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Impact of Growing Conditions on Growth Performance of Improved Lentil (*Lens culinaris* Medikus) Genotypes

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Abstract: The study aimed to identify the most well-adapted lentil genotype and select key physiological traits with strong performance using a randomized complete block design with three replicates. The analysis revealed highly significant differences ($P < 0.001$) among genotypes for biomass yield (t ha^{-1}) at both the Debre Zeit and Akaki sub-stations. In terms of maturation, Beredu was the earliest, reaching readiness at 92 days, while Challew took a prolonged 134 days to reach its peak potential at Debre Zeit. The 42-day difference between these two genotypes highlights the significant diversity in growth rates. At Debre Zeit, the genotypes R-186 (6.76 t ha^{-1}), Derash (6.83 t ha^{-1}), Dz2012-Ln0050 (6.39 t ha^{-1}), and ILL-1760 (6.89 t ha^{-1}) had the highest biomass yields, while at Akaki, X-125-54 (6.3 t ha^{-1}), R-186 (7.37 t ha^{-1}), Derash (5.9 t ha^{-1}), and Dz2012-Ln0050 (5.97 t ha^{-1}) performed best. The highest seed yields were recorded for Derash (2.69 t ha^{-1}), R-186 (2.74 t ha^{-1}), and Dz2012-Ln0050 (2.83 t ha^{-1}) at Debre Zeit, and for R-186 (3.41 t ha^{-1}), Derash (2.71 t ha^{-1}), and Dz2012-Ln0050 (2.82 t ha^{-1}) at Akaki. The results indicated that 20 improved lentil genotypes, planted under warmer temperatures and increased rainfall, contributed to higher yields. Correlation coefficients among all traits were highly significant, with both positive and negative values. At the Debre Zeit station, days to 50% flowering were positively correlated with days to 50% emergence ($r = 0.87$). Biomass yield had the greatest positive direct effect on seed yield ($r = 0.91$).

Keywords: agronomic, genetic, variance, trait, yield.

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1. Introduction

The lentil (*Lens culinaris* Medikus) is a diploid legume ($2n = 14$) with a large genome of 4063 Mbp, is phylogenetically nested within the tribe Vicieae, and belongs to the Papilionoideae subfamily of the Fabaceae family (Schaefer et al., 2012). Due to its low cultivation costs, it could become an excellent option for crop diversification, utilizing marginal soils that would otherwise be left unused in agriculture (Cardenas et al., 2014). Regarding nutritional aspects, lentils contain proteins, carbohydrates, oils, and ash in proportions of 23%, 59%, 1.8%, and 0.2%, respectively, and provide

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iron, calcium, phosphorus, magnesium, vitamin A, and vitamin B (Zafar et al., 2003). Furthermore, worldwide lentil production has increased annually to an estimated 5.6 million hectares (FAOSTAT, 2023). Lentils are vital in the diets of low-income populations in developing countries, serving as a substitute for animal proteins (Zhang et al., 2018). Another characteristic of legumes is their ability to fix atmospheric nitrogen (N2) through symbiosis with bacteria called rhizobia, which form specialized structures known as nodules, benefiting growth in soils with low N2 content (Andrews et al, 2013). Lentils are globally important as a versatile food source, providing essential protein and nutrients while also improving soil through nitrogen fixation. In Ethiopia, they are a key cool-season crop, providing essential nutrition for the population, a major income source for farmers, livestock feed, and enhancing export earnings and overall food security. Lentils thrive in various soil types, from sandy to clay loam, if there is good drainage. A soil pH of 6-8 supports lentil growth, although it can tolerate moderate alkalinity (Mulugeta, 2009).

The crop is cultivated at altitudes between 1700 and 2400 meters above sea level, with annual rainfall ranging from 700 to 2000 mm in Ethiopia. Optimal germination occurs at temperatures above freezing, ideally between 18-21°C, while temperatures above 27°C can damage the crop (Mulugeta, 2009). Incorporating conventional fallow and shallow-rooting pulse crops, such as lentil (*Lens culinaris* Medikus), into oilseed-cereal cropping systems has been shown to reduce dry conditions in the semi-arid Canadian prairies (Gan et al., 2017). Including lentil in crop rotation not only boosts system productivity but also decreases yield variability in oilseed-cereal systems under changing environmental conditions (Kui et al., 2019).

