnitude of yield reduction due to the presence of weeds in comparison with a weed-free check and is calculated as described by Mekonnen (2022):

$$WI = \left(\frac{X-Y}{X}\right) * 100$$

Where, WI denotes weed index, X represents yield in complete weed free environment, and Y represents yield in a particular treatment.

3.5.2. Phenological parameters of crop

Day to emergence: It was recorded at the time when 50% of the seedlings emerged above the ground.

Days to heading: It is the number of days from the date of emergence to the stage when the spikes of 50% of the plants are fully visible (Kebede & Kindie, 2024).

Days to physiological maturity: It is the number of days from emergence to 90% maturity, and the data were recorded when 90% of the crop reaches physiological maturity. The crop reaches physiological maturity if the grain is hard (not easily dented by a fingernail), the flag leaf, spike, glume and peduncle turn yellow (Eshetu, 2024).

3.5.3. Growth parameters of the plant

Plant height (cm): It was measured using a meter stick from ten randomly selected and pre-tagged plants in each net plot area, from the base to the tip of the spike, excluding the awn at physiological maturity (Mekonnen, 2022)

Spike length: Was measured in centimeters, starting from the base of the spike and extending to the tip of the spike, excluding the awns, from ten randomly chosen pre-tagged plants of spikes in each net plot area, and an average was calculated (Ahmad, 2024).

3.5.4. Yield and yield components

Number of total tillers: It was counted at the late tillering stage from ten randomly selected and pre-tagged plants.

Effective tillers: Is the number of tillers that can set spikes and give seed, which was counted at physiological maturity from plants where the tiller number is counted (Mekonnen, 2022).

Thousand seeds weight (g): Thousand seeds were counted, and their weight (g) was recorded, adjusted to 12.5% moisture content (Ahmad, 2024).

Grain yield (t/ha): was measured after threshing the sun-dried plants harvested from each net plot and adjusted to 12.5 moisture level (Mengist et al., 2021).

It is calculated as: $Yadj = Yhar * \left(\frac{100-Mi}{100-Ms}\right)$, where, $Yadj$= adjusted yield at 12.5%, $Yhar$ = harvested yield, *Mi* = initial moisture, *Ms* = Standard moisture (Muzayin et al., 2022).

Above-ground biomass yield (kg/ha): It was recorded from the net plot area by weighing the total above-ground biomass at harvesting (Mekonnen, 2022).

Harvest index (%): It was calculated as the ratio of grain yield to above-ground dry biomass per plot and multiplied by 100 at harvest from the respective treatments (Ahmad, 2024).

$$\text{HI} = \frac{Grain\ yield}{\text{above ground biomass}}\ X\ 100$$

Relative yield loss (%): The loss in seed yield was determined as a percentage of the difference between weeded plots (completely weed-free) and yield in a particular treatment using the formula described by Mengist et al. (2021):

$$\text{RYL} = \frac{Y1-Y2}{\text{Y1}}\ X\ 100$$

Where, RYL = Relative Yield loss, Y1 = Yield that can be obtained from complete weed-free plots, Y2 = Yield that can be obtained in a particular treatment.

3.6 Data Analysis

Collected data was subjected to the analysis of variance appropriate to the design RCBD using the R-Studio computer software package version 4.5.2. Normality of experimental residuals was confirmed using the Shapiro-Wilk test, while homogeneity of variances across treatments was evaluated using Levene's test. Mean separation tests were applied following

the randomized complete block (RCBD) design procedure as described by Gomez and Gomez et al. (1984) using Tukey HSD values to separate differences among treatment means at 5% probability level.

3.7 Correlation Analysis

Correlation Analysis was conducted using R software version 4.5.2. The overall raw data of each parameter was subjected to correlation analysis. This analysis is important to evaluate the relationship among variables. These relationships indicate the influence of one variable on the other, either negatively or positively (Gomez et al., 1984).

3.8 Economic Analysis

Economic analysis was conducted using partial budget analysis following CLMMYT (1988) procedures. The analysis was carried out separately for each durum wheat variety to evaluate the economic feasibility of different weeding frequencies. The costs that varied were the cost of weeding and the cost of the seed. The benefit is also gained from the produced grain and straw. Treatments were first arranged in ascending order of total variable cost, and dominated treatments, those with higher costs and lower net benefits, were excluded from further consideration.

4. RESULTS AND DISCUSSION

4.1. Weed Dynamics

4.1.1. Weed Flora Composition

The experimental site exhibited a diverse population of weed flora comprising nine distinct species. Consistent with the identification guidelines by Atnafu, (2019), the weed species were categorized into broad-leaved weeds and grasses (Table-2). The identified broad leaf species included *Rorippa palustris L.*, *Medicago polymorpha L.*, *Galinsoga parviflora Cav.*, *Galium aparine L.*, *Erodium cicutarium L.*, and *Oxalis stricta L.*, and the grass family included *Poa annua L., Digitaria sanguinalis L., and Spergula arvensis L.*

The findings demonstrate that 64.23% of the weed infestation observed in the experimental site was comprised of broad-leaved weed species, whereas 35.77% was constituted by species categorized as grasses. This result partially deviates from the comprehensive surveys conducted in Ethiopian durum wheat fields, where Mengist et al. (2021) indicated that grasses generally represent 72.7% of the infestation, while broad-leaved weeds constitute 27.3%. The inversion of this pattern in the study locale implies that the prevailing soil conditions and the particular weed seed bank present in Janamora preferentially support broad-leaved species. The data further elucidate that *Spergula arvensis L.* (Starwort) emerged as the most prevalent species within the study area, exhibiting the highest average density of 207.67 plants/m² (26.81%), closely followed by *Galinsago parviflora Cav.* (187.00 plants/m² (24.14%).

In conjunction, these two species comprised a considerable fraction of the overall weed abundance. This elevated density is consistent with the observations made by Gebre-Mariam et al. (2024), who identified *Galinsago parviflora* as a preeminent weed species in the central and northern highland regions of Ethiopia. The abundance of *Spergula arvensis* is particularly alarming, as it is recognized for its rapid growth and prolific seed production, which enables competition with crops for essential resources (Travlos et al., 2025).

