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Research Article

Winter hardiness in Lentil (*Lens Culinaris* Medik)

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Abstract

Climate change affects lentil (Lens culinaris Medik.) cultivation, particularly through extreme winter weather, highlighting the need to assess winter hardiness. This study conducted on of four advanced lentil lines and three controls under winter sowing conditions over three successive growth periods from 2021 to 2023 at the Ikızce Research Application Farm of Field Crops Central Research Institute, Turkey. The analysis aimed to determine the variability in yield and winter resilience of red lentil lines. Results releaveled negligible winter damage, with plant heights ranging from 24 to 30 cm, first pod heights from 23 to 33 cm, and 50% flowering occurring on average of 196 days. Principal Component Analysis (PCA) revealed that 75% of observed variability between genotypes are attributed to genetic factors, while 25% can be ascribed to external influences. Notably, lines AKM 1089 and AKM 1087 have been detected as superior, providing a foundation for future lentil breeding studies to develop climate-resilient varieties with genotypic superiority.

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Introduction

Climate change is causing long-term alterations to global climatic patterns, including changes in temperature, precipitation, and wind direction (UN, 2022). It is important to take action to mitigate the effects of climate change. Developing new varieties of lentil is crucial in the face of climate change that threatens global food security. Millions of people worldwide rely heavily on grain legumes as a source of protein in their diets, making them a vital component in maintaining global food security (Jha et al., 2022).

Among grain legumes, lentil (*Lens culinaris* Medik.) is an annual grain legume that has been domesticated as the first crop since 7000 BC (Erskine et al., 2016) in the Fertile Crescent (Ladizinsky, 1979). It is the third most significant cool-season grain legume after chickpeas and peas worldwide (Sehgal et al., 2021). More than 40 countries cultivate lentils, and the top producers are the US, Canada, India, Australia, and Türkiye (FAO, 2021). According to Kaale et al., (2023),

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the total production amount of lentil climbed by 107% globally in the two decades (2001–2020), from 3.15 to 6.54 million tonnes. Specifically, in Türkiye, where the experiment was carried out, lentil is produced as red and green cultivars, winter and summer, respectively. 98% of it is cultivated for winter in the South-eastern Anatolia and Central Anatolia Regions (Aydoğan et al., 2008).

Lentil is a nutrient-dense plant. It has a high content of protein 22% to 35%, minerals, vitamin content and complex carbohydrates with high energy levels (Dhull et al., 2020). In this respect, its grains are suitable for human consumption and its dry straw is suitable for use as animal feed. In addition to its nutritional properties, lentils fix atmospheric nitrogen in root nodules through a symbiotic relationship with Rhizobium and contribute to increased soil fertility and health (Teng et al., 2015).

Lentil, a cool-season legume that can grow in various soil types and requires an average of 300-400 mm of annual rainfall (Asakereh et al., 2010). However, the production of lentil is limited by several biotic and abiotic factors, including drought, salt, excessive temperature, and mineral shortage (Sehgal et al., 2021). To ensure the sustainability of lentil production, it is crucial to develop new varieties that are resilient to these challenges. Lentil growing in highland regions is challenging due to its vulnerability to freezing temperatures (Kahraman et al., 2004). Nightly frost can decrease seed yields by 15.5 kg/ha per day, and cold can cause a decrease in large leaf and stem mass and yield (Erskine et al., 1993). Despite this, winter-sown lentils can produce 50% to 100% more than spring-sown lentils (Sakar et al., 1998).

To develop climate-resilient and high yielding cultivars, it is crucial to comprehend the relationships that exist between yield and the other plant characteristics (Karadavut, 2009). Although several studies have been carried out to analyse yield and yield components of lentil. This research is essential since analyses recent data on winter lentil plantings in the central Anatolia region. It provides the infrastructure for future lentil breeding studies in the region to see the effects of external factors on the plant yield.

Problem of the study

Assessment of Winter Hardiness in Lentil Lines: Investigate the resilience of various lentil genotypes to winter conditions, focusing on their ability to withstand cold temperatures and other stress factors during the winter season.