The lentil crop is subjected to several biotic and abiotic stresses that limit its production. Lentil is primarily grown in the highlands of Ethiopia, where rainfall is typically high. However, it is highly susceptible to moisture stress and sensitive to waterlogging, with even short exposure potentially causing complete crop failure (Jarso et al., 2009). Lentil varieties currently cultivated have a narrow genetic base due to domestication, which limits the prospects for further adaptation of lentils to changing climatic conditions (Singh, 2014). The demand for lentils and their prices have steadily increased in recent years, highlighting the need to boost production for both domestic and export markets in Ethiopia (Abraham, 2015). Lentil is a cash crop that fetches the highest price in the domestic market compared to other food legumes and major cereal crops. However, lentil production faces challenges due to global climate change, which has introduced several obstacles, although there are limited findings on this issue. Although some studies have focused on the performance of advanced lentil genotypes, cultivation remains confined to only a handful of regions. The goal of improving lentil genetics is to bolster not only the consistent yield of the crop but also its resilience to stress and the quality of its seeds. Consequently, these research endeavors are designed to assess how well the released genotypes adapt and maintain stability across two locations.

2. Materials and Methods

Description of the Experimental Site

A field experiment was conducted during the 2021/2022 main growing season at two locations: Debre Zeit Station (Dz) and Akaki sub-station (Ak).

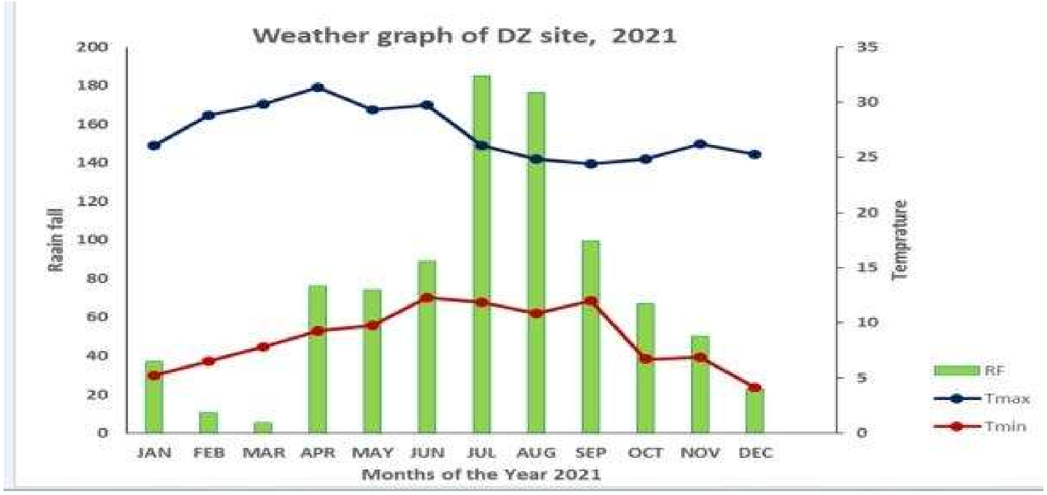

Figure 1: Temperature and rainfall distribution pattern at Dz station in the year 2021.

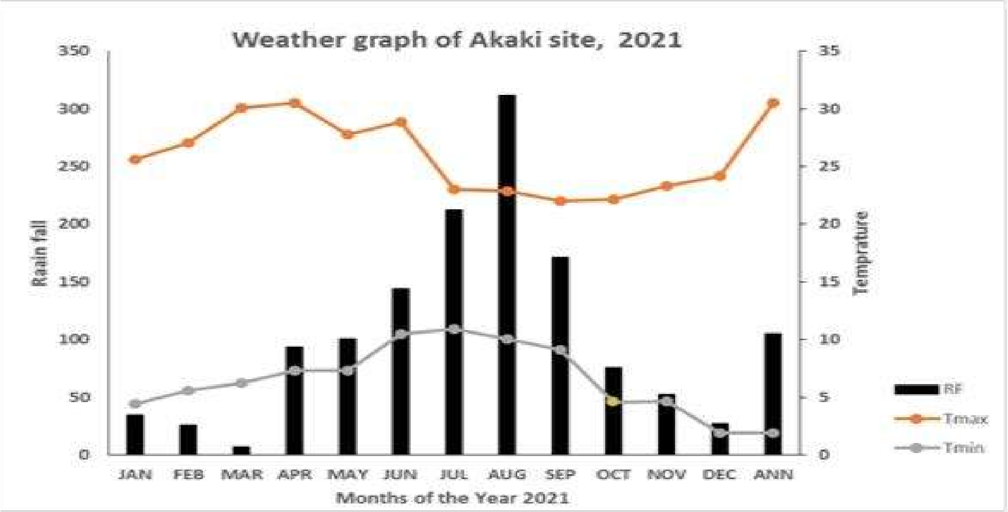

Figure 2: Temperature and rainfall distribution patterns at the Akaki sub-station in 2021.