Table 2: Weed species composition, average density (plants/m²), and present coverage in the study area

Scientific name	Family	Common name	Local name	Average density/m^2	Percent coverage
Broad leaf					
Rorippa palustris L	Brassicaceae	Marsh yellow-cress	Wezber	89.67	11.57%
Medicago polymorpha L.	Fabaceae	California bur-clover	Magett	92.67	11.87%
Galinsago parviflora cav.	Asteraceae	Quick weed	Minqitu	187	24.14%
Galium aparine L.	Rubiaceae	Sticky willy	Ashekt	48.33	6.23%
Erodium cicutarium L.	Geraniaceae	Common stork's bill		58.83	7.48%
Oxalis stricta L.	Oxalaceae	Yellow wood sorrel	Licha	21	2.70%
Grass					
Spegula arvensis L.	Caryophyllaceae	Starwort	Girtat	207.67	26.81%
Digitaria sanguinalis L.	Poaceae	Common grab grass	Muja	30.17	3.89%
Poa annual L.	Poaceae	Winter grass	Gench	39.17	5.10%

4.1.2. Weed Density

Weed density before 15 days to harvest

The analysis of variance revealed that weed density was significantly influenced by the weeding frequency ($P < 0.001$) and variety ($P < 0.01$) at late stages (before 15 days to harvest) (Appendix Table-2). The mean value of the data showed that the highest weed density (974.2 plant/m^2) was observed in the weedy check condition (Table 3), and the lowest weed density (49 plant/m^2) was observed in the thrice weeding which is statistically similar to weed free plots. The first weeding reduces the total weed population by 65%, the remaining 30% is reduced by two weedings, and three weedings reduce the remaining 5% population compared to the weedy check.

Weed population decreases dramatically with increased weeding frequency. This result agrees with Mengist et al. (2025), who reported that increasing weeding frequency

significantly reduces weed density by reducing the soil seed bank replenishment and vegetative regrowth. Among the varieties, the highest weed density (422.6plant/m^2) is observed in Jihur, which is statistically similar to Utuba and Seftu, and the lowest weed density (354.5plant/m^2) was obtained in Abedadary. This is because Abedadary reduce weed density due to its behavior of being the tallest height and having the highest number of tillers. This finding is supported by Addisu et al. (2023), who noted that durum wheat varieties that had quick canopy closure, a higher leaf area index, and rapid early development can suppress weeds and reduce their density more successfully.

Before one hand weeding (before 30 DAS)

The analysis of variance revealed that weed density before 30 DAS was significantly influenced by the weeding frequency ($P < 0.001$) at early stages (before one hand weeding) (Appendix Table-2). The weeding frequency data showed that the highest (760-829plants/m^2) weed population was recorded in all plots left to weeding after 30 days, and there is no weed density under complete weed-free conditions (Table 3). This approves, weed density levels significantly decreased under fully weed-free regimes, improving the crop's access to nutrients and overall growth (Kebede & Kindie, 2024).

Table 3: Effect of weeding frequency and variety on Weed Density (plants/m²) at 30 DAS and 15 days before harvest (DBH)

Treatments	Weed density (15 DBH)	Weed density (30 DAS)
Weeding Frequency		
Weedy Check	974.2 ^{a}	797.3^{a}
Weeding once	636.3 ^{b}	760.6^{a}
Weeding twice	299.4 ^{c}	842.6^{a}
Weeding thrice	48.5 ^{d}	829.5^{a}
Weed Free	0.0 ^{d}	0.0 ^{b}
HSD (0.05)	*55.8*	*105.44*
Variety		
Utuba	390.6^{ab}	664 ^{a}

Seftu	399.1[ab]	643.87[a]
Jihur	422.6 [a]	676.6[a]
Abedadary	354.5 [b]	599[a]
Mean	391.68	646.01
HSD (0.05)	*46.83*	*NS*
CV (%)	*12.18*	*13.96*

Means followed by the same letter within a column are not significantly different using Tukey's HSD test at P<0.05. NS = non-significant, DAS = days after sowing; DBH = Days before harvest.

4.1.3 Weed Biomass

Weed fresh weight

Weed Fresh Weight was highly significantly ($P < 0.001$) affected by weeding frequency, variety, and their interaction (Appendix Table-2). The highest weed fresh weight was recorded in Jihur and Utuba varieties under the weedy check at 1.33 and 1.29 kg/m², respectively, while the lowest was in all varieties at three-time weeding and weed-free plots (Table 4). This indicates that the fresh weight of weeds decreased with increasing weeding frequency.

Kebede & Kindie (2024) also suggest the same finding, that weed biomass buildup is greatly reduced by frequent weeding. Abedadary records the lowest weed fresh weight (0.97 kg/m²) at the weedy check and (0.68 kg/m²) at one weeding compared to other varieties. This is because Abedadary reduces fresh weight of weeds due to its suppressive ability compared to other varieties, and is supported by Addisu et al. (2023) noted that, varieties which had higher suppressive ability can reduce the ability of weeds to compete for resources and lead to reduced weight of weeds.

Table 4: Interaction effect of weeding frequency and variety on Weed Fresh Weight (kg/m²) taken before 15 days of the anticipated harvest.

Weeding Frequency	Varieties				Mean
	Utuba	Seftu	Jihur	Abedadry	
Weedy Check	1.29 [a]	1.20 [b]	1.33 [a]	0.97 [c]	1.2 [a]
Weeding once	0.83 [d]	0.79 [d]	0.77 [d]	0.68 [e]	0.77 [b]
Weeding twice	0.41 [f]	0.37 [fg]	0.39 [fg]	0.33 [g]	0.377 [c]
Weeding thrice	0.16 [h]	0.17 [h]	0.16 [h]	0.13 [h]	0.157 [d]
Weed Free	0.00 [i]	0.00 [i]	0.00 [i]	0.00 [i]	0.0 [e]
Mean	0.54 [a]	0.5 [b]	0.53 [a]	0.42 [c]	
HSD (0.05)	*0.067*				
CV (%)	*4.34*				

Means followed by the same letter within a row and column are not significantly different using Tukey's HSD test at P<0.05.

Weed dry weight

Weed Dry Weight was highly significantly (P < 0.001) affected by weeding frequency, variety, and their interaction (Appendix Table 2). The highest weed dry weight was recorded in the weedy check of the three improved varieties at (0.72 - 0.73 kg/m²), while the lowest was in the three-time weeding of all varieties at (0.04-0.08 kg/m²) and weed-free plots (Table 5).

