SCIENTIA
AGRICULTURAE
BOHEMICA

Article

Exploring the Effect of Different Planting Dates on Lentil (*Lens culinaris* Medikus) Genotypes

Melkam Anteneh[1,3], Tileye Feyissa[2,3], Roubik Hynek[4]

[1] Debre Zeit Agricultural Research Center, Ethiopian Institute of Agricultural Research, Ethiopia
[2] Institute of Biotechnology, Addis Ababa University, Addis Ababa, Ethiopia
[3] Department of Microbial, Cellular and Molecular Biology, Addis Ababa University, Ethiopia
[4] Department of Food and BioResource Technology, Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, 16500 Prague, Czech Republic; roubik@ftz.czu.cz

* Correspondence: meraf2.2008@yahoo.com (Ethiopia)

Abstract: Lentil crops have been noticeably influenced by planting dates, primarily due to variations in rainfall, temperature, and genotypes. Therefore, the study was conducted to examine the effects of planting date and its interactions with genotypes possessing important traits. The results indicated that lentil genotypes planted more than a month earlier exhibited longer times to 50% flowering and emergence. The tallest plants were observed on the main or mid- August planting day for this genotype, with Adda reaching 32.3. 3cm at Ak and 38. 0 cm for genotype 09583227-04 on day 1. The influence of planting date and genotype on plant height was statistically significant. Early seedling emergence, earlier flowering, and greater plant height positively contributed to yield growth. Our data analysis revealed a significant difference (P< 0. 001) in seed yield. A one-month delay in planting caused a yield reduction of 1. 74 t/ha at Bishoftu and 0. 71 t/ha at the Ak sub-station for genotype R- 186. Additionally, the Derash genotype showed larger yield differences of 1. 83 t/ha at the Dz station and 1. 29 t/ha at the Ak sub- station compared to the second planting date. However, the study results demonstrated that the most suitable genotypes for breeding purposes, such as Dz 2012- Ln 0050, R- 186, and Derash, produced higher yields than the tested genotypes at both locations and across the two planting dates. A notable direct relationship was observed between harvest index (HI) and seed yield (r = 0. 56); days from 50 % emergence to flowering (r = 0. 44); and plant height to harvesting index (r =0.2. 2). In conclusion, our results indicate that planting date is a critical factor interacting with genotype to influence traits; therefore, an analysis of genotype by planting date interaction is essential for plant breeding.

Keywords: correlation, flowering, interaction, traits, yield.

Received for publication on May 18, 2025

Accepted for publication on December 11, 2025

1. Introduction

DOI: 10.7160/sab.2026.570221

Adaptation is one of the policy options for reducing the negative impact of climate change (Kurukulasuriya and Mendelsohn, 2008). Adjusting natural or human systems to present or anticipated climatic stimuli or their impacts is known as adaptation to climate change. This helps to minimize harm or seize advantageous chances (IPCC, 2021). Among legumes, lentil (*Lens culinaris* Medikus) is a vital food crop due to its global production, trade, and popularity among consumers (Asakereh et al., 2010). It is also known as poor man's meat. This crop thrives in areas with 300–400 mm of yearly rainfall and is primarily planted in the winter (Sarker et al., 2003). In addition to being a key part of diets, lentils often fetch higher market prices than other staple crops, making them an important income source for farmers.

In Ethiopia, lentils are mainly cultivated as a cool-season food legume, often rotated with other cereal crops such as wheat, barley, and tef, especially in the mid- to highland regions. Yield is influenced by the interaction of various plant characteristics and environmental factors (Tadesse et al., 2014). Lentil farming in Ethiopia occurs at altitudes of 1,700–3,500 meters above sea level (masl), with annual rainfall ranging from 700 to 2,000 mm. Planting typically takes place from late June to early October, depending on rainfall, temperature, and altitude (Abdisa 2018; Chilot et al., 2016). Selecting genotypes based on yield and other agronomic traits is a crucial step in assessing performance, which is greatly influenced by testing locations and years (Tadele T. et al., 2021). Due to genetic traits and environmental conditions, the performance of plant genotypes can vary significantly depending on planting time and location. Research has explored changes in yield related to genotype and planting dates, focusing on traits such as days to 50% flowering, days to 50% emergence, and plant height across different sites (Alemu et al., 2023).

Relying only on seed yield when selecting plants without considering other traits can be misleading. It is important to analyze how yield components interact and focus more on those that greatly influence yield. Combining association analysis with path coefficient analysis provides a more effective way to examine yield and its contributing traits (Mahajan et al., 2011). Path analysis is a structural method used to evaluate relationships between a dependent variable and two or more independent traits or variables. However, understanding trait correlations and path coefficient analysis is essential to assess the effects of genotype and environment on final yield before making selections (Kumar et al., 2013; Dugassa et al., 2014; Hussan et al., 2018). According to Annicchiarico (1997), managing genotypes by year or genotype by location interactions is only possible by selecting for yield stability across environments, which are defined as combinations of location and year.

Although several studies have explored genetic stability, variability, and G × E interactions in lentils (Asefa F., et al, 2022; Tadele T. et al, 2021), many researchers in Ethiopia have examined the genetic variability of lentil germplasm, especially local genotypes, for yield and related traits (Edossa et al., 2010; Tadesse et al., 2014; Dugassa et al., 2014). Ethiopia's average seed yield remains low, emphasizing the need for further improvement and management efforts (FAOSTAT, 2010). Several factors contribute to yield reductions and the significant gap between actual and potential yields in the country. Although major diseases such as rust and the recently emerging viral disease have caused considerable yield losses, ongoing variability in genetic traits and environmental conditions greatly influences the stability of a given genotype or cultivar (Assefa F et al., 2022). Environmental stresses like drought, frost, and heat affect lentil growth, and when they occur during sensitive stages, they further impact biomass and seed yield components (Sehgal et al., 2019).

A useful framework for analyzing environmental and genotypic effects on crop performance defines yield as the product of total biomass produced and the proportion of that biomass allocated to harvestable seed (Charles-Edwards, 1982). Rajandran et al. (2022) also observed that the movement of lentils across different geographic locations depended on significant phenological changes adapted to various seasonal climates and cropping patterns. The interaction and correlation coefficients between yield-related traits, along with their relationships, are crucial for selecting desirable genotypes. A strong genotypic correlation driven by traits influenced by genetics provides an excellent opportunity to enhance seed yield. There is a notable gap in our understanding of how genetic variation affects the performance of lentil genotypes when seeds are planted on different dates. With that in mind, this study aims to explore the mean and interaction effects of 20 distinct lentil genotypes tested across two different planting dates in central Ethiopia.