Evaluation of Genotype and Environmental Influences on Lentil Yield: Analyse the impact of both genetic factors and external affects on the yield and yield components of different lentil genotypes, aiming to identify key determinants of productivity.

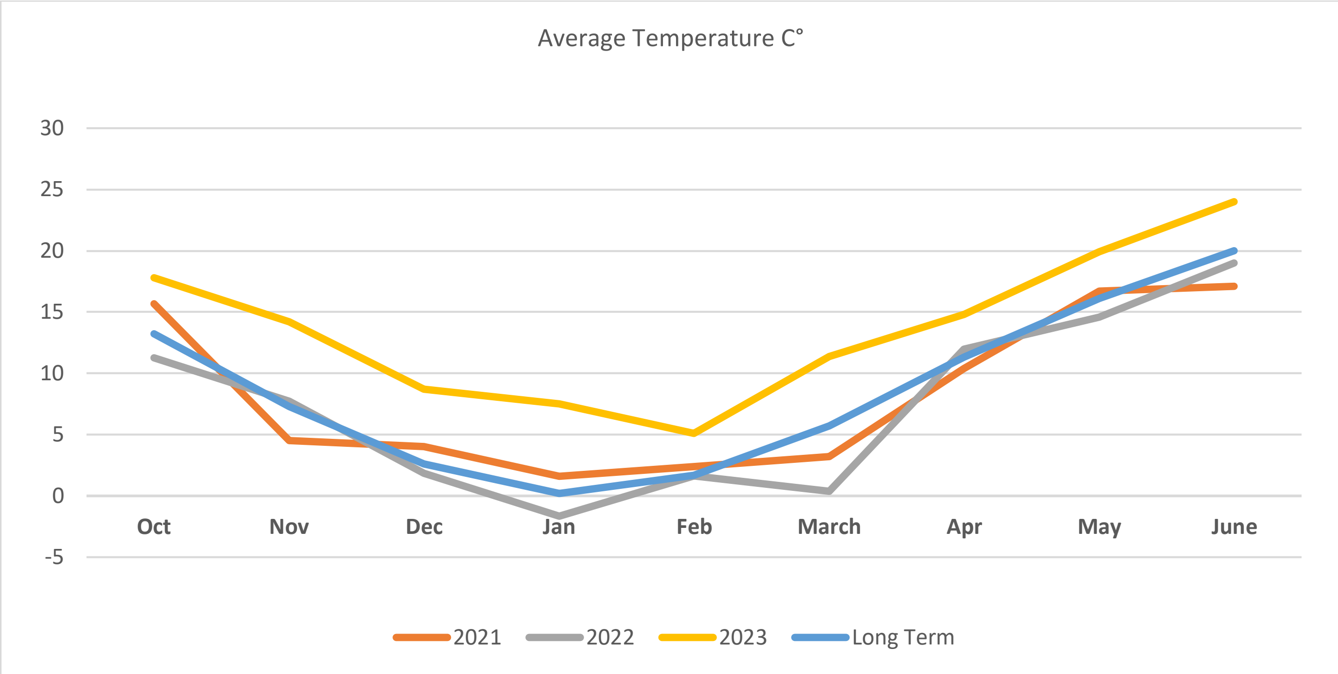
Identification of Superior Lentil Lines for Winter Sowing: Detect lentil lines that demonstrate exceptional performance in winter conditions.

Material and Methodology

The study was conducted as a field trial from 2021 to 2023 as winter sowing (October to June). Four red lentil genotypes 'AKM 1021, AKM 1077, AKM 1087, AKM 1089', and three checks 'Şakar, Çiftçi, Fırat'. The trial was established in the Randomized Blocks trial design, with three replications, on plots of 5.5 m^2, with 350 seeds per m^2, at the Field Crops Central Research Institute İkizce Research Institute, Ankara, Türkiye under rainfed conditions. There was no fertiliser applied during the trial.