Under weedy check conditions Abedadary recorded the lowest weed dry weight (0.55kg/m²), significantly lower than the improved varieties (Utuba, Seftu, Jihur). This confirms the local cultivar (Abedadary) suppressed weed biomass accumulation more effectively than modern varieties under unweeded conditions because of its longest height. This finding aligns with Scavo et al. (2022), who noted that varieties with greater height and canopy closure (typical of local landraces) can shade out weeds and reduce their dry matter accumulation.

Table 5: Interaction effect of weeding frequency and variety on Weed Dry Weight (kg/m²)

Weeding Frequency	Varieties				Mean
	Utuba	Seftu	Jihur	Abedadry	
Weedy Check	0.72 ^{a}	0.72 ^{a}	0.73 ^{a}	0.55 ^{b}	0.68 ^{a}
Weeding once	0.43 ^{cd}	0.43 ^{cd}	0.45 ^{c}	0.39 ^{d}	0.42 ^{b}
Weeding twice	0.20 ^{e}	0.19 ^{e}	0.19 ^{e}	0.11 ^{f}	0.17 ^{c}
Weeding thrice	0.04 ^{gh}	0.08 ^{fg}	0.05 ^{fgh}	0.04 ^{gh}	0.05 ^{d}
Weed Free	0.00 ^{h}	0.00 ^{h}	0.00 ^{h}	0.00 ^{h}	0.0 ^{e}
Mean	0.28 ^{a}	0.28 ^{a}	0.29 ^{a}	0.22 ^{b}	
HSD (0.05)	*0.056*				
CV (%)	*6.76*				

Means followed by the same letter within a column and row are not significantly different using Tukey's HSD test at P<0.05.

4.1.4 Weed Control Efficiency

The analysis of variance revealed that weed control efficiency was highly significantly ($P < 0.001$) influenced by weeding frequency and the interaction of variety with weeding frequency (Appendix-2). The highest weed control efficiency (94.43%) was gained from Utuba with thrice weeding, which is statistically the same with weed-free conditions of all varieties, and the lowest control efficiency (0%) was observed from the weedy check environment (Table 6). At two times weeding comparatively, Abedadary recorded the highest (80.6%) control efficiency than Utuba (72.16%) and Seftu (74.02%).

Under thrice weeding, weed control efficiency increased across all varieties. This indicates that frequent weeding, plus the weed suppression ability of the variety, gives a better weed control efficiency. This finding is supported by Mengist et al. (2021), who indicated that the combination of better wheat varieties with fully weed-free plots gives the highest weed control efficiency.

Table 6: Interaction effect of weeding frequency and variety on Weed Control Efficiency (%)

Weeding Frequency	Varieties				Mean
	Utuba	Seftu	Jihur	Abedadry	
Weedy Check	0.00 ^{g}	0.00 ^{g}	0.00 ^{g}	0.00 ^{g}	0.0 ^{e}
Weeding once	40.72 ^{e}	40.61 ^{e}	38.21 ^{e}	39.30 ^{e}	37.2 ^{d}
Weeding twice	72.16 ^{d}	74.02 ^{d}	74.56 ^{cd}	80.59 ^{c}	75.3 ^{c}
Weeding thrice	94.43 ^{ab}	88.87 ^{b}	92.79 ^{b}	92.67 ^{b}	92.2 ^{b}
Weed Free	100.00 ^{a}	100.00 ^{a}	100.00 ^{a}	100.00 ^{a}	100.0 ^{a}
Mean	61.5 ^{a}	60.7 ^{a}	61.1 ^{a}	60.5 ^{a}	
HSD (0.05)	6.06				
CV (%)	3.2				

Means followed by the same letter within a row and column are not significantly different using Tukey's HSD test at $P<0.05$.

4.1.5. Weed Index

The analysis of variance indicated that weeding frequency, variety, and their interaction had a highly significant effect ($p < 0.001$) on weed index (Appendix Table 2). The highest weed index values were recorded under the weedy check treatment for all improved varieties, ranging from 58.17% to 59.43% (Table 7) indicating severe weed pressure when no control measures were applied. But Abedadary recorded a comparatively small weed index (47.76%) than other improved varieties.

This finding confirms that weed competition substantially limits crop performance when left unmanaged, consistent with previous findings that weed infestation can cause yield reductions of up to 70% in wheat Mengist et al. (2021). Complete weed control resulted in a zero weed index across all varieties, indicating total elimination of weed competition. This agrees with earlier studies reporting that frequent and timely weeding significantly minimizes weed density and biomass (Kebede & Kindie, 2024; Terefe et al., 2016).

Among the tested varieties, Abedadary consistently exhibited lower weed index values in one weeding and weedy check compared to the improved varieties, suggesting superior

competitive ability against weeds. This may be attributed to varietal characteristics such as rapid early growth, better canopy development, and efficient utilization of available resources. Similar observations were reported by Scavo et al. (2022) and Kumar et al. (2022) who noted that competitive varieties suppress weeds more effectively even under reduced weeding frequency.

Although all varieties benefited from increased weeding frequency, the magnitude of weed suppression varied among varieties. This highlights the importance of integrating appropriate weeding regimes with suitable varieties to achieve effective weed control and sustainable durum wheat production. The present findings support earlier reports that combining improved varieties with optimized weed management practices enhances weed suppression and overall crop performance (Kebede & Kindie, 2024; Mengist et al., 2021).

Table 7: Interaction effect of weeding frequency and variety on Weed Index (%)

Weeding Frequency	Varieties				Mean
	Utuba	Seftu	Jihur	Abedadry	
Weedy Check	59.43 ^{a}	58.17 ^{a}	58.91 ^{a}	47.76 ^{b}	56.07 ^{a}
Weeding once	19.44 ^{c}	22.08 ^{c}	19.09 ^{c}	13.09 ^{d}	18.43 ^{b}
Weeding twice	8.39 ^{def}	9.27 ^{de}	6.97 ^{efg}	5.21 ^{efgh}	7.46 ^{c}
Weeding thrice	2.90 ^{fgh}	3.13 ^{fgh}	2.76 ^{fgh}	1.31 ^{gh}	2.53 ^{d}
Weed Free	0.00 ^{h}	0.00 ^{h}	0.00 ^{h}	0.00 ^{h}	0.00 ^{e}
Mean	18.03 ^{a}	18.53 ^{a}	17.55 ^{a}	13.47 ^{b}	
HSD (0.05)	5.94				
CV (%)	11.33				

Means followed by the same letter within a row and column are not significantly different using Tukey's HSD test at P<0.05. NS = non-significant.