2. Methods and Materials

Study Site

The reference set of genotypes (Table 1) was chosen from the station, a legume research program, based on their contrasting relative performance in yields across different environments grown on loam soil at Bishoftu (Debre Zeit = Dz) and heavy clay at the Akaki Sub-Station (Ak). The genotypes were planted in a Randomized Complete Block Design (RCBD) with three replications. Twenty (20) lentil genotypes were planted on both the normal and late planting days at each location. The testing of day 1 and day 2 plantings of lentil seeds, which showed yield traits, affected the initial growth and development of genotypes in the field. A plot consisting of four rows, 3 meters long and 0.8 meters wide (2.4 m^2), with a spacing of 0.2 meters between rows, 0.4 meters between plots, and 1.5 meters between blocks was used. A seed rate of 200 seeds was applied to each plot. At harvest, ten plants were randomly selected from each plot to record yield-related traits such as plant height (in cm). The yield data collected after harvesting included seed yield per plot. The genotypes were planted in August (normal) and September (late) in 2021. Planting dates at Bishoftu were August 12, 2021 (first planting date) and September 23, 2021 (second planting date). At Akaki Sub-Station, the dates were August 13, 2021 (first planting date) and September 24, 2021 (second planting date).

Bishoftu (Debre Zeit = Dz):

It is located 60 km east of Addis Ababa, with a geographic range from 08°45'15'' to 08°46'45'' north latitude and from 38°46'45'' to 39°01'00'' east longitude. The average annual rainfall is 801.3 mm, with maximum temperatures reaching 25.5 °C and monthly temperatures at 23.7 °C in July, and 27.70 °C in May. The average minimum temperature annually is 10.50 °C, with monthly lows from 7.4 °C in December to 12.1 °C in July and August. The area sits at an elevation of 1,850 meters above sea level and has a hot to warm, sub-humid climate.

Table 1: List of 20 Lentil (*Lens culinaris* Medikus) names of varieties, genotypes, year of releases, and breeders/maintainers.

No.	Variety names	Genotype names	Year of Release	Source	Breeder/Maintainer
1	Beredu	FLIP-2011-17L	2019	ICARDA	Deber Zeit ARC EIAR
2	Jiru	R-186 x FLIP86-38L-2	2015	ICARDA	Debre Birhan ARC/ARARI
3	Derso/Derash	FLIP-88-411-02-AK-14	2012	ICARDA	EIAR/DZARC
4	Teshale	FLIP 96-46L	2004	ICARDA	DZARC/EIAR
5	Alem Tena	FLIP 96-49	2004	ICARDA	DZARC/EIAR

6	Gudo	Flip 84-78L	1995	ICARDA	DZARC/EIAR
7	ADA	Flip-86-14L	1995	ICARDA	DZARC/EIAR
8	Chalew	NEL 358	1984	ICARDA	DZARC/EIAR
9	Chekol	EnAL-2704	1984	ICARDA	DZARC/EIAR
10	EI-142	EL-141	1972	ET-L	DZARC/EIAR
11	R-186	R-185	1972	ET-L	DZARC/EIAR
12	Alemaya	FLIP-89-63L	2005	ICARDA	DZARC/EIAR
13		ILL-1760			
14		96006L-984005			
15		Dz-2012-Ln-238			
16		ILL-2178			
17		X125-54			
18		09583227-04			
19		Dz2012-Ln0050			
20		94-003L			

ET-L = Ethiopian Landraces; ICARDA = International Center for Agricultural Research in the Dry Areas.

Akaki Sub-Station (Ak):

It is located 30 km north of Debre Zeit, at 08°05’39” north latitude and 38°04’13” east longitude. The soil mainly consists of heavy clay and eutric vertisol. It has an altitude of 2,400 meters above sea level and a hot-to-warm, sub-humid climate.

Data collection and analysis

The mean data for four different agro-morphological and yield traits, such as days to 50% flowering, days to 50% emergence, plant height, and seed yield, were recorded. At the time of harvesting, ten plants were randomly selected from each plot for recording on yield and associated traits. Analysis of variance (ANOVA) in R software version 4.1.2 was used to examine genotype differences for these measured variables. At a 5% significance level, Tukey's test was used to differentiate. Correlation and interaction effect analyses were also conducted. The effects of interactions on planting dates and 20 lentil genotypes were analyzed using R software version 4.3.3.

3. Results and Discussion

Planting Dates and Genotypes Evaluation on Yield-Related Traits at Bishoftu

Agronomic Trait Evaluations

Table 2 showed that the genotype (Beredu = 7) had fewer days to 50% emergence when planting occurred before mid-August (day 1). The longest period until emergence (Chekol = 16) was recorded when planting took place after mid-September (day 2). Lentil genotypes planted about a month later than the normal planting dates took longer to reach 50% seedling emergence compared to the others on Day 1. According to another study (Vish et al., 2021), late planting improves lentil emergence by 8 days. This finding aligns with research on chickpeas conducted under the same conditions (Richards et al., 2020). The average flowering days for each genotype decreased when planted in mid-August. Flowering days ranged from before mid-August to after mid-September, with Beredu taking 40 days and 09583227-04 taking 76 days, the shortest and longest durations, respectively. Beredu, which was planted on day 1, flowers faster than the plant planted the next day. Data analysis revealed a highly significant variation ($p<0.001$) in flowering days.

Table 2 displays a clear pattern in plant height, with genotype 09583227-04 reaching its peak in mid-August at 38 cm compared to mid-September, especially when compared to other genotypes. It shows that planting dates significantly influence lentil height. Plant height ranged from 22.93 cm for genotype Chekol to 38.0 cm for genotype 09583227-04 (day 1). A closer look at the two planting dates reveals that delaying sowing by just one month caused a noticeable decrease in plant height, with genotype 09583227-04 shrinking by about 5cm. When planted in mid-August, the Chekol genotype reached 22.06 cm, while sowing in mid-September resulted in a minimum height of 18.67 cm. Additionally, the effects of planting date and genotype on plant height were statistically significant (Table 3b). Delaying planting from November to February led to a significant drop in plant height; it decreased by 28%, from 30.3 cm to 21.9 cm, as reported by Ouji and Mouelhi (2017). This delay had notable implications for the plants' development.

Table 2: Mean values for yield-related traits on two different planting dates of Lentil at Debre Zeit (Bishoftu).