Dz is 50km from Addis Ababa, within the East Shewa Zone in the Oromia region, at an elevation of 1,920 masl. The soil at Dz is classified as vertisols, known for their clay texture and swelling-shrinking properties. Rainfall at Dz was recorded at 7mm in March and 180mm in July; the maximum and minimum temperatures ranged from 4 °C in December to 13 °C in April (Figure 1). Ak is located 27km southeast of Addis Ababa. Ak is a highland area at 2200 meters above sea level (masl). Rainfall at the Ak sub-station ranged from about 15mm in March to 320mm in August; temperatures were also lower, from 10°C in December up to 32°C in April (Figure 2). Before sowing, the land was plowed, harrowed, and leveled.

Experimental Materials and Design

This study evaluated twenty improved lentil genotypes, including Adda (FLIP 86-14L), 94-003L, R-186, ILL-1760, 96006L-984005, Alemtena (FLIP 96-49L), Chekol (ENAL-2704), Alemaya (FLIP 89-63L), Dz-2012-Ln-238, Gudo (FLIP 84-78L), ILL-2178, X-125-54, 09583227-04, Jiru, Beredu, Challew (NEL 358), Dz2012-Ln0050, ELL-142, Teshale (FLIP 96-46L), and Derash. The experiment was conducted during the main cropping season on August 12, 2021, at Dz Station and August 13, 2021, at Ak Substation using a Randomized Complete Block Design (RCBD) (Gomez & Gomez, 1984). Each experimental plot consisted of four rows, measuring 1.2 meters in length and 0.8 meters in width, covering a total plot area of 2.4m². The row spacing was 0.2 meters, with 0.4 meters between plots and 1.5 meters between blocks to minimize inter-plot interference (Steel et al., 1997). Seeds were sown manually using hand-drilling at a depth of 3–5 cm, with a seeding rate of 200 seeds/m². Seedling emergence began 4 to 6 days after sowing, with 80–90% of seedlings emerging within 10–12 days (Erskine et al., 2011). The crop was harvested between late November and mid-December, with pre-harvest observations recorded for days to 50% emergence, days to 50% flowering, and maturity time. The net harvested area per plot was 2.4 m², and key post-harvest traits recorded included seed yield, thousand-seed weight, and biological yield (t ha^{-1}).

Data was recorded

Phenology and Growth Parameters: The days to 50% flowering (when at least one open flower appeared on 50% of plants) and physiological maturity (when 90% of plants turned golden brown with fully developed pods) were recorded (Sarker & Erskine, 2006). The reproductive growth period was defined as the interval from 50% flowering to physiological maturity.

Yield and Yield Components: - At maturity, plants were harvested by cutting them at ground level. Seeds were separated from the straw by hand threshing, and the seed yield was measured. Seed size was determined by weighing a sample of 100 seeds (Kumar et al., 2013).

Data Analysis

Data collected from the RCBD experiment were analyzed using ANOVA (R software version 4.1.2). Significant differences among means were determined using Tukey’s test at a 5% significance level (Montgomery, 2020). To ensure statistical validity, the variance ratio test for homogeneity of variance was also conducted (Gomez & Gomez, 1984).

3. Results and Discussion

Importance of Variation among Yield and Yield-Related Traits

The effects of twenty improved lentil genotypes were evaluated based on biomass yield, days to 50% emergence, days to 50% flowering, maturity, and thousand-seed weight. Significant differences were observed in lentil yield and related traits. At the Dz station, an analysis of variance revealed highly significant differences among genotypes ($p < 0.001$) for nearly all measured traits. Notable differences ($p < 0.001$) were specifically found in biomass yield (t ha^{-1}), days to 50% emergence, days to 50% flowering, maturity at 90%, seed yield per plot, and thousand-seed weight.

Table 1: Mean square value for Biomass (**Bio(t/ha)**, Number of seed per plant (**Ns/p)**, Plant height [**PtH(cm)]**, days 50% emerge (**Day 50%E)**, days 50% flower (**Day 50% F)**, days to 90% maturity (**MtY)**, seed yield per plant (**Sy/Pt)**, and thousand seed weight (TSW) at Dz station.

Source	Df	Bio(t/ha)	Ns/pt	PtH(cm)	Day 50%E	Day 50% F	MtY	Sy/Pt	TSW
Genotype	**19**	337465***	101.37*	183.69**	8.13***	24.61***	1824***	22915***	0.95***
Replication	**2**	35490	235.62	14.19	3.6	0.62	30.47	2876.8	0.02
Error	**38**	55460	41.56	15.05	1.33	1.89	17.78	1568	0.11

F-value	**-**	6.0849	2.44	12.21	6.09	12.97	102.55	14.61	8.83
P-value	**-**	<0.001	0.05	0.01	<0.001	<0.001	<0.001	0.001	0.001

Note: *, **, and *** denote significant difference at P<0.05, P<0.01, and P<0.001, respectively. NS = non-significant difference.