4.2. Phenological and Growth Parameters

4.2.1. Days to 50% Emergence

The analysis of variance indicated that the durum wheat variety had a highly significant effect ($P < 0.001$) on the days to emergence, whereas weeding frequency and its interaction did not show any significant effect (Appendix Table -1). This finding aligns with Ayana et al. (2021), who reported that weed does not affect the emergence of durum wheat. Abedadary exhibited the earliest emergence at 6.00 days, followed closely by Utuba at 6.47 days, while Seftu and Jihur required the longest duration at 7.00 and 6.93 days, respectively (Table-8). This variation is purely genetic and relates to the vigor of the seeds and the characteristics of the seed coats of the different varieties (Kebede & Kindie, 2024).

4.2.2. Days to 50% Heading

The analysis of variance indicated that the durum wheat variety had a highly significant effect ($P < 0.001$) on the days to flowering. In contrast, the frequency of weeding and the interaction of main factors did not exhibit a significant impact (Appendix Table-1). Abedadary took longer days to flower (91.0 days), compared to the improved varieties (Utuba, Seftu, and Jihur), which bloomed between 70.9, 72.13 and 72.6 days, respectively (Table-8).

Contrary to previous studies (Kebede & Kindie, 2024; Naruhn et al., 2021) this study's results showed that weeding frequency did not significantly influence phenological stages. This discrepancy can be attributed to the high water-use efficiency and abundant rainfall during the summer season in the study area, and weed competition for water is low. In the comparative studies conducted on irrigation, weed competition likely induced moisture stress, leading to altered days to heading. However, in this trial, the non-limiting moisture conditions allowed the varieties to express their inherent genetic potential for heading, independent of weed pressure. This idea is supported by Dabi et al. (2021), the phenology of durum wheat is primarily governed by moisture (water), next to genetic character. Under conditions of high rainfall or non-limiting moisture, the competitive effect of weeds on developmental duration (phenology) is often negligible (Singh et al., 2022).

4.2.3. Days to 90% Maturity

Maturity date was significantly affected by variety ($P < 0.001$) (Appendix Table 1). Jihur had the latest maturation (164.0 days), while Abedadary reached maturity the earliest at 153.3 days (Table 8), confirming farmers' preference for local varieties due to their early maturation. Weeding frequency did not affect the number of days to maturity of durum wheat.

Although some previous studies, Alemu et al. (2020) and Nigir et al. (2025) have reported significant effects of weeding frequency on days to maturity in wheat under irrigated conditions, this rainy-season trial did not. This is likely because moisture availability remains the primary environmental signal influencing the maturity date of durum wheat, and weed competition for water is negligible due to sufficient rainfall. Research has shown that under less water availability, weed competition for water is high and it alters wheat phenology by reducing plant lifespan and hastening senescence, causing earlier maturity, whereas adequate water supply stabilizes developmental timing (Mullualem et al., 2024; Singh et al., 2022).

Table 8: Phenological parameters of durum wheat varieties as influenced by weeding frequency.

Treatments	Days to 50% Emergence	Days to 50% Flowering	Days to 90% Maturity
Weeding Frequency			
Weedy Check	6.58	76.33	158.75
Weeding once	6.67	76.75	160.83
Weeding twice	6.67	76.75	158.75
Weeding thrice	6.58	76.67	161.25
Weed Free	6.50	76.83	161.67
HSD (0.05)	*NS*	*NS*	*NS*
Variety			
Utuba	6.47 [b]	70.93 [c]	162.00 [a]
Seftu	7.00 [a]	72.13 [b]	161.67 [a]

Jihur	6.93 [a]	72.60 [b]	164.00 [a]
Abedadary	6.00 [c]	91.00 [a]	153.33 [b]
Mean	6.6	76.7	160.25
HSD (0.05)	*0.29*	*0.49*	*2.82*
CV (%)	*4.42*	*0.65*	*1.79*

Means followed by the same letter within column are not significantly different using Tukey's HSD test at P<0.05. NS = non-significant.

4.2.4. Plant Height

Plant height was highly significantly (P < 0.001) influenced by variety but was not affected by weeding frequency and interaction (Appendix Table-3). Abedadary recorded the highest plant height (123.8 cm), while the shortest plant height was recorded on improved varieties (Utuba, Seftu, and Jihur), which ranged from 79.3 to 93.2 cm (Table 9). This confirms Abedadary as the local landrace, which is typically taller. This may be attributed to varietal characteristics such as genetic makeup and efficient utilization of available resources.

In contrast to the findings of Mengist et al. (2021), who reported a significant increase in plant height with increased weeding frequency, this study found no significant effect. This discrepancy is attributed to the specific environmental conditions of the Janamora district in 2025, where high soil moisture potentially minimized resource competition. This study strengthened by Tegenu et al. (2021) suggests that water is the second (next to genetic factor) primarily used for cell elongation and plant growth than other resources.

Table 9: Plant height of durum wheat varieties as influenced by weeding frequency.

Treatments	Plant Height (cm)
Weeding Frequency	
Weedy Check	96.45
Weeding once	97.05
Weeding twice	96.33
Weeding thrice	98.34

Weed Free	98.31
HSD (0.05)	*NS*
Variety	
Utuba	93.17 [b]
Seftu	92.98 [b]
Jihur	79.28 [c]
Abedadary	123.75 [a]
Mean	97.3
HSD (0.05)	*3.13*
CV (%)	*3.28*

Means followed by the same letter within a column are not significantly different using Tukey's HSD test at P<0.05. NS = non-significant.

4.3 Yield and Yield Components

4.3.1. Spike Length

The analysis of variance showed that spike length has a significant variation due to variety ($P < 0.001$) and weeding frequency ($P < 0.05$), however, not affected by their interaction (Appendix Table 3). Abedadary produced the longest spikes (7.43 cm), while Jihur produced the shortest (5.15 cm) (Table-10). This indicates that different durum wheat varieties have their own spike length governed by inherent genetic character. The same finding by Tegenu et al. (2021) noted that the spike length of durum wheat has high broad-sense heritability, frequently exceeding 60% and reaching as high as 72–99% in certain populations, and its height is governed by this heritable character.