Genotypes	Days to 50% emerge		Days to 50% flowers		Plant Height (cm)		Seed Yield (t/ha)		HI	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day1	Day2
Adda	10.0^{bcd}	10.0^{cde}	47^{bcd}	65.3^{b-e}	35.33^{abc}	31.73^{abc}	0.95^{fgh}	0.47^{d-g}	0.16^{hij}	0.09^{c-f}
94-003L	8.33^{def}	8.00^{e}	45.66^{def}	58.33^{e-h}	29.2^{c-f}	27^{def}	1.73^{cd}	0.52^{c-g}	0.32^{b-e}	0.11^{b-f}
R-186	10.66^{abc}	8.66^{de}	50^{a}	65.33^{b-e}	35.2^{abc}	32.4^{ab}	2.74^{ab}	1.0^{a}	0.41^{b-f}	0.17^{ab}
TILL-1760	11.0^{abc}	11.33^{bc}	50^{a}	74.0^{a}	35.2^{abc}	29.13^{a-d}	1.67^{cd}	0.67^{c-g}	0.24^{e-i}	0.15^{c-f}
96006L-984005	8.33^{def}	10.66^{bcd}	44.33^{f}	56.33^{gh}	29.6^{c-f}	27.2^{def}	1.66^{cd}	0.92^{ab}	0.4^{b-d}	0.24^{a}
Alemtena	8.33^{def}	12.0^{bc}	46.66^{cde}	62.33^{d-g}	28.73^{def}	22.93^{g}	0.84^{def}	0.11^{c-g}	0.32^{b-e}	0.04^{ef}
Chekol	12^{a}	16.3^{a}	50^{a}	62.67^{d-g}	22.07^{g}	18.67^{h}	0.03^{j}	0.03^{g}	0.04^{j}	0.01^{f}
Alemaya	9.33^{cde}	12^{bc}	45.33^{def}	62.33^{d-g}	31.67^{a-f}	25.4^{d-g}	1.43^{def}	0.47^{c-g}	0.30^{b-e}	0.14^{a-d}
Dz-2012-Ln-238	8.0^{ef}	11.33^{bc}	44.3^{f}	57.33^{fgh}	32.67^{a-f}	25.27^{d-g}	1.51^{de}	0.62^{bcd}	0.32^{b-e}	0.16^{ab}
Gudo	8.0^{ef}	12.66^{b}	44.66^{ef}	57.33^{fgh}	36.53^{ab}	28.2^{cde}	0.74^{gh}	0.26^{efg}	0.18^{d-i}	0.08^{def}
ILL-2178	11.66^{ab}	11.0^{bc}	50.0^{a}	71.0^{abc}	32.2^{a-f}	28.87^{bcd}	1.08^{efg}	0.64^{b-e}	0.24^{c-h}	0.12^{b-f}
X-125-54	7.66^{ef}	12.0^{bc}	44.3^{f}	60.67^{d-g}	32.27^{a-f}	27.6^{def}	1.85^{cd}	0.5^{b-f}	0.37^{bcd}	0.11^{a-e}
09583227-04	10.66^{abc}	11.33^{bc}	49.0^{ab}	76.33^{a}	38^{a}	32.93^{a}	0.73^{gh}	0.22^{efg}	0.12^{ij}	0.05^{ef}
Jiru	12.0^{a}	12.66^{b}	49.0^{ab}	64.33^{c-f}	32.33^{a-f}	27.67^{def}	0.58^{hi}	0.23^{fg}	0.16^{d-i}	0.07^{def}
Beredu	7.0^{f}	12.0^{bc}	40.0^{g}	53.33^{h}	30.53^{b-f}	24.67^{efg}	2.12^{bc}	0.27^{efg}	0.63^{a}	0.1^{c-f}
Challew	11.66^{ab}	11.66^{bc}	50.0^{a}	72.0^{ab}	32.47^{a-f}	24.33^{efg}	0.49^{hi}	0.32^{defg}	0.12^{ghi}	0.07^{ef}
Dz2012-Ln0050	8.0^{ef}	12.0^{bc}	44.66^{ef}	56.0^{gh}	34.8^{a-d}	26.2^{defg}	2.83^{a}	0.76^{bcd}	0.44^{bc}	0.22^{ab}
EL-142	10.66^{abc}	10.66^{bcd}	48.66^{abc}	63.0^{d-g}	26.27^{fg}	24.53^{efg}	0.16^{ij}	0.12^{c-g}	0.06^{ij}	0.04^{def}
Teshale	11.33^{ab}	12.33^{b}	49.0^{ab}	65.67^{bcd}	28.13^{efg}	24.26^{fg}	0.23^{ij}	0.11^{c-g}	0.12^{f-i}	0.03^{ef}
Derash	9.33^{cde}	11.33^{bc}	44.33^{f}	56.33^{gh}	33.13^{a-e}	26.8^{d-g}	2.69^{ab}	0.86^{bc}	0.39^{bcd}	0.22^{abc}
Mean	**9.7**	**11.5**	**46.82**	**63**	**31.82**	**26.79**	**1.303**	**0.455**	**0.23**	**0.11**
CV	**11.9**	**10.74**	**2.94**	**6.92**	**12.23**	**8.8**	**28.65**	**28.17**	**29.19**	**30.38**

Note: Some letters in some columns are not significantly different.

Yield Evaluation and Interactions of Planting Dates with Genotypes

Different planting dates led to varying seed yields. The highest seed yield on day 1 was from the genotype Dz2012-Ln0050 (2.83 t/ha), R-186 (2.74 t/ha), Derash (2.69 t/ha), and Beredu (2.12 t/ha). The seed yield of lentil genotypes planted in mid-September was relatively higher among the tested genotypes, such as R-186 (1.0 t/ha), 96006L-984005 (0.92 t/ha), Dz2012-Ln0050 (0.76 t/ha), and Derash (0.86 t/ha). Similar results showed higher seed yields when sowing occurred in November, which was linked to an increased number of pods. Likewise, according to the results of Lancelot et al. (2023), overall phenological development, including vegetative phase duration, flowering, and podding, decreased with delayed sowing.

The lentil crops planted in mid-August (Day 1) tend to grow taller and produce higher seed yields than those planted later (Day 2). The earlier-planted crops benefit from a longer growing season and favorable conditions that support their development. At the Dz station, the genotype Beredu stood out on day 1 of planting with a remarkable harvesting index of 0.628 (Table 2). Our data analysis revealed a significant difference ($P<0.001$) in seed yield. The effects of genotypes and the interaction between planting dates were also highly significant for days to 50% emergence, flowering, and seed yield (Table 3a and 3b).

Genotypes also played a key role, with the interaction between different sowing dates being notably significant. Excitingly, lentil genotypes planted later (on day 2) appeared to experience a potential decline in seed yield, probably due to increased flower abortions. Tawaha et al. (2002) showed that delaying sowing adversely impacted key metrics, including grain output, plant height, the number of primary branches per plant, and the number of pods per plant. These results align with our findings. Our results also agree with Rehman et al. (2014), who found that early sowing of two soybean genotypes produced significantly higher values in the number of seeds per plant and seed yield compared to late sowing.

Table 3a: Analysis of lentil genotypes with planting date and its effect on the interaction, their analysis of variance, sum, and mean square for days to 50% emergence and days to 50% Flower at Debre Zeit Research Station.

Source	**Df**	**Days to 50% Emerge**			**Days to 50% flower**		
		Sq	**Mq**	**Pr(>F)**	**Sq**	**Mq**	**Pr(>F)**
Replication vector	2	12.54	6.27	0.015*	30.4	15.2	0.2407857
Genotype(G)	19	187.3	9.85	2.563e-10 ***	2294.5	120.8	1.377e-15 ***
Planting date (PD)	1	95.8	95.82	3.395e-12 ***	7836.5	7836.5	< 2.2e-16 ***
G X PD	19	124.7	6.56	6.403e-07 ***	552.7	29.1	0.0008361 ***
Residual	78	110.38	1.41		817.9	10.5	

Sq = sum square, mq = mean square

Table 3b: Analysis of lentil genotypes with planting date and its effect on the interaction, their analysis of variance, sum, and mean square for plant height and seed yield at Debre Zeit Research Station.