Additionally, plant height (cm) varied significantly ($p < 0.01$) among genotypes. There were also significant differences ($p < 0.05$) in the number of seeds produced per plant across the different genotypes, as shown in Table 1. It's fascinating to note that the Ak sub-station exhibited some significant differences ($p < 0.05$) in genotypes based on thousand-seed weight. However, that's not all; even more notable were the highly significant differences ($p < 0.001$) found in several key measures: biomass yield (t ha^{-1}), days to reach 50% flowering, days to 90% maturity, seed yield per plot, the number of seeds per plant, and the overall height of the plants (cm). The analysis of days to 50% emergence showed significant differences ($p < 0.01$) at the Dz station but not at the Ak sub-station (Table 2).

Table 2: Mean square value for Biomass (**Bio(t/ha)**, Number of seed per plant (**Ns/p)**, Plant height [**PtH(cm)]**, days 50% emerge (**Day 50%E)**, days 50% flower (**Day 50% F)**, days to 90% maturity (**MtY)**, seed yield per plant (**Sy/Pt)**, and thousand seed weight (TSW) at Akaki sub-station.

Source	Df	Bio(t/ha)	Ns/pt	PtH(cm)	Day 50%F	Day 50% E	MtY	Sy/Pt	TSW
Genotype	**19**	470463***	2887.2**	71.23***	98.28***	24.61	158.8***	28928.0***	2.43*
Replication	**2**	208792	1490.6^{ns}	13.74^{ns}	9.02^{ns}	0.62^{ns}	6.72^{ns}	1010.60^{ns}	1.42^{ns}
Error	**38**	48002	1008.3	6.04	11.19	1.89	47.42	824.30	1.21
F-value	**-**	9.80	2.90	11.78	8.78	12.97	3.35	35.09	2.00
P-value	**-**	<0.001	0.01	<0.001	<0.001	>0.05	<0.001	0.001	0.05

Note: *, ** and *** denote significant differences at P<0.05 P<0.01, and P<0.001 respectively. ns = non-significant difference.

The seed yield is affected by a complex interaction of various factors, and significant variation ($p < 0.01$) was observed among different genotypes. This difference arises from inherent genotypic variations. Other studies support these findings; different varieties showed noticeable differences ($p \leq 0.05$) in the time to flower, while even more significant variations ($p \leq 0.01$) were found across varieties in plant height, the number of pods per plant, grain yield, and the weight of a thousand seeds (Yirga and Zinabu, 2018). Similarly, Mondal et al. (2007) emphasized important differences among lentil accessions, including days to first flowering and maturity, plant height, the number of branches, pods per plant, seeds per pod, thousand-seed weight, and seed yield per plant, although plant height and the number of branches showed less variation. These findings align with those reported by Dugassa et al. (2015).

Genotypic Variation of Yield and Yield-Related Traits

Evaluation of days to 50% emergence, days to 90% maturity, and 50% flower

Assessing the emergence of lentil genotypes reveals an interesting picture. At the Dz research station, two genotypes, Chekol and Jiru, stood out by taking a notable 12 days to emerge. In contrast, the Beredu genotype was slower, emerging in just 7 days. At the Ak sub-station, Alemaya, ILL-2178, and

ELL-142 had the highest emergence times (11.33 days), while 96006L-984005 had the lowest (9.33 days).

When we take a closer look at how different genotypes measure up in terms of reaching 90% physiological maturity, it turns out that lentils grown from the Beredu genotype really stand out. They matured a full day earlier at the Dz station compared to their counterparts at the Ak sub-station (as illustrated in Table 3). Isn't it interesting how location can influence growth times like this? The increased or decreased temperature and rainfall may be playing a significant role here. The average days to flowering ranged from 40 to 70 days across two different locations. This study's findings differ from those of Erskine (1983), who reported days to flower ranging from 118 to 162 days, and Yasin (2015), who observed a range of 65 to 72 days. Regarding the number of days to reach the critical 50% flowering point, the Dz station revealed some interesting results. Among the varieties, ILL-1760, R-186, ILL-2178, Challew, and Chekol all had the longest blooming periods, taking about 50 days to flower. In contrast, Beredu completed its cycle in just 40 days, significantly shorter than the 90 days required by the others. At the Ak substation, the standout was genotype 09583227-04, which stayed in the flowering phase for an impressive 70.6 days. Meanwhile, 96006L-984005 and Beredu finished in 47 and 48 days, respectively.

Table 3: Mean Values of genotypes on Maturity, days to 50% Emergence, and days to 50% Flower at Debre Zeit station (Dz) and Akaki sub-station (Ak) in 2020/21 cropping season.