Weeding frequency positively influenced spike length. The shortest spikes were recorded in the weedy check (5.82 cm), while twice-weeded and thrice-weeded plots produced significantly longer spikes (6.18 cm). This is because competition for water and nutrients is reduced with increasing weeding frequency and leads to increased spike length. Mulatu et al. (2024), support this study, noting that adequate resource availability in weed-free plots supports better cell elongation for spike development.

4.3.2. Number of Total and Effective Tillers

The analysis of variance showed that both total and effective tillers were highly significantly ($P < 0.001$) influenced by weeding frequency and variety, however, not affected by their interaction (Appendix Table 3). The lowest total and effective tiller numbers were recorded in the weedy check (2.7, 2.55), respectively, while the highest total and effective tiller numbers were recorded from twice, thrice, and weed-free treatments (Table-10).

Increasing weeding frequency from weedy check to one weeding (30 DAS) increases total and effective tillers by 21%. Increasing weeding frequency from weedy check to twice weeding (30 and 50 DAS) increases total and effective tiller by 30%, statistically the same as thrice weeding (30, 50, and 70 DAS) (31.2%) and weed free (34.7%). This is because the highest population of weeds in the early and critical period of weed-crop competition interferes with the tillering ability of the crop due to competition for resources.

This confirms Misganaw & Ayalew (2020), who stated that yield losses from weeds are primarily due to a reduction in tillering caused by early-season competition. Abedadary produced the highest number of total tillers (4.21) and effective tillers (4.00), significantly higher than the improved varieties Utuba, Seftu, and Jihur (3.15-3.29). This may be attributed to varietal characteristics such as genetic makeup, rapid early growth, and efficient utilization of available resources (Taranto et al., 2023).

Table 10: Yield and yield components of durum wheat varieties as influenced by weeding frequency.

Treatments	Spike Length (cm)	Total Tillers (No/plant)	Effective Tillers (No/plant)	Thousand Seed Weight (g)
Weeding Frequency				
Weedy Check	5.82 ^{b}	2.70 ^{c}	2.55 ^{c}	54.17
Weeding once	6.03^{ab}	3.42 ^{b}	3.22 ^{b}	53.33
Weeding twice	6.18 ^{a}	3.89 ^{a}	3.69 ^{a}	54.58

Weeding thrice	6.18 [a]	4.00 [a]	3.73 [a]	55.83
Weed Free	6.15[ab]	4.11 [a]	3.90 [a]	55.83
HSD (0.05)	*0.33*	*0.46*	*0.46*	*NS*
Variety				
Utuba	5.71 [b]	3.40 [b]	3.29 [b]	60.67 [a]
Seftu	5.99 [b]	3.59 [b]	3.23 [b]	58.67 [a]
Jihur	5.15 [c]	3.29 [b]	3.15 [b]	49.33 [b]
Abedadary	7.43 [a]	4.21 [a]	4.00 [a]	50.33 [b]
Mean	6.07	3.62	3.42	54.75
HSD (0.05)	*0.28*	*0.38*	*0.39*	*2.97*
CV (%)	*4.71*	*10.82*	*11.53*	*5.52*

Means followed by the same letter within a column are not significantly different using Tukey's HSD test at P<0.05. NS = non-significant.

4.3.3. Thousand Seed Weight

The analysis of variance showed that thousand seed weight was highly significantly ($P < 0.001$) affected by variety but not by weeding frequency and interaction (Appendix Table -4). Utuba and Seftu recorded the highest seed weight (60.67 g, and 58.67 g respectively) (Table-10), while Jihur and Abedadary produced significantly lighter seeds (49.33 g and 50.33 g respectively). The finding indicates that Utuba and Seftu have a better kernel filling trait than Abedadary and Jihur. This means that different durum wheat varieties have their own different thousand kernel weight governed by a genetic trait.

This finding aliens with Okbagabir et al. (2024), suggests that a variety with inherent stress tolerance and efficient grain-filling can better capitalize on resource availability, leading to improved seed weight**.** The seeds have a stable genetic trait, seed weight is less sensitive to weed stress (Kaur et al., 2021).

4.3.4. Above-Ground Biomass

The analysis of variance shows that the main effect of weeding frequency ($P < 0.01$) and its interaction with variety ($P < 0.001$) significantly affect above-ground biomass (Appendix Table 4). The highest biomass (16.13 t/ha) was gained from Utuba under thrice weeding (30, 50, and 70 DAS) (Table 11), which was statistically the same as weed-free plots, thrice and twice weeding of all varieties.

The lowest biomass yield was gained from Utuba (8.44t/ha) under weedy conditions. In contrast, Abedadary sustained a relatively higher biomass (11.55 t/ha) even in weedy conditions, demonstrating its stability under stress. The overall data showed that the biomass yield increased with increasing weeding frequency, and this supports the findings of Kebede & Kindie (2024) who stated that there was a considerable increase in above-ground biomass or biological yield when the frequency of weeding was raised from zero to one and from one to two weeding.

Table 11: Interaction effect of weeding frequency and variety on Above Ground Biomass (t/ha)

Weeding Frequency	Varieties				Mean
	Utuba	Seftu	Jihur	Abedadry	
Weedy Check	8.44^{f}	10.26^{ef}	9.88^{ef}	11.55^{de}	10.03^{c}
Weeding once	15.27^{ab}	12.75^{cd}	13.28^{bcd}	13.13^{bcd}	13.61^{b}
Weeding twice	15.47^{ab}	15.23^{ab}	14.53^{abc}	15.22^{ab}	15.11^{a}
Weeding thrice	16.13^{a}	15.31^{ab}	14.73^{abc}	16.05^{a}	15.55^{a}
Weed Free	15.65^{a}	15.79^{a}	15.04^{abc}	15.81^{a}	15.57^{a}
Mean	14.19^{ab}	13.87^{ab}	13.49^{b}	14.35^{a}	
HSD (0.05)	2.37				
CV (%)	5.47				

4.3.5. Grain Yield

Grain yield showed highly significant differences ($P < 0.001$) due to weeding frequency, variety, and their interaction (Appendix Table 4). The mean grain yield data showed that the highest grain yield (6.06 t/ha) was gained from the Utuba variety with weed-free conditions, which is statistically the same as other varieties in thrice (30, 50, and 70 DAS) and twice weeding (30 and 50 DAS) (Table 12). The lowest grain yield (2.07 t/ha) also obtained from Utuba with weedy check plots.