Source	Df	Plant Height (cm)			Seed Yield		
		Sq	Mq	Pr(>F)	Sq	Mq	Pr(>F)
Replication vector	2	26.27	13.14	0.2814	0.363	0.181	0.04*
Genotype(G)	19	1327.55	69.87	3.624e-10 ***	40.805	2.148	<2e-16 ***
Planting date (PD)	1	758.94	758.94	5.672e-13 ***	58.244	58.244	<2e-16 ***
G X PD	19	127.91	6.73	0.8455	38.966	2.05	<2e-16 ***
Residual	78	795.07	10.19		4.229	0.054	

Sq = sum square, mq = mean square

Planting Dates and Genotypes Evaluation on Yield-Related Traits at Akaki Sub-Station

Agronomic Trait Evaluations

The variable changed based on genotype, planting date, and their interaction (genotype x planting date). The analysis revealed significant differences with a p-value below 0.01, clearly showing that key factors such as the time to reach 50% flowering, plant height, and seed yield per plot varied notably. The days needed for lentil genotypes to reach the critical 50% emergence level varied widely; some, like genotype 96006L-984005, emerged within 9 days when sown in mid-August, while others, such as ILL-142, took 14 days when planted in mid-September. Fast-emerging genotypes tend to produce higher yields, whereas late-emerging genotypes usually perform better with early planting dates due to unfavorable conditions like cold temperatures and water stress.

The average number of days for 50% of plants to bloom showed significant differences. For example, the 96006L-984005 variety started blooming quickly in just 47 days when it was sown in mid-August. The results revealed an interesting trend: genotypes such as 96006L-984005, which bloom in only 47 days, and Beredu, at 48 days, demonstrated a strong ability to flower earlier when planted in mid-August. Interestingly, when seeds were sown about a month later, in mid-September, genotype 96006L-984005 flowered after just 52 days, highlighting its rapid flowering. In contrast, the 09583227-04 genotype took longer, up to 76 days, when planted in mid-September. Conversely, this genotype was slower, taking 70 days to reach flowering. Overall, genotype 09583227-04 was the slowest among all tested genotypes (Table 4). In other words, the days to reach 50% flowering were shorter when the lentil genotype was planted in mid-August (day 1) compared to mid-September (day 2).

Table 4: Mean values for yield and yield-related traits on two different planting dates of Lentil at Akaki sub-station.

Genotypes	Days to 50% emerge		Days to 50% flowers		Plant Height(cm)		Seed Yield (t/ha)		HI	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day1	Day2
Adda	9.66^{bc}	10.33^{c}	54.33^{efg}	59.33^{fgh}	32.3^{a}	25.66^{ab}	1.73^{de}	1.4^{b}	$0.32^{c\text{-}g}$	0.31^{bcd}
94-003L	10.33^{abc}	11.33^{abc}	$55.0^{d\text{-}g}$	$60.0^{e\text{-}h}$	27.2^{bc}	20.73^{def}	2.37^{bc}	1.4^{b}	$0.41^{a\text{-}f}$	0.39^{ab}

R-186	11.0^{ab}	12.33^{abc}	62.33^{bc}	67.33^{bcd}	31.1^{ab}	23.13^{a-d}	3.41^{a}	2.7^{a}	0.46^{c-g}	0.43^{bc}
ILL-1760	10.66^{abc}	11.33^{abc}	64.66^{b}	68.0^{bc}	21.47^{def}	22.67^{a-d}	1.35^{ef}	1.4^{b}	0.36^{a-d}	0.34^{b-e}
96006L-984005	9.33^{c}	10.0^{c}	47.0^{i}	52.0^{j}	19.93^{f}	18.53^{ef}	0.87^{g}	0.7^{cde}	0.29^{a-e}	0.27^{bc}
Alemtena	10.66^{abc}	11.66^{abc}	58.33^{cde}	63.33^{c-f}	15.13^{f}	20.8^{def}	0.34^{hij}	0.3^{efg}	0.28^{abc}	0.15^{ef}
Chekol	10.3^{abc}	11.3^{abc}	60.3^{bcd}	65.3^{b-e}	14.93^{g}	13.4^{g}	0.03^{j}	0^{g}	0.03^{g}	0.0^{f}
Alemaya	11.33^{a}	13.33^{ab}	53.0^{e-h}	58.0^{f-i}	25.53^{c}	20.8^{def}	0.94^{fg}	0.6^{def}	0.07^{efg}	0.22^{b-e}
Dz-2012-Ln-238	11.0^{ab}	12.33^{abc}	53.0^{e-h}	58.0^{f-i}	25.3^{cd}	21.27^{c-f}	2.12^{cd}	1.2^{bc}	0.48^{b-g}	0.35^{d-f}
Gudo	10.0^{abc}	10.66^{bc}	51.33^{ghi}	56.33^{hij}	24.67^{cde}	22.8^{a-d}	0.72^{gh}	0.4^{efg}	0.22^{c-g}	0.19^{ab}
ILL-2178	11.33^{a}	13.33^{ab}	64.0^{b}	69.0^{b}	21.4^{def}	25.53^{ab}	1.79^{de}	1.4^{b}	0.39^{a-d}	0.30^{def}
X-125-54	10.66^{abc}	11.33^{abc}	52.66^{fgh}	57.66^{ghi}	26.4^{c}	18.33^{f}	2.03^{cd}	1.2^{bc}	0.32^{c-g}	0.38^{ab}
09583227-04	11.0^{ab}	12.0^{abc}	70.66^{a}	75.66^{a}	26.86^{c}	26.27^{a}	0.89^{fg}	0.7^{cde}	0.18^{d-g}	0.15^{def}
Jiru	10.66^{abc}	12.33^{abc}	56.66^{d-g}	61.66^{e-h}	20.73^{ef}	24.8^{abc}	0.54^{ghi}	0.5^{efg}	0.25^{a-e}	0.17^{cde}
Beredu	10.0^{abc}	11.33^{abc}	48.0^{hi}	53.0^{ij}	25.87^{c}	22.1^{b-e}	2.05^{cd}	1.3^{bc}	0.49^{a}	0.46^{a}
Challew	9.66^{bc}	10.66^{bc}	57.0^{c-f}	62.0^{d-g}	17.93^{fg}	21.13^{c-f}	0.7^{gh}	0.6^{def}	0.37^{ab}	0.14^{def}
Dz2012-Ln0050	9.66^{bc}	10.33^{c}	53.66^{efg}	58.66^{fgh}	27.0^{c}	21.66^{c-f}	2.82^{b}	1.1^{bcd}	0.47^{a-d}	0.32^{bc}
EL-142	11.33^{a}	13.66^{a}	55.66^{d-g}	60.66^{e-h}	25.1^{cd}	19.93^{def}	0.21^{ij}	0.1^{fg}	0.08^{fg}	0.07^{def}
Teshale	9.66^{bc}	11.0^{abc}	56.0^{d-g}	61.0^{e-h}	17.47^{fg}	18.33^{f}	0.33^{hij}	0.3^{efg}	0.11^{d-g}	0.18^{bcd}
Derash	11.0^{ab}	13.33^{ab}	55.0^{d-g}	60.0^{e-h}	27.27^{bc}	20.2^{def}	2.71^{b}	1.42^{b}	0.46^{a-f}	0.38^{bc}
Mean	**10.47**	**11.7**	**56.43**	**61.35**	**23.68**	**21.35**	**1.39**	**0.936**	**0.28**	**0.26**
CV	**9.19**	**13.9**	**5.93**	**5.32**	**10.38**	**10.51**	**20.52**	**30**	**29.63**	**28.5**

Note: Some letters in some columns are not significantly different.