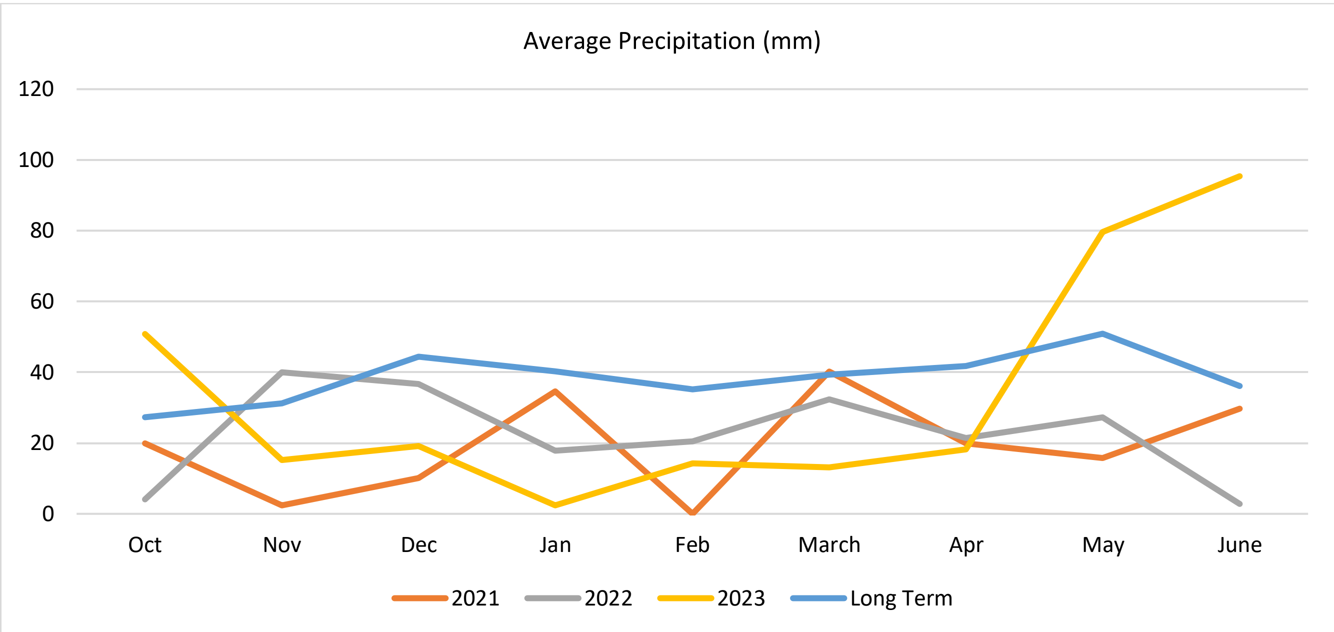
The soil type of the experiment field is in the brown soil group, clayey, loamy soil structure. The pH level of the soil is 7.8, and its structure leans slightly towards alkalinity. Soil CaCO3 content is 33.3% (Karakurt, 2012).

Figure 1-2 shows the variation in average precipitation (mm) and average temperature (°C) during the experimental period. Temperature and precipitation were increased over the years during the growing periods. The lowest temperature was observed in the second year of the trial with -1.7 °C, while the highest temperature was observed in June last year with 24 °C in total, precipitation has increased over the years, including 173 mm, 202.6 mm, and 308.3 mm.



Source: General Directorate of Meteorology

Figure 1. The average temperature of the experiment period



Source: General Directorate of Meteorology

Figure 2. The average rainfall amount during the experiment period

Morphological observations were made during each year of the trial period according to IBPGR, (1985). The number of days for 50% flowering, plant height, first pod height, and winter damage were observed, respectively, starting from the germination date. In particular, an assessment of winter damage (Singh et al., 1989) was carried out in April using a scale of 1 to 9 (1 is resistant and 9 is sensitive). Evaluations include post-harvest thousand-seed weight (g) and calculation of yield (kg/da).

For evaluating the obtained data, statistical analyses were carried out with the JMP15 statistical software. Groupings were made by applying variance analysis and LSD test, and the standard error of the mean (S.E.), and coefficients of variation (C.V.) (Steel et al., 1997) were tested to test the importance of the differences between the means.

