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(Research Article)

Genetic variability and heritability among durum wheat (*Triticum durum* Desf.) lines for grain yield and its components performance

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Abstract

Durum wheat (*Triticum durum* Desf.) is a staple crop in Tunisia and the Mediterranean region, where yield is strongly influenced by environmental variability. The present study evaluated 19 durum wheat lines over two cropping seasons (2021–2022 and 2022–2023) to assess genetic variability, heritability, and expected genetic advance for grain yield and its components. Variance analysis revealed significant effects of genotype, year and their interaction on most traits. Environmental conditions accounted for the largest proportion of variation in grain yield (77.91%), highlighting the dominant influence of year-to-year climatic differences. Significant genotypic variation was observed for number of plants per square meter, number of spikes per square meter, number of grains per spike, thousand-kernel weight, and grain yield, identifying promising lines for further selection. A high broad-sense heritability for the number of grains per spike (83.04%) with a corresponding expected genetic gain of 9.18, indicating strong additive genetic control and potential for effective selection. Other traits exhibited lower heritability and genetic gains, reflecting a substantial environmental influence. These findings provide valuable information for durum wheat breeding programs aimed at enhancing grain yield and stress adaptation in Tunisia and similar environments.

Keywords: Durum wheat; Genetic variability; Heritability; Grain yield; Mediterranean environment

1. Introduction

Durum wheat (*Triticum durum* Desf.) is a major cereal crop in Tunisia and across the Mediterranean region, where it plays a crucial role in food security and agricultural sustainability. In Tunisia, durum wheat is predominantly cultivated under rainfed conditions, often characterized by irregular rainfall, recurrent drought, and increasing temperature stress. These constraints lead to strong variability in grain yield and emphasize the need to improve yield potential and stability through well-adapted breeding strategies [1,2].

Grain yield in durum wheat is a complex quantitative trait resulting from the combined expression of several yield components, including plant density, number of spike per unit area, number of grain per spike, and thousand-kernel weight. Under Mediterranean environments, these traits are differentially affected by environmental conditions, particularly water availability during critical growth stages, which complicates direct selection for grain yield [3]. Consequently, identifying yield components with strong genetic control and reliable contribution to grain yield is essential for effective selection.

The existence of genetic variability among breeding lines is a prerequisite for genetic improvement. The partitioning of phenotypic variance (σ^2p) into its genetic (σ^2g) and environmental components provides insight into the relative

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importance of genetic factors controlling trait expression [4]. Analysis of variance is commonly used to detect significant differences among genotypes, indicating the presence of exploitable genetic diversity for grain yield and its related traits. Heritability in the broad sense (h^2) is a key parameter for predicting the efficiency of selection, as it reflects the proportion of phenotypic variation that is genetically determined. However, heritability alone does not fully describe the expected response to selection. The estimation of genetic advance (GA), which combines heritability with the magnitude of phenotypic variability, allows a more realistic assessment of the potential improvement achievable through selection [5]. Traits characterized by high heritability and high genetic advance are generally governed by additive gene action and are considered reliable targets for selection in breeding programs. Previous studies conducted under Mediterranean and North African conditions have reported variable estimates of genetic variance, heritability, and genetic advance for grain yield and its components in durum wheat, depending on genetic background and environmental conditions [6]. Therefore, evaluating these genetic parameters under Tunisian conditions remains essential to identify traits with high breeding value and to support the development of improved durum wheat cultivars adapted to Mediterranean environments.

In this context, the present study aims to assess genotypic and environmental effect on grain yield and its related traits and to estimate phenotypic variance (σ^2p), genetic variance (σ^2g), broad-sense heritability (h^2), and expected genetic advance (GA) for studied traits. The results are expected to provide valuable information for selecting traits and genotypes with high genetic potential for yield improvement under Tunisian and Mediterranean conditions.

2. Material and Methods

2.1. Plant Material

The experiment was conducted using 19 durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) Husn) lines provided by the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) (Table 1).

Table 1 List of studied durum wheat lines

Genotype Number	Code
1	L1
2	L2
3	L3
4	L4
5	L5
6	L6
7	L7
8	L8
9	L9
10	L10
11	L11
12	L12
13	L13
14	L14
15	L15
16	L16
17	L17
18	L18
19	L19

2.2. Experimental Design

The trial was carried out during the 2021/2022 and 2022/2023 cropping seasons at the National Institute of Field Crops at El Marja experimental platform, located 8 km from the city of Boussalem, Jendouba governorate, at 36°31'55.41" N latitude, 8°57'15.87" E longitude. This site belongs to the semi-arid zone, characterized by hot and dry summers and mild winters with frequent dew days. The experiment was conducted under rainfed conditions.