The study's results indicated that lentil genotypes planted over a month apart resulted in an increased number of days to 50% flowering and emergence. The effects of late sowing on lentil crops vary greatly depending on the genotype, planting date, and traits measured. At Akaki, there was a significant genotype by environment interaction for seed yield and plant height, while at Debre Zeit, this interaction was absent. However, Debre Zeit did show notable interaction in traits like 50% emergence and flowering. It's interesting how the environment affects these traits differently! It's interesting to note that every phenological stage of the crop appeared to be affected, as highlighted by Wahid et al. (2007). In contrast to the findings of Yamamoto et al. (2008), late sowing under adverse temperature fluctuations actually results in a shorter phenological duration compared to normal sowing conditions. Landraces flowered and matured earlier than both released cultivars and exotic lentil germplasm. This result aligns with the reports of Mekonnen et al. (2014b) and Kefelegn et al. (2025).

When sowing was delayed by just one month, the Adda genotype plants experienced a notable decrease in height, dropping by 6.64cm. It is interesting how such a small change in timing can lead to a significant difference in growth. Additionally, the tallest plants were observed when planting took place on the main or mid-August planting day for this genotype (Adda = 32.3 cm). Later planting resulted in shorter plants and fewer leaves per plant, most likely because there was less time for vegetative growth. An intriguing interaction between various genotypes and planting timing influenced the plants' height. The sowing date, the types of lentils chosen, and how these factors interact made a significant difference (p<0.001) in plant height (Table 5b). As a result, plant heights were affected by planting dates, genotypes, and growing seasons. Conversely, delayed planting led to taller plants in six of the 20 genotypes studied. For example, the genotypes Teshale, Challew, Ill-2178, Jiru, Alemtena, and ILL-1760 showed greater plant heights on the second planting date. Similar studies show that late planting reduces plant height compared to regular planting, as well as heading and maturity (NWRP, 2017; Singh et al., 2011). The effect of origin was significant for days to 50% flowering in all trials; however, there was no significant effect of geographical origin on plant heights (Abdelmonim Z et al., 2024).

Yield Evaluation and Interactions of Planting Dates with Genotypes

The seed yield was higher for the genotypes R-186 (3.41 t/ha), Dz2012-Ln0050 (2.82 t/ha), Beredu (2.05 t/ha), and Derash (2.71 t/ha). Additionally, on the second planting day (day 2), seed yield was also higher for genotype R-186 (2.7 t/ha), Derash (1.42 t/ha), Beredu (1.3 t/ha), and Dz2012-Ln0050 (1.1 t/ha). Comparing the two planting dates shows a notable difference, especially for the lentil genotype R-186, which was planted in mid-August and resulted in a yield difference of 0.71 t/ha. The results indicate that the two planting dates responded differently, and a one-month delay in sowing led to a decrease in yield. Almost all genotypes perform better when planted on day 1 (mid-August). Meanwhile, the harvesting index at the Ak substation reached a healthy 0.49. However, don't overlook Beredu, which once again performed well at the Ak substation with an impressive 0.48 (Table 4). Singh et al. (2007) reported that planting in mid-September produced significantly higher fruit yields than plantings in mid-October and mid-November. Similarly, Lewis (2003) observed a decreasing effect of delayed planting on yield. The difference in yield per plant due to planting time may be caused by variations in the growing environment and the vegetative growth phase, a point supported by Chandler et al. (1991). In late sowing conditions, crops experience lower temperatures up to the booting stage, and they are subjected to increasing temperatures, which negatively affect grain development (Singh et al., 2011).

Table 5a: Analysis of lentil genotypes with planting date and their effect on the interaction, their analysis of variance, sum, and mean square for days to 50% emergence and days to 50% Flower at Akaki Sub-Station.

Source	Df	Days to 50% Emerge			Days to 50% flower		
		Sq	Mq	Pr(>F)	Sq	Mq	Pr(>F)
Replication vector	2	1.667	0.833	0.62823	28.8	14.41	0.2647
Genotype(G)	19	83.833	4.412	0.00274 **	3656.4	192.44	< 2.2e-16 ***
Planting date (PD)	1	45.633	45.633	2.718e-06 ***	725.2	725.21	3.089e-12 ***
G X PD	19	9.033	0.475	0.99897	4.0	0.21	1.00
Residual	78	139.0	1.782		78	831.2	10.66

Sq = sum square, mq = mean square

Table 5b: Analysis of lentil genotypes with planting date and its effect on the interaction, their analysis of variance, sum, and mean square for plant height and seed yield at Akaki sub-Station.

Source	Df	Plant Height (cm)			Seed Yield		
		Sq	Mq	Pr(>F)	Sq	Mq	Pr(>F)

Replication vector	2	0.62	0.308	0.9496	3240	1620	0.1692
Genotype(G)	19	1370.43	72.128	3.688e-16 ***	709202	37326	< 2.2e-16 ***
Planting date (PD)	1	163.33	163.333	1.364e-06 ***	68362	68362	3.179e-13 ***
G X PD	19	511.15	26.902	1.020e-06 ***	65273	3435	1.204e-05 ***
Residual	78	465.09	5.963		69514	891	

Sq = sum square, mq = mean square

Planting dates and genotypes significantly influenced days to 50% emergence and days to 50% flowering ($p<0.001$) (Table 5a). Additionally, the interaction between planting date and genotype was significant ($p < 0.001$), indicating that different genotypes responded differently in terms of seed yield and plant height (Table 5b). At Akaki, there was a significant genotype by environment interaction for seed yield and plant height, while at Debre Zeit, this interaction was absent. However, Debre Zeit did show notable interaction in traits like 50% emergence and flowering. It's interesting how the environment affects these traits differently! Similar findings were reported by Aziz (1992) and Sekhon et al. (1986). Several studies have also shown that there are highly significant differences in morpho-agronomic traits among lentil genotypes (Crippa et al., 2009; Edossa et al., 2010; Pandey et al., 2015; Hussan et al., 2018; Sakthivel et al., 2019).

The effects of sowing dates, lentil genotypes, and their interaction were significant for plant height and seed yield (Table 5b) (Ouji and Mouelhi, 2017). They demonstrate a clear interaction effect on seed yield at Debre Zeit compared to Akaki within a specific planting date range (Golla et al., 2018). Another study found that different planting dates also significantly affect grain yield and related traits (Ke F, Ma X, 2021; Meleha AMI, 2020). The decline in yield with delayed planting results from changes in plant and environmental conditions, or a combination of both (Egli and Cornell, 2009).