Treatment	**Maturity**		**Day to 50% Emergence**		**Day to 50% flower**	
	Dz	**Ak**	**Dz**	**Ak**	**Dz**	**Ak**
ILL-1760	112.00^{ab}	111.00^{abc}	11.00^{abc}	10.67^{abc}	50.00^{a}	64.66^{b}
Derash	103.33^{cd}	98.00^{def}	9.33^{cde}	11.00^{ab}	44.33^{f}	55.00^{d-g}
R-186	108.67^{abc}	107.30^{a-e}	10.67^{abc}	11.00^{ab}	50.00^{a}	62.30^{bc}
Dz2012-Ln0050	101.67^{de}	94.30^{f}	8.00^{ef}	9.67^{bc}	44.66^{ef}	53.60^{efg}
09583227-04	112.00^{ab}	115.00^{a}	10.67^{abc}	11.00^{ab}	49.00^{ab}	70.60^{a}
Adda	111.33^{ab}	113.66^{ab}	10.00^{bcd}	9.66^{bc}	47.00^{bcd}	54.30^{efg}
94-003L	107.33^{a-d}	96.30^{ef}	8.33^{def}	10.33^{abc}	45.66^{def}	55.00^{d-g}
X-125-54	107.66^{a-d}	96.30^{ef}	7.67^{ef}	10.67^{abc}	44.00^{f}	52.60^{fgh}
Alemaya	110.67^{ab}	110.00^{abc}	9.33^{cde}	11.33^{a}	45.33^{def}	53.00^{e-h}
Ln-238	103.00^{cd}	96.66^{ef}	8.00^{ef}	11.00^{ab}	44.00^{f}	53.00^{e-h}
ILL-2178	106.33^{bcd}	104.00^{a-f}	11.67^{ab}	11.33^{a}	50.00^{a}	64.00^{b}
96006L-984005	102.00^{cd}	93.00^{f}	8.33^{def}	9.33^{c}	44.33^{f}	47.00^{i}
Callew	133.67^{a}	108.66^{a-d}	11.67^{ab}	9.66^{bc}	50.00^{a}	57.00^{c-f}
Gudo	111.33^{ab}	112.00^{ab}	8.00^{ef}	10.00^{abc}	44.67^{ef}	51.30^{ghi}
Jiru	111.67^{ab}	103.30^{b-f}	12.00^{a}	10.67^{abc}	49.00^{ab}	56.60^{d-g}
Beredu	91.67^{f}	92.66^{f}	7.00^{f}	10.00^{abc}	40.00^{g}	48.00^{hi}
ELL-142	95.00^{ef}	100.00^{c-f}	10.67^{abc}	11.33^{a}	48.66^{abc}	55.67^{d-g}
Alemtena	111.33^{ab}	98.30^{def}	8.33^{def}	10.66^{abc}	46.66^{cde}	58.33^{cde}
Teshale	112.00^{ab}	103.00^{b-f}	11.33^{ab}	9.66^{bc}	49.00^{ab}	56.00^{d-g}
Chekol	93.00^{ef}	96.60^{ef}	12.00^{a}	10.33^{abc}	50.00^{a}	60.33^{bcd}
Mean	**101.633**	**102.51**	**9.7**	**10.4666**	**46.81**	**56.433**
CV	**4.14**	**6.71**	**11.9**	**9.19**	**2.94**	**5.93**
LSD	**6.97**	**11.38**	**1.9**	**1.59**	**2.27**	**5.53**

Note: the same letter in some columns is not significantly different.

This rich tapestry of data reminds us that the journey to flowering can vary significantly among different genotypes, a point also highlighted by Darai et al. (2017). Moreover, uncovered a fascinating insight: it appears that temperature wields a significantly greater influence over the timing of flowering in lentils than does the duration of daylight. In a similar vein, those soaring temperatures have a sneaky way of impacting chickpeas, leading to a lower pod set. Well, it turns out that heat tends to diminish both the viability of the pollen and the amount of pollen each flower produces (Devasirvatham et al., 2012). Stigma receptivity can also be affected at very high temperatures (≥ 40/30°C), leading to failure of fertilization (Kumar et al., 2012).