Under stress (Weedy check), the local variety Abedadary yielded better grain yield (4.30 t/ha), significantly outperforming the improved varieties (Utuba: 2.07 t/ha (51.8%); Seftu: 2.73 t/ha (36.5%); Jihur: 3.13 t/ha (27.2%)). The grain yield of Utuba increased by 65.8% with increasing of weeding frequency from weedy check to weed-free whereas Abedadary increased by 22.5%. This highlights that improved varieties like Jihur and Utuba require effective weed management to express their genetic potential, whereas the local variety is more resilient to poor management (Mengist et al., 2021).

Table 12: Interaction effect of weeding frequency and variety on Grain Yield (t/ha)

Weeding Frequency	Varieties				Mean
	Utuba	Seftu	Jihur	Abedadry	
Weedy Check	2.07 ^{f}	2.73 ^{ef}	3.13 ^{e}	4.30 ^{d}	3.06 ^{c}
Weeding once	4.76 ^{cd}	4.36 ^{d}	5.12 ^{abcd}	5.01 ^{bcd}	4.81 ^{b}
Weeding twice	5.51 ^{abc}	5.68 ^{abc}	5.85 ^{ab}	5.38 ^{abc}	5.61 ^{a}
Weeding thrice	5.93 ^{ab}	5.82 ^{ab}	5.98 ^{ab}	5.53 ^{abc}	5.81 ^{a}
Weed Free	6.06 ^{a}	5.97 ^{ab}	6.05 ^{a}	5.55 ^{abc}	5.91 ^{a}
Mean	4.86 ^{b}	4.91 ^{ab}	5.23 ^{a}	5.15 ^{ab}	
HSD (0.05)	1.01				
CV (%)	6.46				

4.3.6. Harvest Index

The analysis of variance indicated that the harvest index was significantly influenced by the frequency of weeding, the variety of the crop, and the interaction between these factors ($p < 0.01$) (Appendix Table 4). The highest harvest index values (40.65%) were observed from the interaction of Jihur with thrice weeding, which is statistically similar with all varieties across one weeding (30 DAS), twice weeding (30 and 50 DAS), and thrice weeding (30, 50 and 70 DAS) (Table 13). In contrast, Utuba under the weedy check produced the lowest harvest index value (24.53%), which is statistically the same as Seftu and Jihur, highlighting their sensitivity to weed competition.

This is because weeds compete with wheat for nitrogen during the grain filling stage, which forces the plant to invest its energy for survival rather than grain filling (Misgana et al., 2025). The finding indicates that harvest index improved by increasing weeding frequency from zero weeding to one weeding. This finding agrees with Mengist et al. (2021), who reported that timely weed removal is essential for achieving the biological potential of the crop. In contrast, Abedadary gives the highest harvest index (37.4%) under weedy check conditions compared to Utuba and Seftu in the same weedy environment. The finding indicates that durum wheat varieties have different weed competition responses, making their harvest index different even in the same weeding environment (Asadi et al., 2020).

Table 13: Interaction effect of weeding frequency and variety on Harvest Index (%)

Weeding Frequency	Varieties				Mean
	Utuba	Seftu	Jihur	Abedadry	
Weedy Check	24.53^{c}	26.56^{bc}	31.51^{abc}	37.40^{a}	30.00 ^{b}
Weeding once	31.24^{abc}	34.42^{ab}	38.73^{a}	38.16^{a}	35.64 ^{a}
Weeding twice	35.70^{ab}	37.52^{a}	40.26^{a}	35.41^{ab}	37.22 ^{a}
Weeding thrice	36.68^{a}	38.06^{a}	40.65^{a}	34.46^{ab}	37.46 ^{a}
Weed Free	38.68^{a}	38.09^{a}	40.18^{a}	35.14^{ab}	38.02 ^{a}

Mean	33.37 b	34.93 b	38.26 a	36.12 ab
HSD (0.05)	9.53			
CV (%)	*8.61*			

4.3.7. Relative Yield Loss

Relative Yield Loss was highly significantly ($P < 0.001$) affected by weeding frequency, variety, and their interaction (Appendix Table 4). The highest yield loss observed from the interaction of the improved varieties (Utuba, Seftu, and Jihur) (58.17-59.4%) under weedy conditions (Table 14), signifying their status as the most susceptible varieties. The lowest yield losses were also observed in Abedadary with thrice weeding (1.31%), which is statistically the same as all other varieties in thrice weeding and free weeding.

Conversely, Abedadary exhibited the least yield reduction (47.7%) in weedy environments and 13.09% under once weeding compared to the improved variety. This result showed that the local variety Abedadary is a weed competent and gives better yield under a weedy environment than the improved variety. This observation supports the hypothesis that indigenous varieties exhibit a greater resilience to weed competition, whereas improved varieties present a higher potential for yield maximization when subjected to proper management practices (Bogale, 2020).

Table 14: Interaction effect of weeding frequency and variety on Relative Yield Loss (%)

Weeding Frequency	Varieties				Mean
	Utuba	Seftu	Jihur	Abedadry	
Weedy Check	59.43 a	58.17 a	58.91 a	47.76 b	56.07 a
Weeding once	19.44 c	22.08 c	19.09 c	13.09 d	18.43 b
Weeding twice	8.39 def	9.27 de	6.97 efg	5.21 efgh	7.46 c
Weeding thrice	2.90 fgh	3.13 fgh	2.76 fgh	1.31 gh	2.53 d
Weed Free	0.00 h	0.00 h	0.00 h	0.00 h	0.00 e

Mean	18.03 [a]	18.53 [a]	17.55 [a]	13.47 [b]
HSD (0.05)	5.94			
CV (%)	11.33			

4.4. Correlation analysis of parameters

The Pearson correlation coefficients among various growth, yield, and weed-related parameters are presented in the lower triangular matrix (Table-16). The analysis revealed several significant relationships that elucidate the competitive dynamics among the crops and weed species, as well as the physiological basis for yield determination.

Spike length was strongly correlated with plant height ($r = 0.91^{***}$, $p < 0.001$) and days to 50% flowering ($r = 0.86^{***}$, $p < 0.001$). These associations show that the structural development of the crop is highly synchronized; taller plants generally supported longer spikes and required more time to transition to the reproductive phase.