Analysis of Correlation Coefficient

A notable link exists between agronomic traits and the harvesting index; the analysis also revealed connections among the traits studied, as shown in Table 6. A strong positive correlation was found between the harvesting index and seed yield ($r = 0.56$), which exhibited a higher direct effect and favorable traits for the breeding program. Additionally, a significant relationship was observed between the number of days for 50% of the plants to emerge and the days for 50% to flower ($r = 0.44$). Traits such as plant height and seed yield also showed positive, significant links with the harvesting index, indicating their usefulness for improving yield. These traits were positively associated with grain yield through gene linkages during the coupling phase, suggesting that selecting for these traits could help increase seed yield. The findings align with those of Assefa Funga et al. (2022), Hussan et al. (2018), Chowdhury et al. (2019), and Kishor et al. (2020). A significant positive correlation was also reported between plant height, pods per plant, and seed yield by Sharma et al. (2014) and Dalbeer et al. (2013). Plant height, biomass production, hectoliter weight, harvest index, and thousand-kernel weight all demonstrated strong positive relationships with grain yield at both genotypic and phenotypic levels, according to Dabi et al. (2016). At the phenotypic level, Sarwar et al. (2013) and Dugassa et al. (2014) also found positive, significant correlations between plant height, above-ground biomass, and harvest index. A greater magnitude of genotypic correlation helps in selecting genetically controlled traits and offers a better chance for seed yield improvement than phenotypic association alone (Robinson et al., 1951).

Table 6: Correlation coefficient among agronomic traits derived from 20 Lentil Genotypes in the combined Matrix auto-method R version 4.3.3.

Parameter 1	Parameter 2	r	95%	T (238)	P
Day to 50% Emergence	Days to 50% F	0.44	[0.33,0.54]	7.56	<0.001***
Day to 50% Emergence	Plant height	-0.19	[-0.31, -0.07]	-3.04	0.011*
Day to 50% Emergence	Seed Yield	-0.17	[-0.29, -0.04]	-2.65	0.017*
Day to 50% Emergence	HI	-0.24	[-0.36, -0.12]	-3.87	<0.001***
Days to 50% Flower	Plant height	-0.19	[-0.31, -0.06]	-2.98	0.011*
Days to 50% Flower	Seed Yield	-0.11	[-0.23.0.02]	-1.71	0.088
Days to 50% Flower	HI	-0.24	[-0.36, -0.12]	-3.88	<0.001***
Plant height	Seed Yield	-0.27	[-0.38, -0.15]	-4.31	<0.001***
Plant height	HI	0.20	[0.07,0.32]	3.12	0.010*
SY t/ha	HI	0.56	[0.47,0.64]	10.54	<0.001***

p-value adjustment method: Holm (1979); Observations = 240

*, **, and *** indicate significance at 0.05, 0.01, and 0.001 probability levels, respectively.

A significant negative correlation was observed between the harvesting index and both the days to reach 50% emergence and the days to reach 50% flowering (r = -0.24). This indicates an interesting trend: as the harvesting index increases, the time needed for plants to reach these stages decreases. The findings of Mohammad et al. (2005) indicated that days to 50% heading had a negative correlation with the harvest index. Additionally, seed yield showed negative correlations with days to 50% emergence (r = -0.17), days to 50% flowering (r = -0.11), and plant height (r = -0.27). A notable negative correlation was also found between plant height and two important traits: the time until 50% of the plants had germinated (r = -0.19) and the time until 50% reached flowering (r = -0.19). Similar findings were also reported by Abdelmonim et al (2024); plant height showed a significant negative correlation with days to flowering at Sidi El Aidi (r = -0.23) and at Adana during the 2021 season (r = -0.21). Correlation studies between agronomic traits such as yield and its components can help plant breeders and agronomists improve crop growth and yield attributes (Ezzat and Ashmawy, 1999). Similarly, variation in lentil crop performance under different fertilizer levels was reported by Jain et al. (1995) and Pandey et al. (1992). Kumar et al. (2017) also reported a highly significant and positive genotypic association of seed yield per plant with the harvest index, above-ground biomass, number of secondary branches, number of pods per plant, 1000 seed weight, and number of seeds per pod.

4. Conclusions

The results showed that the first batch of lentils planted produced a significantly higher seed yield per plot than the second batch. There is considerable variation among lentil genotypes for all studied traits, and the performance of different varieties (genotypes) varies depending on their planting date. Therefore, plant performance was influenced by genotype, planting date, and their interaction (genotype x planting date). Significant differences were observed between genotypes and planting dates, which could affect the selection of varieties for different production conditions. The variation in days from 50% flowering to 50% emergence, along with plant height and yield, may reflect differences in genetic makeup and varying responses to sowing date.

Early seedling emergence, earlier flowering, and increased plant height positively contributed to yield growth. Delaying planting by a month caused reductions of 1.74 t/ha and 0.71 t/ha in the genotype R-186 at Bishoftu and Ak sub-station, respectively. Furthermore, the genotype Derash recorded higher yield differences of 1.83 t/ha at Dz station and 1.29 t/ha at Ak sub-station compared to the second planting date. Changes in rainfall and temperature, which influence the overall performance of our tested lentil genotypes, were observed. The R-186 variety, which outperformed all other genotypes, showed yield differences between normal and late sowing conditions. Late sowing of lentil plants increases the growing period from emergence to flowering, reduces vegetative growth, and leads to higher flower abortion, ultimately lowering yield and its components. The timing of sowing affected the behavior of lentil genotypes, as late sowing induced heat stress.

The effect of interactions between genotypes and planting dates on 50% emergence, 50% flowering, and yield was highly significant ($p<0.001$). A stronger genotypic correlation improves traits controlled by genetics and increases the potential for boosting lentil seed yield. Correlation studies of agronomic traits such as yield and its components can help plant breeders and agronomists enhance crop growth and yield characteristics. An interesting connection emerged, revealing a notable relationship between the harvest index (HI) and seed yield, indicated by a correlation of $r = 0.56$. Additionally, the time it takes for 50% of the plants to emerge and bloom showed a significant connection, with a correlation coefficient of $r = 0.44$. When examining the relationship between plant height and HI, a weaker correlation was observed at $r = 0.2$. These insights can serve as valuable guidance for improving different genotypes.

Author Contributions: Conceptualization was performed by M.A., T.F, supervision was performed by T.F, all authors were involved in writing and editing the manuscript, investigation was performed by M.A., T.F, data collection and analysis, methodology, and writing original draft were performed by M.A., T.F., R.H. All authors agree to be accountable for the research presented.

Funding: This research did not receive any specific grant from any funding agency in the public, commercial, or non-profit sectors.

Acknowledgments: This research paper, a result of countless hours and unwavering dedication, wouldn't have been possible without God's support. I'm deeply grateful to everyone who stood by me throughout this process. Your cooperation and kind encouragement played a vital role in this achievement. Additionally, I cannot overlook the significant contribution of the One Planet Fellowship; your support not only strengthened my research but also enhanced my leadership skills in this important field of study. Thank you all for being an essential part of this journey.

Compliance with ethical standards, Conflict of interest

The authors declare that they have no conflict of interest.