Evaluation of Yield at Debre Zeit Station and Ak Sub-station

As seen from Table 4, R-186(6.76t ha^{-1}), Derash(6.83t ha^{-1}), Dz2012-Ln0050(6.39t ha^{-1}) and ILL-1760(6.89t ha^{-1}) had the highest biomass yield at Dz station, while X-125-54(6.3t ha^{-1}), R-186(7.37t ha^{-1}), Derash(5.9t ha^{-1}), Dz2012-Ln0050(5.97t ha^{-1}) had the highest yield at Ak sub-station. Compared to the other examined kinds, these values were noticeably higher. The difference in biomass yield across locations suggests that abiotic factors play a crucial role in genotype performance. Among the tested genotypes, Chekol demonstrated the minimum biomass yield at both stations. The overall results indicated that the variation in biomass yield may be attributed to both genotypic differences and the combined effects of abiotic/biotic influences. The highest seed yields were noted for the genotype Derash (2.69t ha^{-1}), R-186 (2.74t ha^{-1}), and Dz2012-Ln0050 (2.83t ha^{-1}) at Dz Station. At Ak Sub-station, the top yields came from R-186 (3.41t ha^{-1}), Derash (2.71t ha^{-1}), and Dz2012-Ln0050 (2.82t ha^{-1}). The observed yield variations underscore the production potential of the study areas (Geja, 2019). Yasine (2015) also reported that grain yield had a wide variation (from 943.6 to 1239 kg ha^{-1}) in tested lentil materials. At Dz Station, Teshale (14g), Jiru (13.6g), and Beredu (13.7g) stood out with the highest thousand-seed weight. Meanwhile, at Ak Sub-station, something interesting happened: both Beredu and Teshale shared the spotlight, each weighing 13.6 grams. However, the lowest thousand-seed weight was recorded for Chekol at Ak Sub-station (11.26 g) and Dz Station (11.3g). Significant differences among genotypes might be due to inherent genetic potential and existing conditions. The result is consistent with the findings of Yasine (2015); Yirga and Zinabu (2018).

Correlation between Yield and other related traits at Dz

Significant positive correlations were found between some yield-related features using correlation analysis (Table 5). For example, a significant positive connection (r = 0.87) between days to 50% flowering and days to 50% emergence. Plant height (r = 0.75), root length (r = 0.7), and seed yield (r = 0.73) also showed a substantial positive connection with biomass, suggesting that these traits are selection criteria for high-yielding genotypes under typical circumstances. Additionally, it demonstrates unequivocally how plant height and root length directly affect seed yield. These outcomes are consistent with research published by Malhotra et al. (2004).

Table 4: Mean Value of genotypes on thousand seed weight (TSW), seed yield(ton/hectare), and Biomass(ton/hectare) at Dz and Ak in the 2020/21 cropping season.

Genotype	**Biomass(ton/hectare)**		**TSW (gm)**		**Seed Yield(ton/hectare)**	
	Dz	**Ak**	**Dz**	**Ak**	**Dz**	**Ak**
ILL-1760	6.89^{a}	3.7^{efg}	12.0^{b}	12.45^{def}	1.67^{cd}	1.35^{ef}
Derash	6.83^{ab}	5.933^{abc}	13.0^{b}	12.88^{d}	2.69^{ab}	2.71^{b}
R-186	6.76^{ab}	7.37^{a}	12.6^{b}	12.62^{def}	2.74^{ab}	3.41^{a}
Dz2012-Ln0050	6.39^{abc}	5.97^{abc}	13.0^{b}	13.00^{bcd}	2.83^{a}	2.82^{b}
09583227-04	5.897^{a-d}	4.83^{b-f}	12.0^{c}	12.15^{ef}	0.73^{gh}	0.89^{fg}
Adda	5.85^{a-d}	5.43^{bcd}	13.0^{b}	12.96^{cd}	0.95^{fgh}	1.73^{de}
94-003L	5.34^{a-e}	5.8^{bc}	13.0^{b}	12.88^{d}	1.73^{cd}	2.37^{bc}
X-125-54	4.98^{b-f}	6.3^{ab}	13.0^{b}	12.92^{cd}	1.85^{cd}	2.03^{cd}
Alemaya	4.75^{c-f}	5.2^{b-e}	13.0^{b}	12.94^{cd}	1.43^{def}	0.94^{fg}
Ln-238	4.69^{c-f}	5.6^{bcd}	13.0^{b}	12.76^{d}	1.51^{de}	2.12^{cd}
ILL-2178	4.49^{d-g}	4.53^{c-f}	12.7^{b}	12.49^{def}	1.08^{efg}	1.79^{de}
96006L-984005	4.17^{d-h}	2.97^{gh}	12.7^{b}	12.61^{def}	1.66^{cd}	0.87^{g}
Callew	4.17^{d-h}	1.87^{hij}	12.7^{b}	12.67^{de}	0.49^{hi}	0.699^{gh}
Gudo	4.09^{d-g}	3.33^{fgh}	13.0^{b}	12.65^{def}	0.74^{gh}	0.72^{gh}
Jiru	3.61^{e-i}	2.13^{hij}	13.6^{a}	13.49^{abc}	0.58^{hi}	0.54^{ghi}
Beredu	3.36^{f-i}	4.2^{d-g}	13.7^{a}	13.58^{ab}	2.12^{bc}	2.05^{cd}
ELL-142	2.61^{g-j}	2.7^{ghi}	12.0^{c}	12.07^{f}	0.16^{ij}	0.21^{ij}
Alemtena	2.59^{hij}	1.2^{ij}	12.6^{b}	12.84^{d}	0.84^{def}	0.34^{hij}
Teshale	1.97^{ij}	2.97^{gh}	14.0^{a}	13.63^{a}	0.23^{ij}	0.33^{hij}
Chekol	0.78^{j}	1.03^{j}	11.3^{d}	11.27^{g}	0.03^{j}	0.03^{j}
Mean	**4.51**	**4.15**	**2.80**	**2.743**	**1.3**	**1.4**
CV	**25.31**	**22.72**	**13.98**	**12.92**	**30.67**	**20.52**
LSD	**0.188**	**0.156**	**0.0065**	**0.587**	**65.45**	**47.45**