Results and Discussion

The effects of winter damage on lentil lines and varieties that were acquired concurrently with climate data are shown in Table 1. Over time, lines and varieties' ability to withstand cold damage during the growing season has changed, both about one another and in individual analyses. The plant development period, the blooming period, and the period immediately preceding flowering were used to evaluate the extent of winter damage. Then their averages were calculated. Following Akçin's findings (1988), lentils have demonstrated resilience to short periods of low temperature, with the capacity to endure temperatures as low as -12 °C. The extent of winter damage was quantified on a scale ranging from 1 to 5, as detailed in Table 1. Notably, no severe damage was detected during the study, indicating a certain level of winter hardiness among the evaluated lentil lines and varieties.

Table 1. Winter hardness observations averages

2021	Score	2022	Score	2023	Score
AKM 1021	2	AKM 1021	3	AKM 1021	2
AKM 1087	3	AKM 1087	2	AKM 1087	1
AKM 1089	2	AKM 1089	3	AKM 1089	2
AKM 1077	3	AKM 1077	2	AKM 1077	1
Şakar	3	Şakar	5	Şakar	2
Fırat 87	3	Fırat 87	2	Fırat 87	2
Çiftçi	3	Çiftçi	3	Çiftçi	2

According to Kahraman et al., 2004 it is important to ascertain relationships between various plant characteristics and winter hardiness. Thus, the study considered the agronomic features of the plant as well as yield and yield components.

Yield values of lines and varieties have changed over the years (Table 2). It was found statistically significant at 5%. The statistical analysis of yield values throughout the trial period revealed that the genotypes consistently demonstrated values surpassing the controls. According to the three-year average, the highest efficiency average was observed in AKM 1087 and AKM 1089. When compared based on lines and varieties, AKM 1087 received the highest value in the second year of the trial with 224 kg/da; when the varieties were compared, the Çiftçi variety showed the highest value with 188 kg/da in the same year. Notably, these results surpass the findings of a previous study by Aydoğan et al. (2008), where the highest yield reported was 176.2 kg/da.

Despite the Şakar variety exhibiting the highest winter damage with a score of 5 points in the second year of the experiment, no significant differences were observed in yield values over the years. It is worth noting that harsh winter conditions lead to yield losses, as stated by Bélanger et al. (2006).

In the year 2021, the Fırat87 variety displayed the lowest yield, and in 2022, the Şakar variety showed the second lowest yield at 116 kg/da and 132 kg/da, respectively. It is interesting to highlight that, contrary to the study conducted by Çölkesen et al. (2014), where the Fırat 87 variety exhibited yields ranging from 180.50 to 243.68 kg/ha with an average of 212.09 kg/ha during the 2011-12 seasons, the material tested under current conditions achieved the highest yield of 166 kg/ha in 2023. This suggests an increase in the yield value of the cultivar over the years, displaying its adaptability or potential improvement under the specific conditions of the experiment.

Numerous studies, including Mekonnen et al. (2014), have consistently reported variations among lentil genotypes in terms of per-plant yield. Additionally, Toklu et al. (2015) have noted substantial phenotypic diversity within lentil genotypes. These findings underscore the importance of understanding and harnessing genetic and phenotypic variability in lentil populations, providing valuable insights for breeding programs and cultivation practices aimed at optimizing yield and overall crop performance.