5. References

1. Abdelmonim Z, Mohammed M, Aziz B, Bacar A, Nadia B, Hanane O, Esra Ç, Valerio HV, Agata G, Elisabetta M, Hakan Ö, Omar I (2024): Assessment of the phenotypic diversity and agronomic performance of a Mediterranean lentil collection under rainfed conditions: towards efficient use in breeding programs for adaptation to Mediterranean-type environment. Laboratory of Agrifood and Health, Faculty of Sciences and Techniques, Hassan First University. https://doi.org/10.21203/rs.3.rs-4268289/v2License
2. Abdisa TB (2018): Distribution and management of Fusarium wilt (*Fusarium oxysporum* f. sp. lentis) of lentil (*Lens culinaris* Medikus) in central highlands of Ethiopia. Thesis, Haramaya University, Haramaya.
3. Alemu MA, Fikre A, Negassa TM, Feyisa T (2023): Effects of Planting Time on Growth, Yield, and Yield-Related Traits of Lentil "*Lens culinaris* Medikus" at Central Ethiopia. ICRRD Journal 4(4), 140-152).
4. Ali M, Saraf CS, Singh PP, Rewari RB, Ahlawat IPS (1993): Agronomy of lentil in India. [In, Lentils in South Asia: Erskine, W. and Saxena, M.C., Eds.], ICARDA, Aleppo, Syria: 103-25.
5. Ahlawat IPS, Singh A, Saraf CS (1982): Yield of lentil cultivars as affected by date and rate of seeding, under late sown conditions. Indian Journal of Agron. 27:257-62.
6. Annicchiarico P (1997): Joint regression vs AMMI analysis of genotype environment interactions for cereals in Italy. Euphytica 94(1), 53- 62
7. Asakereh A, Shiekh Davoodi MJ, Safaieenejad M (2010): Energy consumption pattern of organic and conventional lentil in Iran. A case study: Kuhdasht County. Asian Journal of Agricultural Sciences 2,111–116.
8. Assefa F, Nigusie G, Lijalem K, Dagnachew B, Ridwan M, Fasil H, Genet M, Amin F, Abebe H, Nigusie K, Tadele T, Yasin G, Asnake F (2022): BLUP and Stability Analysis of Mult-Environment Trials in Lentil (Lens culinaris Medic) Genotypes under Rainfed Conditions of Ethiopia. Ethiopian Journal of Crop Science Vol 9 No.2
9. Aziz, MA (1992): Response of lentil (L-5) to different sowing dates. Lens Newsletter 19: 18-20.
10. Charles-Edwards, DA (1982): Physiological determinants of crop growth. Academic Press, Sydney.
11. Chandler CK, Albregts EE, Howard CM (1991): Planting time affects early season Strawberry production in West Central Florida. Proc. Fla. State Horticulture Society 140 (1991), pp. 227-228.
12. Chilot Y, Yigezu AY, Aw-Hassan A (2016). Diffusion of improved lentil varieties in Ethiopia: A comparison of adoption estimates from expert panel, community focus group discussions, and sample household surveys. In: Abebe Kirub (Ed). Addis Ababa: Ethiopian Institute of Agricultural Research. http://www.eiar.gov.et.
13. Chowdhury MM, Haque MA, Malek MA, Rasel M, Ahamed KU (2019): Genetic variability, correlation, and path coefficient analysis for yield and yield components of selected lentil (*Lens culinaris* Medikus) genotypes. Funda Appl Agri 4(2):769 -776.
14. Crippa I, Bermejo C, Espósito MA, Martin EA, Cravero V, Liberatti D, Enrique A (2009): Genetic variability, correlation and path analyses for agronomic traits in lentil genotypes. Integrated Journal of Plant Breeding 3(2):76–80.
15. Dabi A, Mekbib F, Desalegn T (2016): Estimation of genetic and phenotypic correlation coefficients and path analysis of yield and yield contributing traits of bread wheat (*Triticum aestivum* L.) genotypes. International Journal of Natural Resource Ecology Management 1(4), 145–154.
16. Dalbeer, ShivaNath, Verma OP, Kavita, Kisan Kumar (2013): Correlation and path-coefficient analysis for yield attributes in lentil (*Lens culinaris* L.). International Journal of Science and Research. 4 (8): 158-161.
17. Dugassa A, Hirpa L, Negash G (2014): Genetic variability, yield, and yield association of Lentil Genotypes Grown at Gitilo Najo, Western Ethiopia. Science, Technology and Arts Research Journal 3(4): 10-18.
18. Edossa F, Kassahun T, Endashaw B (2010): A comparative study of morphological and molecular diversity in Ethiopian lentil landraces. Journal of Plant Sci.ence 4(7): 241-254.
19. Eba Muluneh Sorecha, Nano Alemu Daba (2018): Evaluation of Lentil Genotypes (*Lens culinaris* Medikus) for Growth and Yield Performances across Climate Conditions of Central Highlands of Ethiopia. Turkish Journal of Agriculture - Food Science and Technology, 6(11): 1575-1581.
20. Egli DB, Cornelius PL (2009): A regional analysis of the response of soybean yield to planting date. Agronomy Journal 101, 330–335.
21. Ezzat ZM, Ashmawy F (1999): Performance of some exotic lentil genotypes under Egyptian conditions. Zigzag Journal of Agricultural Research, 26, 267-280.

22. FAOSTAT (2010): Agricultural Data on Primary Crops. FAO (Food and Agriculture Organization of the United Nations)
23. Golla B, Tadesse B, Chalsisa D, Bayisa E (2018): Effect of sowing time and environmental variation on yield of different Maize varieties. Open Journal of Political Science 3:41–45. 10.17352/ojps.000014
24. Hussan SU, Khuroo NS, Lone AA, Dar ZA, Dar SA, Dar MS (2018): Study of variability and association analysis for various agro-morphological traits in lentil (*Lens culinaris* Medikus). Journal of Pharmacognosy and Phytochemistry 7(2): 2172-2175.
25. IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Berger S, Caud N, Chen Y, Goldfarb L, Gomis MI, Huang M, Leitzell K, Lonnoy E, Matthews JBR, Maycock TK, Waterfield T, Yelekçi O, Yu R, Zhou B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
26. Jain Madaria Rao, Nigath PK, 1995: Analysis of yield factors in lentils. Indian Journal of Agricultural Research 29(4):173-180.
27. Kefelegn N, Benor S, Haile G. Agro-morphological characterization and comparative performance of Ethiopian and exotic lentil (*Lens culinaris* Medikus) germplasm. Genetic Resources and Crop Evolution 72, 4491–4506. https://doi.org/10.1007/s10722-024-02204-y
28. Ke F, Ma X (2021): Responses of maize hybrids with contrasting maturity to planting date in Northeast China. Scientific Reports 1(1):1–9. 10.1038/s41598-021-95328-5
29. Kishor, R. (2020): Correlation and Path analysis for yield and its component traits in Lentil (*Lens culinaris* Medikus) in Bundelkhand. Journal of Pharmacognosy and Phytochemistry 9(6), 2175-2178.
30. Kumar P, Vimal SC, Kumar A (2017): Study of simple correlation coefficients for yield and its component traits in lentil (*Lens culinaris* M). International Journal of Cultural Studies 6(9):3260–5.
31. Kumar S, Barpete S, Kumar J, Gupta P, Sarker A (2013): Global lentil production constraints and strategies. SATSA Mukhapatra-Ann Techn 17:1–13.
32. Kurukulasuriya P, Mendelsohn R (2008b): "Crop Switching as an Adaptation Strategy to Climate Change" African Journal of Agriculture and Resource Economics 2: 105-126.
33. Lewis JC (2003): A modified "plasticulture" system for strawberries in Nova Scotia, N.F. Childers (Ed.), The Strawberry, A Book for Growers, Others, Dr. Norman F. Childers Publications, Gainesville, FL, USA (2003), pp. 53-62.
34. Maphosa Lancelot, Preston Aaron, Richards Mark F (2023): Effects of Sowing Date and Environment on Phenology, Growth and Yield of Lentil (*Lens culinaris* Medikus) Genotypes. National Library of Medicine, National Center for Biotechnology Information. PubMed. 12(3):474. 10.3390/plants12030474
35. Mekonnen F, Firew M, Shiv K, Seid A, Tilak S (2014b) Phenotypic variability and characteristics of lentil (*Lens Culinaris* Medik) Germplasm of Ethiopia by multivariate analysis. Journal of Agriculture and Crops 2(6):104–116
36. Meleha AMI, Hassan AF, El-Bialy MA, El-Mansoury MAM (2020): Effect of planting dates and planting methods on water relations of wheat. International Journal of Agronomy 1–11. 10.1155/2020/8864143
37. Mohammad T, Haider S, Amin M, Khan MI, Zamir R (2005): Path coefficient and correlation studies of yield-associated traits in candidate bread wheat (*Triticum aestivum* L.) lines. Suranaree Journal of Science and Technology 13(2), 175–180.
38. Mahajan RC, Wadikar PB, Pole SP, Dhuppe MV (2011): Variability, correlation, and path analysis studies in sorghum. Research Journal of Agricultural Sciences 2(1):101–3.
39. NWRP (2017): Rice-wheat system: opportunities and constraints. National Wheat Research Program (NWRP) Nepal Agricultural Research Council, Bhairahawa, Rupandehi, Nepal (2017).
40. Ouji A, Mouelhi, (2017): Influence of Sowing Dates on Yield and Yield Components of lentil under the semi-arid region of Tunisia. Volume 38(2). www.jnsciences.org E-ISSN 2286-5314.
41. Pandey S, Bhatore A, Babbar A (2015): Studies on genetic variability, interrelationships, association, and path analysis in indigenous germplasm of lentils in Madhya Pradesh, India. Electronic Journal of Plant Breeding 6(2):592–9.
42. Pandey A, Singh DP, Singh BB, 1992. Interrelation of yield and yield components in lentil germplasm. Indian Pulse Research 5(2):142-144.