Note: Some letters in the same column are not significantly different from each other.

Table 5: Pearson correlation coefficient on yield and yield-related traits in Lentil at Dz station (Dz).

E	**F**	**M**	**BioY**	**S/Y**	**PtH**	**RtL**	**Ns/Pt**	**Pn/Pt**	
1	0.87***	-0.19^{ns}	-0.12^{ns}	-0.54*	-0.14^{ns}	-0.28^{ns}	0.0095^{ns}	0.17^{ns}	**E**
	1	0.027^{ns}	0.014^{ns}	-0.43^{ns}	-0.035^{ns}	-0.079^{ns}	0.24^{ns}	0.34^{ns}	**F**
		1	0.21^{ns}	0.28^{ns}	0.36^{ns}	0.38^{ns}	0.52*	0.44^{ns}	**M**
			1	0.73***	0.75***	0.70***	0.61**	0.33^{ns}	**Bio/Y**
				1	0.41^{ns}	0.56*	0.58**	0.21^{ns}	**S/Y**
					1	0.79***	0.41^{ns}	0.26^{ns}	**PtH**
						1	0.43^{ns}	0.35^{ns}	**RtL**
							1	0.79***	**Ns/Pt**
								1	**Pn/Pt**

E= days to 50% emerge, F= days to 50% flower, M= above 90% of the plant Mature, BioY=Biomass yield, S/Y= Seed Yield, PtH=plant height, RtL= Root length, Ns/pt= number of seed per plant, Pn/Pt=pod number per plant: ***,** and * Significant at the 0.001, 0.01 and 0.05 levels, respectively. ns= non-significant.

Additionally, the number of pods per plant was positively correlated with the number of seeds per plant (r = 0.79). The number of seeds per plant and pod number per plant were also positively correlated, reinforcing the significance of pod number as an essential selection criterion in breeding programs, as previously reported by Erskine et al. (1989). Additionally, Babayeva et al. (2018) covered a compelling and positive link between the weight of seeds per plant, the number of seeds, and the number of pods each plant produces in lentils. This relationship was further corroborated by earlier findings from Babayeva et al. (2014), hinting at a consistent trend worth exploring in greater detail.

Conversely, a negative and non-significant correlation was observed between days to 50% emergence, maturity (r = -0.19), biomass yield (r = -0.12), plant height (r = -0.14), and root length (r = -0.28). Days to 50% flowering also had a weak negative correlation with seed yield (r = -0.43), plant height (r = -0.035), and root length (r = -0.079). A weak, non-significant negative association was also seen with biomass yield. Eissa et al. (1987) found that days to first and mid-flowering were negatively correlated with seed yield per plant, pods per plant, and harvest index in foreign entries. While seed yield per plot was positively correlated with all traits except days to 50% emergence and flowering, a significantly positive association with yield would improve the productivity of Lentil crops. Previous studies have reported that many correlation coefficients between yield and yield components in lentils were found to be insignificant (Manggoel et al.,2012).

Correlation between yield and other related traits at Ak Sub-Station

The correlation analysis of different growth parameters and seed yield-contributing traits during the main cropping season indicated a statistically significant positive correlation ($p < 0.05$) between some characteristics and yield. Days to 50% flowering showed a positive correlation with days to 50% emergence, while a negative correlation was observed with the number of primary branches ($p < 0.05$, r = -0.49). The number of days until 50% bloom revealed a strongly significant negative correlation with nearly all the factors examined, except for days to maturity, which stood out with a correlation of r = 0.768. This stark contrast even echoes what Abo Hegazy and colleagues found back in 2012. The correlation coefficient values ranged between -0.54 and 0.91. A significant positive association (r = 0.91) was found between biomass yield and seed yield. Biological yield, as highlighted by Kumar et al. (2022), showcases a robust and encouraging relationship with seed yield, evidenced by a correlation coefficient of r = 0.528 at the phenotypic level. When we delve deeper into the genotypic realm, this correlation becomes even more pronounced and significant, presenting a striking figure of r = 0.523.