The results highlight the deleterious impact of weed biomass on crop development. Weed dry weight had a significant negative correlation with the number of total tillers ($r = -0.75^{***}$, $p < 0.001$) and effective tillers ($r = -0.74^{***}$, $p < 0.001$). This suggests that increased weed pressure significantly reduced the crop's ability to produce and maintain productive tillers through competition for essential resources like light, nutrients, and moisture. Weed dry weight also had strong negative correlations with above-ground biomass ($r = -0.83^{***}$, $p < 0.001$). This reinforces to say that weed interference is a primary limiting factor for durum wheat productivity in the study environment.

Grain yield was found to be highly dependent on the accumulation of total biological mass and the efficiency of nutrient partitioning. According to correlation analysis of grain yield and yield components of durum wheat, grain yield was strongly and positively correlated with total number of tillers (0.71***), number of effective tillers (0.71***), spike length (0.73***), harvest index (0.8***), and dry biomass yield (0.89***) (Table 16). This implies

that, with the improvement in the value of these yield components, the grain yield of bread wheat can be further improved and vice versa. Hunde et al. (2021)also reported that the significant positive correlation of grain yield with number of effective tillers produced per plant, number of tillers produced per plant, aboveground dry biomass yield, and spike length.

The effectiveness of weed management strategies was validated by the correlation between weed control efficiency and yield parameters. Weed control efficiency was strongly and positively correlated with grain yield ($r = 0.85^{***}$, $p < 0.001$) and negatively correlated with relative yield loss ($r = -0.94^{***}$, $p < 0.001$). These suggest that as weed control efficiency increases, grain yield also increases and vice versa. The weed index also showed a strong negative correlation with grain yield ($r = -0.91^{***}$, $p < 0.001$), indicating that higher weed interference levels directly lead to predictable declines in durum wheat performance.

Table 15: The correlation between weed and durum wheat parameters in Janamora District in 2025

Parameter	PH	SL	TT	ET	WD	WDW	AGB	GY	TSW	HI	WCE	RYL
PH	1											
SL	0.91***	1										
TT	0.51***	0.55***	1									
ET	0.50***	0.56***	0.94***	1								
WD	-0.1	-0.2	-0.72***	-0.72***	1							
WDW	-0.14	-0.24	-0.75***	-0.74***	0.98***	1						
AGB	0.17	0.21	0.73***	0.71***	-0.81***	-0.83***	1					
GY	0.06	0.11	0.71***	0.71***	-0.84***	-0.87***	0.89***	1				
TSW	-0.15	-0.16	-0.04	-0.06	-0.13	-0.09	0.14	0	1			
HI	-0.07	0.01	0.45***	0.47***	-0.56***	-0.61***	0.45***	0.80***	-0.22	1		
WCE	0.03	0.14	0.68***	0.67***	-0.98***	-0.98***	0.83***	0.85***	0.13	0.55***	1	
RYL	-0.12	-0.22	-0.73***	-0.73***	0.93***	0.95***	-0.88***	-0.91***	-0.04	-0.65***	-0.94***	1

Where: PH= Plant height, SL=Spike length, TT=Total tiller, ET=Effective tiller, WD=Weed density, WDW=Weed dry weight, AGB=Above ground biomass, GY=Grain yield, TSW=Thousand seed weight, HI=Harvest index, WCE=Weed control efficiency, RYL=Relative yield los

4.5 Economic Analysis

The economic analysis was done using the partial budget procedure as described by (CLMMYT, 1988). Seed cost and labor cost for weeding was used for analysis. This analysis was performed in order to evaluate the economic feasibility of the treatments at the minimum rate of return of 50 to 100 % (CLMMYT, 1988). Seed yield and straw yield of durum wheat from experimental plots were adjusted downward by 10% for management and plot size differences to regulate the difference between the experimental yield and the yield that farmers could expect from the same treatment. Farm gate prices of durum wheat grain were ETB 80/kg and straw price ETB 3/kg of the average of one month from the time of crop harvesting, durum wheat seed price ETB 95/kg for improved and ETB 70/kg for local variety and labor cost for weeding ETB 500 per person per day were used for variable cost determination, while other input costs used as constant for all treatments.

The result of partial budget analysis indicated that the highest net benefit of ETB 386612.5/ha with a marginal rate of return 198.8% was obtained from Utuba combined with twice weeding. For variety Abedadary, one weeding resulted in the highest net benefit (361172 Birr/ha) with a marginal rate of return of 326%, and two weeding resulted in a net benefit (380400 Birr/ha) with a marginal rate of return of 153% (Table-15), indicating a profitable investment. Additionally weeding increased costs without corresponding yield benefits and was therefore dominated. Treatments with MRR < 100% are not acceptable, because investing one ETB credited less than one ETB.

Table 16: Partial budget analysis of variety and weeding frequency for durum wheat production at Janamora District in 2025.

Treatment	Grain Yield (t/ha)	Straw Yield (t/ha)	Adjusted Grain Yield (t/ha)	Adjusted Straw Yield(t/ha)	Gross Benefit (ETB/ha)	Variable Cost (ETB/ha)	Net Benefit (ETB/ha)	MRR (%)
W0V4	2.073333	6.368334	1.8659997	5.7315	329175	8750	320425	-
W0V1	2.725	7.533667	2.4525	6.7803	166474.5	11875	154599.5	D
W0V2	3.133333	6.75	2.8199997	6.075	216540.9	11875	204665.9	D
W0V3	4.3	7.25	3.87	6.525	243825	11875	231950	D
W1V4	4.758333	10.50833	4.2824997	9.4575	382422	21250	361172	325.976
W1V1	4.358333	8.391667	3.9224997	7.5525	370972.5	24375	346597.5	D
W1V2	5.116667	8.158333	4.6050003	7.3425	336457.5	24375	312082.5	D
W1V3	5.006667	8.126666	4.5060003	7.314	390427.5	24375	366052.5	156.176
W2V4	5.508333	9.958334	4.9574997	8.9625	414150	33750	380400	153.04
W2V1	5.683333	9.55	5.1149997	8.595	423487.5	36875	386612.5	198.8
W2V2	5.85	8.675	5.265	7.8075	434985	36875	398110	-
W2V3	5.383333	9.833334	4.8449997	8.85	444622.5	36875	407747.5	-
W3V4	5.925	10.20833	5.3325	9.1875	426217.5	40250	385967.5	D
W3V1	5.816667	9.491666	5.2350003	8.5425	454162.5	43375	410787.5	46.76923
W3V2	5.983333	8.741667	5.3849997	7.8675	444427.5	43375	401052.5	D
W3V3	5.525	10.525	4.9725	9.4725	454402.5	43375	411027.5	-
W4V4	6.058333	9.591667	5.4524997	8.6325	427297.5	45750	381547.5	D
W4V1	5.966667	9.825	5.3700003	8.8425	462097.5	48875	413222.5	39.90909
W4V2	6.05	8.991667	5.445	8.0925	456127.5	48875	407252.5	D
W4V3	5.55	10.25833	4.995	9.2325	459877.5	48875	411002.5	D

Where: W=Weeding, V=variety, D=Dominated treatment, MMR=Marginal rate of return

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The study was conducted to determine the effect of weeding frequency on the yield and yield components of different durum wheat varieties in Janamora District, North Gondar Zone. The results demonstrated that weed competition is a critical limiting factor for durum wheat production in the study area, with significant variations observed based on variety and management practices. *Spergula arvensis* and *Galinsoga parviflora* dominated the diverse weed flora that infested the experimental site.