43. Rajandran V, Raul O, Jacqueline KVS, Jakob BB, Jules SF, Valerie FGH, Willie E, Ian CM, Kirstin EB, James LW (2022) Genetic analysis of early phenology in lentil identifies distinct loci controlling component traits. Journal of Experimental Botany 73(12):3963–3977.
44. Rehman M, Khaliq T, Ahmad A, Wajid SA, Rasul F, Hussain J, Hussain S (2014): Effect of planting time and cultivar on soybean performance in semi–arid Punjab, Pakistan. Global J. Sci. Front. Res. Agric. Vet., *14*, 41–45.
45. Robinson HF, Comstock RE, and Harvey PH (1951): Genotypic and phenotypic correlations in corn and their implications in selection. Agronomy Journal 43: 262-267.
46. Roy TS, Nishizawa T, Islam MS, Razzaque MA, Hasanuzzaman M (2009): Potentiality of small seedling tuber derived from True Potato Seed (*Solanum tuberosum* L.) and its economic return as affected by progeny and clump planting. International Journal of Agriculture Environment & Biotechnology 2 (4): 385-392.
47. Richards MF, Preston AL, Napier T, Jenkins L, Maphosa L (2020): Sowing date affects the timing and duration of key Chickpea (*Cicer arietinum* L.) growth phases. Plants 9, 1257.
48. Sakthivel G, Jeberson S, Singh NB, Sharma PR, Kumar S, Jalaj VK, Sinha B, Singh NO (2019): Genetic variability, correlation, and path analysis in lentil germplasm (*Lens culinaris* Medikus). Fundamental and Applied Agriculture 4(2):769–76.
49. Sarker A, Erskine W, Singh M (2003): Regression models for lentil seed and straw yields in the Near East. Agricultural and Forest Meteorology 116: 61-72.
50. Sarwar G, Abbas G, Asghar MJ. Quantitative analysis of yield-related traits in lentil (*Lens culinaris* Medikus) germplasm. Journal of Agriculture Research 51(3):239–46.
51. Sekhon HS, Dhingra KK, Sadhu PS, Bhandari SC (1986): Effect of time of sowing, phosphorus, and herbicides on the response to *Rhizobium inoculation*. Lens Newsletter 13: 11-15.
52. Sehgal A, Sita K, Bhandari K, Kumar S, Kumar J, Vara Prasad PV, Siddique KHM, Nayyar H (2019): Influence of drought and heat stress, applied independently or in combination during seed development, on qualitative and quantitative aspects of seeds of lentil (*Lens culinaris* Medikus) genotypes, differing in drought sensitivity. Plant, Cell & Environment 42, 198–211.
53. Sharma V, Paswan Sunil Kumar, Singh Vivek Kumar, Khandagale S (2014): Correlation and path coefficient analysis of economically important traits in lentil (*Lens culinaris* Medikus) germplasm. The Bioscan, 9(2):819-822.
54. Singh A, Singh D, Kang J, Aggarwal N (2011): Management practices to mitigate the impact of high temperature on wheat: a review IIOAB J., 2 (7) (2011), pp. 11-22
55. Singh R, Sharma RR, Goyal RK (2007): Interactive effects of planting time and mulching on 'Chandler' strawberry (*Fragaria* × *ananassa* Duch.) Scientia Horticulturae 111 (2007), pp. 344-351.
56. Singh K, Singh S, Jain A, Singh PP (1990): Effect of sowing date and row spacing on the yield of lentil varieties. Lens Newsletter 17: 9-10.
57. Tadesse T, Leggesse T, Mulugeta B, Sefera G (2014): Correlation and path coefficient analysis of yield and yield components in lentil (*Lens culinaris* Medikus) germplasm in the highlands of Bale, Ethiopia. International Journal of. Biodiversity and Conservation 6(1):115–20.
58. Tawaha AM, Turk MA (2002): Effects of dates and rates of sowing on yield and yield components of lentil (*Lens culinaris* Medikus) under semi-arid conditions. Pakistan Journal of Bio Sciences 5(5):531-532. 10.
59. Vish Kumari V, Nath R, Sengupta K, Nalia A, Banerjee S, Chandran MAS, Ibrahimova U, Dessoky ES, Attia AO, Hassan MM (2021): The Response of Lentil (*Lens culinaris* Medikus) to Soil Moisture and Heat Stress Under Different Dates of Sowing and Foliar Application of Micronutrients. Frontiers in Plant Science 12, 679469.
60. Wahid A, Gelani S, Ashraf M, Foolad MR (2007): Heat tolerance in plants: an overview Environ. Exp. Bot., 61 (3) (2007), pp. 199-223
61. Yamamoto Y, Aminaka R, Yoshioka M, Khatoon M, Komayama K, Takenaka D, Yamashita A, Nijo N, Inagawa K, Morita N, Sasaki T, Yamamoto Y (2008): Quality control of photosystems II: impacts of light and heat stresses Photosynthesis Research 98(1) (2008), pp.589-608.