The height of the plants exhibited a decisive positive relationship with both biomass yield (r = 0.83; $p < 0.01$) and seed yield (r = 0.77; $p < 0.01$). In simpler terms, as the plants grew taller, they also produced more biomass and seeds. However, the weakest correlation (-0.54) was observed between root length and days to 50% flowering (Table 6). An interesting pattern emerged from the findings: plant height and seed yield exhibited an exceptional correlation coefficient of r = 0.997. This strong link indicates a close relationship between these two factors. Conversely, root length displayed a relatively weak correlation, with a coefficient of just r = 0.0938, suggesting its impact may be limited in this context. Consistent with Kavitha et al. (2018), plant height showed a highly significant and positive correlation with the number of seeds per pod (r = 0.281), the number of branches per plant (r = 0.273), and the pod clusters per plant (r = 0.376) at the genotypic level. There were significant positive correlations with the number of seeds per pod (r = 0.303), the number of branches per plant (r = 0.276), and the pod clusters per plant (r = 0.373). According to Ezzat et al. (2005), notable and favorable correlations were observed between thousand-seed weight, pods per plant, seeds per plant, and seed yield per plant.

Table 6: Pearson correlation coefficient on yield and yield-related traits in Lentil at Ak sub-station (Ak).

E	**F**	**M**	**BioY**	**S/Y**	**PtH**	**RtL**	**Ns/Pt**	**N/PB**	
1	0.47*	0.18^{ns}	0.22^{ns}	0.11^{ns}	0.17^{ns}	-0.37^{ns}	0.12^{ns}	-0.49*	**E**
	1	0.51*	-0.0033^{ns}	-0.065^{ns}	-0.088^{ns}	-0.54^{ns}	-0.36^{ns}	-0.14^{ns}	**F**
		1	0.0027^{ns}	-0.17^{ns}	0.22^{ns}	-0.24^{ns}	0.086^{ns}	-0.06^{ns}	**M**
			1	0.91***	0.83***	-0.1^{ns}	0.69***	-0.19^{ns}	**Bio/Y**
				1	0.77***	-0.069^{ns}	0.62**	-0.061^{ns}	**S/Y**
					1	0.12^{ns}	0.73***	-0.24^{ns}	**PtH**
						1	0.42^{ns}	0.21^{ns}	**RtL**
							1	0.17^{ns}	**Ns/Pt**
								1	**NP/B**

E= days to 50% emerge, F= days to 50% flower, M= above 90% Mature, BioY=Biomass yield, S/Y= Seed Yield, PtH=plant height, RtL= Root length, Ns/pt= number of seeds per plant, N/PB= number of primary branches/ plants: ***, **, and * Significant at the 0.001, 0.01, and 0.05 levels, respectively. ns= non-significant

Conclusion and Recommendations

Assessing the performance of enhanced lentil genotypes is crucial for developing superior varieties that enhance seed yield and productivity. The complex interaction between genotypes significantly affects seed yield and other agronomic traits, necessitating a detailed statistical analysis to identify the most promising candidates. Findings revealed that, at the Ak sub-station, lentil genotypes matured 18 days earlier than those at the Dz station. Biomass yields varied notably by location, with genotype R-186 achieving 7.4 t ha^{-1} and X-125-54 (6.3t ha^{-1}) at the Ak sub-station. The top performers in biomass at Dz were ILL-1760 (6.89 t ha^{-1}), followed by Derash (6.82 t ha^{-1}), and R-186 (6.76 t ha^{-1}). The variations in biomass yield among enhanced lentil genotypes are closely linked to their unique genetic traits. In our study, genotype R-186, Derash, and Dz2012-Ln0050 excelled, showing remarkable seed and biomass yield at both locations.

Additionally, the Teshale, Jiru, and Beredu notably excelled with the highest thousand-seed weight at both sites, making them strong candidates for improving nutritional value. The relationships between seed yield, plant height, root length, and seed count per plant showed a clear positive correlation with biomass yield. This aligns with observations at the Ak sub-station, although root length was an exception, displaying a negative and statistically insignificant correlation with biomass yield. Interestingly, biomass yield, which reached a notable 0.91, proved to be the most important factor directly influencing seed yield at Ak sub-station. This highlights its importance as a key element for breeding efforts. Moving forward, future research should explore a broader range of environmental conditions and focus on greater genetic diversity.

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Data availability statement: The data highlighted in this study can be accessed upon a reasonable request directed to the corresponding author. Feel free to reach out if you need it!

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