A randomized complete block design (RCBD) with three replications was used. Each experimental plot covered an area of 4.8 m^2 (1.2 m × 4 m) and consisted of six sowing rows with 0.2 m inter-row spacing.

The soil was classified as loamy-clay in texture. Physico-chemical analyses indicated that the soil contained 22.75 ppm of P_2O_5, 345.75 ppm of K_2O, and 1.25% organic matter. Relevant information about rainfall amount during 2021/2022 and 2022/2023 growing seasons are provided in Figure 1.

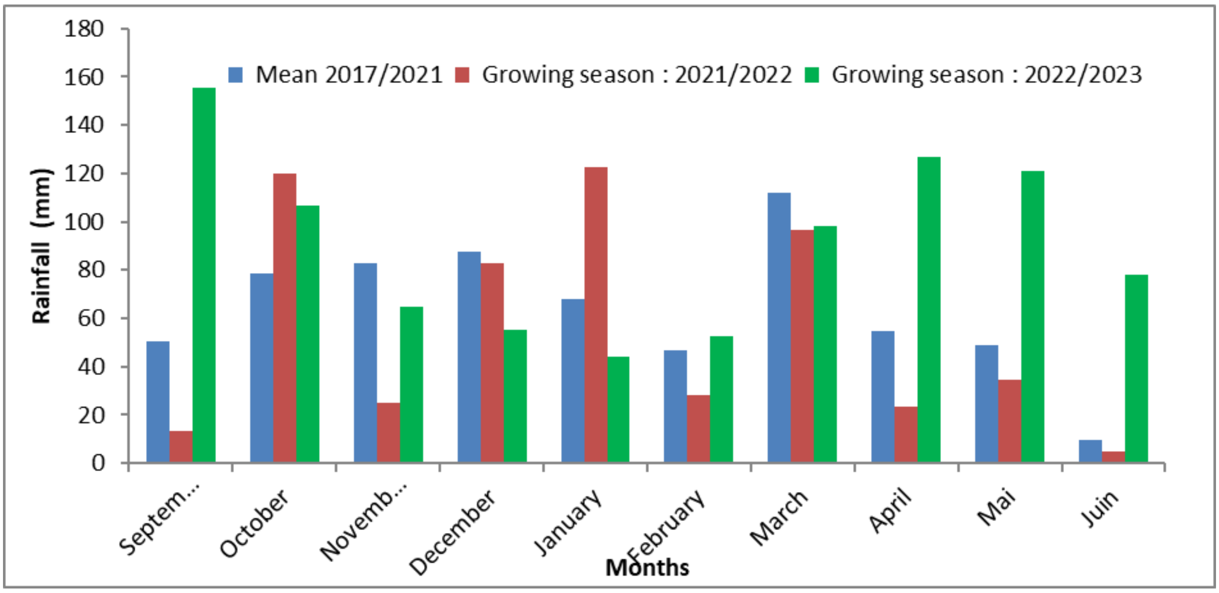

Figure 1 Rainfall (mm) over four years (2017–2021) and during the cropping seasons 2021/2022 and 2022/2023 at El Marja site

2.3. Data collection

2.3.1. Agro-morphological traits

Data relating to number of plant per square meter (PN/m^2), number of spike per square meter (NS/m^2), number of grain per spike (NG/S), 1000-grain weight (TKW) and grain yield were randomly collected from each line at maturity.

2.3.2. Genetic parameters estimate

Heritability in broad sense (H^2 or h^2) was estimated according to Falconer [7] using the following equation :

$$h^2 = \sigma^2 g / \sigma^2 ph$$

h^2: Heritability; $\sigma^2 g$: genotypic variance and $\sigma^2 ph$: phenotypic variance. Genotypic ($\sigma^2 g$) and Phenotypic

($\sigma^2 ph$) were obtained from the analysis of variance table according to Comstock and Robinson [8] using these equations.

$$\sigma^2 g = (CM1/CM2)/r*s$$

$$\sigma^2 ph = CM1/(r*s)$$

Where r: replication, s: season, MS1: Mean square for genotype, MS2: Mean square for genotype × growing season.

Genetic advance (GA) was calculated with the method suggested by Allard [9] using the following equation:

$$GA= K * \sigma ph * h^2$$

Where GA: genetic advance ; K: constant = 2.06 at 5% selection intensity ; σph: square root of phenotypic variance ; h^2: Heritability.