Table 2. Yield evaluations (kg/da)

		Year			
Genotypes	**2021**	**2022**	**2023**	**Least Sq Mean**	**Range**
AKM 1087	152	224	206	194	A
AKM 1089	147	208	206	187	A
AKM 1077	134	187	219	180	A
ÇİFTÇİ	160	188	168	172	AB
AKM 1021	144	208	159	171	AB
FIRAT 87	116	153	166	145	BC
ŞAKAR	137	132	143	137	C
Source	**DF**	**Sum of Squares**	**F Ratio**		
Year	2	24812,794	13,5594**		
GEN	6	24274,159	4,4217**		
GEN*Year	12	13896,984	1,2657 **ns**		
Rep[Year]	6	4065,81	0,7406 **ns**		
Error	36	32938,857	914,97		
C. Total	62	99988,603			
%CV	17,85990148				
LSD	28,91914374				

The thousand-seed weight was found to be statistically significant at the 1% level. Over the years, there has been a noticeable downward trend in the values of lines and genotypes. The average thousand-seed weight for lines and varieties across years is 39 g, as detailed in Table 3, which provides comprehensive statistics and reference ranges.

Lines and varieties exceeding the trial averages for thousand-seed weight across years are highlighted in the table. The recorded values range from the lowest of 34 g in Fırsat87 to the highest of 49 g in Şakar. Notably, among the lines, AKM 1077 stands out with a superior value of 43 grams.

Comparing the advanced lentil lines to the check varieties reveals a greater phenotypic diversity, a finding consistent with Toklu et al. (2017). Additionally, Tyagi et al. (2011) reported significant differences in 1000-seeds weight between lines and checks. These observations underscore the importance of considering and leveraging such diversity for optimizing seed weight in lentil breeding programs.

Table 3. Statistical analysis of 1000-seeds weight

		Year			
Genotypes	**2021**	**2022**	**2023**	**Least Sq Mean**	**Range**
ŞAKAR	49	41	40	43	A
AKM 1077	43	37	37	39	B
ÇİFTÇİ	40	35	40	38	B
AKM 1087	39	38	37	38	B
FIRAT 87	43	35	34	38	BC
AKM 1021	39	35	38	37	BC
AKM 1089	38	35	36	36	C
Source	**DF**	**Sum of Squares**	**F Ratio**		
GEN	6	250,46444	11,6144*		
Rep[Year]	6	46,14381	2,1398		
Year	2	295,93556	41,169		
GEN*Year	12	168,56889	3,9084		
Error	36	129,38952	3,5942		
C. Total	62	890,50222			
%CV	4,9228002				
LSD	1,812504033				

Table 4 presents the morphological data evaluation for the lentil genotypes. Notably, plant height, a crucial factor for harvesting and pod binding, exhibited variations across the genotypes. Fırat87 displayed the highest plant height, reaching 33 cm in the final year of the experiment, with the peak values observed in the third year of the trial. Control varieties exhibited the shortest and longest values for plant height, with Fırat87 recording the longest value in 2023 (33 cm) and Çiftçi registering the shortest in 2021 (23.7 cm).

In terms of lines, AKM 1089 and 1077 achieved the longest values at 30 cm and 31 cm, respectively, in 2023. Additionally, the first pod height exhibited an average ranging from 7 cm to 16 cm among the lines. The three-year average for the 50% flowering time was reported as 196 days, a trait known to significantly influence lentil yield.
Comparing these findings to a lentil breeding study conducted at the same location in 2001 and 2003, where flowering dates changed from 197 to 261 days, underscores the dynamic nature of flowering traits over time (Kahriman et al., 2015). These observations emphasize the importance of understanding and monitoring morphological traits for informed lentil breeding strategies.

Table 4. Morphological observations

		2021			2022			2023	
Genotypes	**%50 f.d**	**p.h.**	**f.p.h**	**% 50 f.d**	**p.h.**	**f.p.h**	**% 50 f.d**	**p.h.**	**f.p.h**
AKM1021	189	24,7	12	208	25	15	196	29	8
AKM1087	189	24,7	12	206	28	13	195	26	8
AKM1089	189	24,7	12	204	26	16	196	31	8
AKM1077	187	26,7	12	206	27	14	194	30	8
Şakar	188	26,3	13	204	25	10	191	31	9
Fırat 87	188	24,3	11	209	25	16	196	32	7
Çiftçi	189	23,7	12	208	26	15	195	28	7
Min	187	23,7	11	204	25	13	191	28	7
Max	189	26,7	13	209	28	16	196	32	9
Average	189	25	12	206	26	14	194	29	8

(%50 f.d.: 50% Flowering days, p.h.: Plant Height (cm), f.p.h: First pod height (cm))

Upon evaluating the stability of the genotypes was evaluated with respect to the yield and thousand-seed weight (Figure 3, 4), it was observed that AKM 1077 and AKM 1087 had high stability over the years, besides having high yield. However, while Şakar has the lowest stability in terms of yield value, it has the highest stability in terms of thousand-seed weight.