According to the study, uncontrolled weed growth has serious repercussions, resulting in a relative yield loss of roughly 56.07% in the weedy check plots when compared to weed-free conditions. This demonstrates that efficient weed control is essential to the district's sustainable wheat production, not just a choice. Phenological and growth parameters were significantly influenced by both variety and weeding frequency, while days to emergence, flowering, and maturity were primarily governed by the genetic makeup of the varieties.

Under unweeded conditions, the improved varieties (Utuba, Seftu, and Jihur) were less successful in suppressing weed biomass than the local landrace, Abedadary, which demonstrated superior competitive ability against weeds due to its greater plant height and rapid early growth. The frequency of weeding had a linear effect on grain yield. Plots that were weed-free and those that were weeded three times produced the highest yields; however, statistically, the yield from two hand weeding was similar to the maximum potential yield. Under ideal weed control, the improved varieties Jihur and Utuba in particular showed great yield potential; however, under weed infestation, they suffered severe yield penalties. On the other hand, under weedy conditions, the local variety Abedadary outperformed improved varieties and demonstrated yield stability; however, under high-input management, it showed a lower response ceiling.

5.2. Recommendations

Based on the results derived from this study, the following recommendations are made for farmers, development agents, and researchers in Janamora District: Farmers should adopt a practice of hand weeding twice during the crop growing season to mitigate yield losses. The first weeding should be conducted at 30 days after sowing (DAS) and the second at 50 DAS. This frequency is statistically comparable to weed-free conditions and is economically viable.

It is advised that farmers cultivate the improved varieties Jihur or Utuba if they are capable of timely weeding (at least twice). When weed competition is eliminated, these cultivars have the highest yield potential (about 6.0 t/ha). Farmers with limited resources who struggle with labor shortages or are unable to ensure timely weeding should think about growing the local variety, Abedadary. When compared to the improved varieties, it showed better natural competitiveness against weeds and greater yield stability under stress.

The maximum grain yield of 5.68 t/ha and the highest net benefit of ETB 386612/ha with a marginal rate of return of 198.8% were recorded from variety Utuba combined with twice hand weeding. Therefore, variety Utuba and twice hand weeding is recommended for bread wheat production in Janamora district and similar agro-ecologies. However, this study was conducted during a single growing season at one location, Hand weeding was the only weed control method tested, and further studies at different locations for more than one cropping season should be considered to provide broader recommendations for durum wheat production.

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7. APPENDIX

Appendix-1 Analysis of variance (ANOVA) table of treatments of Phenological parameter

Factor	df	ED	FD	MD
Rep	2	0.02616^{ns}	5.62***	76.25***
Weed	4	0.08635^{ns}	0.46^{ns}	23.54*
Var	3	3.10105***	1377.02***	334.86***
weed : var	12	0.09197^{ns}	0.31^{ns}	4.65^{ns}
Error mean	38	0.0851	0.25	8.27
CV (%)		4.42	0.65	1.79

Appendix-2 Analysis of variance (ANOVA) table of treatments of Weed parameter

factor	df	WDB	WDA	WCE	WI	WFW	WDW
rep	2	52412**	4435^{ns}	0.6^{ns}	11.1^{ns}	0.00224*	0.00243**
weed	4	1577050***	2036533***	20958***	6353***	2.832***	0.96404***
var	3	17141^{ns}	11983**	2.7^{ns}	80.5***	0.0412***	0.01639***
weed : var	12	28031**	4271***	35.3***	16.8***	0.0130***	0.00406***
Error mean	38	8138	2279	3.8	3.7	0.00047	0.00032
CV (%)		13.96	12.18	3.2	11.33	4.34	6.75

Appendix-3 Analysis of variance (ANOVA) table of treatments of Growth parameter

	df	PH	SL	TT	ET
rep	2	56.2**	0.4095*	0.5732*	0.2207
weed	4	11.5^{ns}	0.2894*	4.0331***	3.6018***
var	3	5301***	14.2269***	2.5411***	2.3006***
weed : var	12	3.4^{ns}	0.0534^{ns}	0.1288^{ns}	0.1667^{ns}
Error mean	38	10.2	0.0818	0.1537	0.1552
CV (%)		3.8	4.7	10.8	11.5

Appendix-4 Analysis of variance (ANOVA) table of treatments of Yield parameter

	df	TSW	HI	RYL	GY	AGB
rep	2	1.25^{ns}	0.062^{ns}	11.1^{ns}	2.153***	17.513***
weed	4	14.17^{ns}	129.88***	6353***	16.95***	66.025**
var	3	495.97***	63.95***	80.5***	0.476**	2.177*
weed : var	12	14.72^{ns}	30.02**	16.8***	0.73***	2.19***
Error mean	38	9.14	9.423	3.7	0.1061	0.585
CV (%)		5.5	8.6	11.33	6.46	5.47

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

'***' (Highly significant at 0.001) '**' (Highly significant at 0.01) '*' (significant at 0.05), ' ns' (Nonsignificant)

Note: ED=Emergence Date, FD=Flowering Date, MD=Maturity Date, PH=Plant height, SL= Spike Length, TT=Total Tiller, ET=Effective Tiller, WDB= Weed Density before one hand weeding, WDA= Weed Density before 15 days to harvest, WFW=Weed fresh weight, WDW =Weed dry weight, WCE=Weed control efficiency, WI=Weed index, TSW=Thousand Seed Weight, HI=Harvest Index, RYL=Relative Yield Loss, GY=Grain Yield, AGB=Above Grou nd Biomass,