2.4. Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) using SPSS software version 26.0. Mean comparisons for the measured traits were performed using Duncan's multiple range test at a 5% significance level.

3. Results and discussion

3.1. Variance analysis

All collected data were subjected to multivariate statistical analysis. The analysis of variance (ANOVA) performed for the different traits measured in the 19 durum wheat lines over the two cropping seasons (2021–2022 and 2022–2023) revealed a highly significant year effect ($p < 0.001$) for all evaluated parameters (Table 2). This result reflects the strong influence of interannual climatic variability on durum wheat performance, which is characteristic of Tunisian and Mediterranean agro-ecosystems, where rainfall distribution and temperature fluctuations largely determine crop growth and yield formation [10,11].

Table 2 Analysis of variance (mean squares) for plant number per square meter (PN/m^2), spike number per square meter (SN/m^2), grain number per spike (GN/S), thousand-kernel weight (TKW,g), and grain yield (GY,q/ha) of different durum wheat lines evaluated over two cropping seasons (2021/2022 and 2022/2023).

SV	df	PN/m^2	SN/m^2	GN/S	TKW(g)	GY (q/ha)
Year (Y)	1	11956.63***	1220782.53***	94.05***	2496.79***	6324.60***
Genotype (G)	18	665.27***	3016.354***	172.82***	52.51***	53.75***
Y × G	18	482.21ns	2958.21***	29.31***	42.44**	45.84***

Y: years; G: Genotypes; SV: source of variation; df: degrees of freedom; ns: not significant; *: significant at $p < 0.05$; **: significant at $p < 0.01$; ***: significant at $p < 0.001$.

The ANOVA result revealed a significant genotype effect for GY and its components, including PN/m^2, SN/m^2, GN/S, and TKW. The presence of significant genotypic differences indicates substantial genetic variability among the evaluated lines, which is a prerequisite for effective selection and genetic improvement [12]. Similar findings have been reported in previous studies on durum wheat under Mediterranean and semi-arid conditions, highlighting the existence of exploitable genetic diversity for yield-related traits [13].

The year × genotype interaction was significant for grain yield and several yield components, notably, SN/m^2, GN/S, TKW and GY. This interaction suggests that the relative performance of genotypes varied across cropping seasons, reflecting differential responses to environmental conditions. Such genotype-dependent behavior across years has been widely reported in durum wheat and emphasizes the importance of multi-environment or multi-year evaluations to reliably assess yield stability and adaptation under Mediterranean conditions [14,15].

In contrast, the non-significant interaction effects observed for PN/m^2 indicate a relatively stable expression of this trait across years and genotypes, possibly due to limited genetic variability or stronger environmental control. Similar observations have been reported for physiological traits which revealed a reduced genetic differentiation under field conditions [16].

3.2. Environmental Effect

As shown in Table 3, the lowest mean values for PN/m^2 (77.67), SN/m^2 (83.77), GN/S (29.80), TKW (34.80 g), and GY (11.49 q/ha) were recorded during the 2022–2023 cropping season. In contrast, the highest values for all measured traits were observed during the 2021–2022 season, indicating more favorable growing conditions during that year.

Table 3 Number of plant per square meter (PN/m^2), number of spike per square meter (SN/m^2), number of grain per spike (GN/S), thousand-kernel weight (TKW,g), and grain yield (GY, q/ha), averaged across all durum wheat lines, over two cropping seasons (2021/2022 and 2022/2023).

	PN/m^2	SN/m^2	GN/S	TKW (g)	GY (q/ha)
GS :2021/2022	98.15	290.73	31.62	44.16	26.38
GS :2022/2023	77.67	83.77	29.80	34.80	11.49

GS : growing season

Statistical analysis confirmed a significant environmental (year) effect on all evaluated traits. The environment accounted for 77.91% of the total variation in grain yield, whereas the genotype × environment interaction and the genotype effect explained 10.16% and 11.91% of the variation, respectively (Table 4). These results clearly demonstrate that grain yield in durum wheat is a highly environment-dependent trait, particularly under Mediterranean and Tunisian conditions characterized by strong interannual climatic variability [17,18].

Table 4 Percentage contribution to the total sum of squares**.**

	df	SC	% TSS
Years	1	6324.605	77.9151703
Genotypes	18	967.57	11.9198561
Years*genotypes	18	825.121	10.1649737
Total		8117.296	

df: degrees of freedom; SS: sum of squares; TSS: total sum of squares.