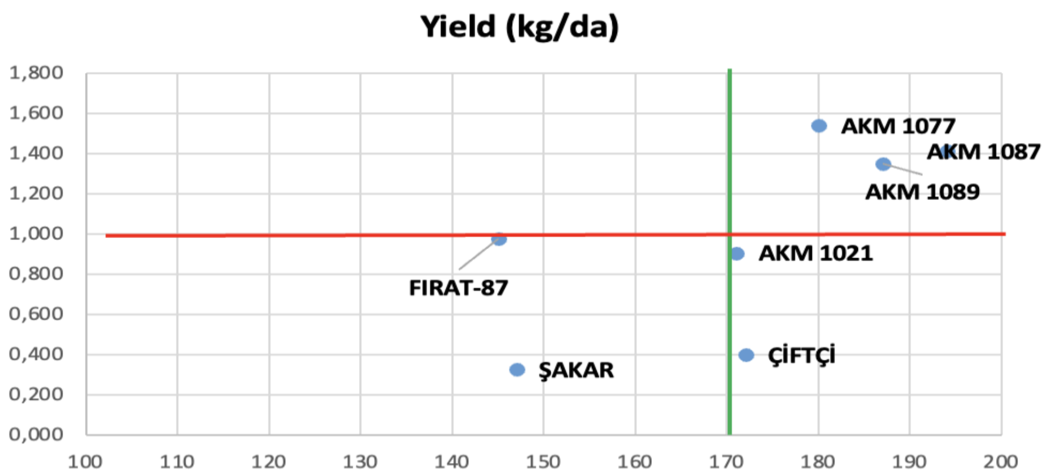


Figure 3. The stability analysis of yield value

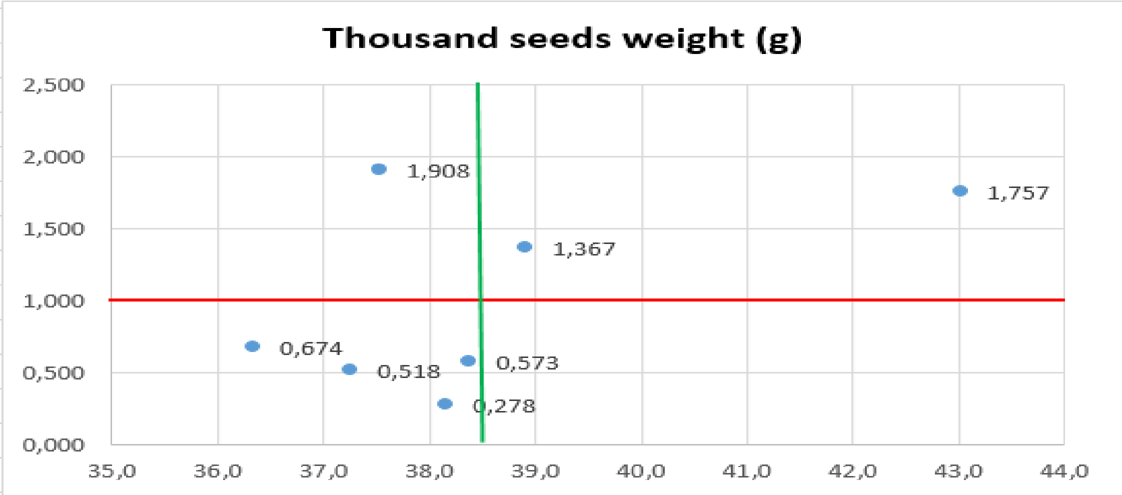
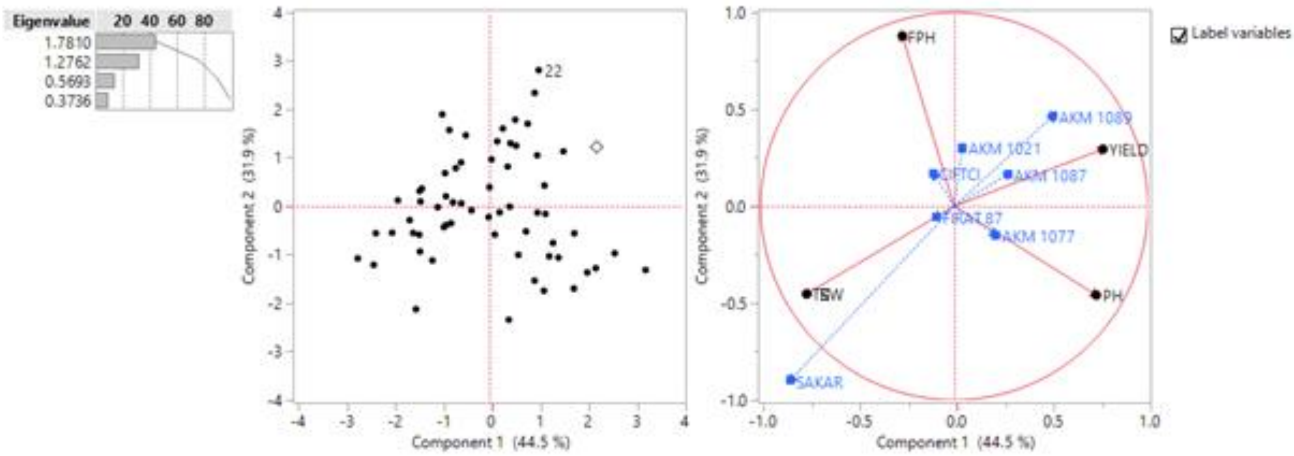


Figure 4. The stability analysis of thousand-seed weight

With the principal component analysis (Figure 5), it was shown that the proximity of the lines to each other and their superiority are specified in the figure. For plant breeding comprehension the basis of genotype × environment (GxE) interaction is vital (Subedi et al., 2021). According to the principal component analysis, results suggest that the majority (75%) of the variation observed in the dataset is attributed to differences between genotypes. The remaining 25% of the variation is attributed to external factors. These external factors could include environmental conditions, management practices, or any other non-genetic influences that contribute to the observed differences among the genotypes. It indicates that a significant portion of the observed differences is genetically determined, while a smaller proportion is influenced by external, non-genetic factors. The findings suggest that a substantial portion of the observed variation can be explained by genetic factors, reinforcing the importance of genotype-related differences in the context of the studied plant population.



(ph: plant height, tsw : thousand seed weight, fph: first pod height)

Figure 5. Principal component analysis

Conclusion

Climate change is exerting a significant influence on lentil yield and yield components, primarily due to irregular alterations in temperature and rainfall. A recent three-year study conducted under Ankara Haymana conditions, focusing on seven genotypes, yielded noteworthy findings. Observations on winter damage indicated some impact between lines from 1 to 5, although it was not particularly pronounced. The findings of the study suggest that a significant portion (75%) of the observed variation within the studied plant population can be attributed to genetic factors. This reinforces the pivotal role of genotype-related differences in shaping the traits and characteristics under investigation. The remaining 25% of the variation is influenced by external factors, highlighting the complex interplay between genetic and environmental elements.

Recommendations

Key outcomes of the study identified specific lines, namely AKM 1077 and AKM 1087. These lines demonstrated high yield potential, resilience against winter damage, substantial thousand-seed weight, and remarkable vegetative characteristics. This updated and comprehensive dataset contributes valuable insights for future lentil breeding studies, particularly in the context of addressing climate change challenges.

Data Availability

Researchers who want to access data for further analysis should use relevant data and documents; For any questions or requests regarding the dataset, please contact the corresponding author.

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