Unfavorable environmental conditions, such as water deficit and high temperatures during critical growth stages, are known to negatively affect grain yield and lead to substantial economic losses. Several studies have emphasized that higher heritability of grain yield is generally observed under favorable conditions, whereas stress environments tend to reduce the expression of genetic potential and increase environmental variance [19–21]. In this regard, the genetic expression of a given genotype is more likely to be fully expressed under optimal conditions, while it may differ considerably under stress-prone environments, such as those frequently encountered in rainfed Mediterranean systems [22,23].

3.3. Genotypic Effect

Significant differences were observed among the evaluated durum wheat lines for several agro-morphological traits (Table 5), confirming the presence of substantial genetic variability within the studied material. For the PN/m^2, line L6 exhibited the highest mean value (109), although it did not differ significantly from lines L15, L10, L18, L11, L2, L4, and L19. The observed variation in plant number among lines may reflect differences in establishment ability and early vigor, traits that are particularly important under rainfed Mediterranean conditions [27].

Regarding the SN/m^2, the highest value (230) was recorded for line L18, followed by L12, L11, L14, L1, L6, L15, L5, L4, and L10. Spike number is a major determinant of grain yield in wheat and is strongly influenced by both genetic background and environmental adaptability [27]. Lines exhibiting higher spike number are generally considered better adapted to environments with variable rainfall, as this trait contributes to yield stability [28].

For the GN/S, lines L17 and L6 showed the highest values, with approximately 38 grains per spike, and did not differ significantly from line L14 (36 grains). This trait reflects spike fertility and is closely associated with reproductive success under stress conditions, particularly during flowering and grain set [29].

TKW also varied significantly among genotypes. The highest TKW was observed in line L17 (43.98 g), followed by lines L11 (42.72 g) and L9 (42.66 g), respectively. Grain weight is generally considered a more stable yield component compared to other traits and often shows higher heritability, making it a reliable selection criterion in breeding programs targeting drought-prone environments [30].

GY differed significantly among the studied lines, with the highest yield recorded for line L11 (24.73 q/ha), followed by L6 (23.01 q/ha) and L17 (22.61 q/ha). The superior performance of these lines suggests a favorable combination of yield components, including spike number, grain number and grain weight. Similar results have been reported in previous studies on wheat and other cereals, where genotypes with higher grain yield under water-limited conditions were identified as valuable genetic resources for breeding programs [31,32].

Overall, the significant genotypic variation observed for grain yield and its components indicates that the tested germplasm contains promising lines with potential tolerance to water stress. These lines could be exploited as parents in breeding programs aiming to improve grain yield and adaptation to drought-prone Mediterranean environments.

Table 5 Genotypic variation for agro-morphological traits in durum wheat lines : plant number per square meter (PN/m²), spike number per square meter (SN/m²), grain number per spike (GN/S), thousand-kernel weight (TKW, g) and grain yield (GY, q/ha).

Genotypes	PN/m²	SN/m²	GN/S	TKW (g)	GY (q/ha)
L1	85.42^{bcdef}	201.67^{abc}	35.33^{abc}	41.85^{abc}	20.41^{abcde}
L2	91.67^{abcdef}	179.17^{bcd}	25.08^{e}	38.28^{abcde}	18.94^{bcde}
L3	83.33^{bcdef}	161.67^{cd}	32.27^{bcd}	40.73^{abc}	19.25^{bcde}
L4	90.83^{abcdef}	187.50^{abc}	31.17^{cd}	40.91^{abc}	20.22^{abcde}
L5	78.33^{cdef}	197.50^{abc}	29.48^{d}	40.89^{abc}	20.15^{abcde}
L6	108.75^{a}	200.42^{abc}	37.53^{a}	41.17^{abc}	23.01^{ab}
L7	68.33^{f}	136.50^{d}	24.58^{e}	39.93^{abcd}	17.59^{cdef}
L8	81.67^{bcdef}	175.83^{bcd}	35.12^{abc}	41.04^{abc}	21.01^{abcd}
L9	85.00^{bcdef}	166.67^{cd}	35.57^{abc}	42.66^{ab}	22.03^{abc}
L10	101.67^{abc}	185.42^{abc}	34.03^{abc}	37.01^{bcde}	16.83^{def}
L11	95.00^{abcde}	209.17^{abc}	31.42^{cd}	42.72^{ab}	24.73^{a}
L12	76.67^{def}	224.17^{ab}	24.58^{e}	37.53^{bcde}	16.17^{def}
L13	85.00^{bcdef}	179.67^{bcd}	33.83^{abcd}	41.36^{abc}	19.57^{bcde}
L14	75.00^{ef}	202.50^{abc}	36.04^{ab}	36.41^{cde}	15.65^{ef}
L15	105.00^{ab}	198.33^{abc}	20.67^{e}	36.31^{cde}	15.49^{ef}
L16	84.17^{bcdef}	175.00^{cd}	22.83^{e}	34.36^{de}	13.82^{f}
L17	85.83^{bcdef}	166.67^{cd}	37.71^{a}	43.98^{a}	22.61^{ab}
L18	99.58^{abcd}	230.00^{a}	24.83^{e}	33.21^{e}	15.88^{ef}
L19	89.17^{abcdef}	180.00^{bcd}	31.50^{bcd}	39.84^{abcd}	16.51^{def}

Means followed by the same letter within the same column are not significantly different at the 5% probability level.

3.4. Heritability Estimation and Expected Genetic Gain

Phenotypic variance (σ^2p) represents the observable variation in a trait within a population, encompassing both genetic and environmental components. Therefore, its magnitude depends on the environmental conditions under which the population is evaluated [33]. Broad-sense heritability (h^2), defined as the proportion of total phenotypic variance attributable to genetic variance (σ^2g) [34], provides an estimate of the extent to which a trait is genetically controlled. Heritability values are commonly classified as very high (≥ 80%), moderately high (60–79%), moderate (40–59%) or low (≤ 40%) [35]. If the heritability of a trait is very high, selection for this trait may be effective in improving grain yield in durum wheat. However, heritability alone does not provide information on the expected improvement in the selection for a given trait. Thus, it is useful to estimate the expected genetic advance.

In the present study, estimated heritability varied considerably among the measured traits (Table 6). The highest heritability was observed for the GN/S (83.04%), which also exhibited the highest expected genetic advance (9.18%). This suggests that the genetic control of this trait is predominantly additive, making this trait highly responsive to selection and a reliable target for breeding programs aiming to improve grain yield under Mediterranean conditions [36,37].

Table 6 Broad sense heritability (h^2,%), phenotypic variance (σ^2p), genotypic variance (σ^2g), GA : genetic advance for various agro-morphological traits in tested durum wheat lines

Traits	σ^2g	σ^2p	h^2 (%)	GA (%)
PN/m²	30.511	110.879667	27.5172184	5.96894678
SN/m²	9.68966667	502.725667	1.92742629	0.89024702
GN/S	23.9176667	28.8036667	83.0368819	9.18041135
TKW	1.678	8.75233333	19.1720303	1.16841535
GY	1.319	8.959	14.7226253	0.90778342

PN/m^2:plant number per square meter, SN/m^2:spike number per square meter, GN/S : grain number per spike, TKW : thousand-kernel weight, GY :grain yield.

Conversely, PN/m^2, SN/m^2, TKW, and GY, exhibited low heritability values (ranging from 1.93% to 27.52%) with correspondingly low expected genetic advances (0.89–5.97%). These low values indicate a strong influence of environmental factors on these traits, consistent with the results of our ANOVA and environmental effect analyses, where year accounted for the majority of variation in grain yield (77.91%) [17,18].

The observed low heritability for most traits highlights the challenge of improving grain yield directly under variable Mediterranean conditions, where environmental fluctuations can mask genetic differences [38]. Nevertheless, traits with higher heritability and genetic advance, such as GN/S, offer reliable indirect selection criteria, as increasing spike fertility can contribute significantly to overall grain yield even in stress-prone environments [22,36]. These findings are in agreement with previous studies, which reported that selection for yield components with high heritability is more effective than direct selection for grain yield in wheat and other cereals under drought or semi-arid conditions [37,39].

4. Conclusion

This study demonstrated significant genetic variation among the 19 evaluated durum wheat lines for grain yield and its components under Tunisian Mediterranean conditions. Environmental factors, particularly interannual climatic variability, had a dominant effect on most traits, with grain yield being highly environment-dependent. Broad-sense heritability and expected genetic advance revealed that the number of grain per spike is the most promising trait for selection, due to its strong genetic control and high potential for improvement. These results highlight the importance of integrating genotypic evaluation, environmental assessment, and selection for highly heritable yield components in breeding programs. Overall, the identified lines represent valuable genetic resources for developing durum wheat cultivars with improved grain yield and adaptability to water-limited Mediterranean conditions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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