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# VARIETAL ASSESSMENT, HERITABILITY AND CORRELATION ANALYSIS OF ADAPTATION- AND PRODUCTION-RELATED TRAITS IN BREAD WHEAT LANDRACES OF THE ALGERIAN SAHARA OASES

**M. Boulacel [1] T. Hadji [1]* A. Ghennai [1] M. Hadji [2] A. Benlahbib [1] N. Souilah [1] H. Bendif [3]**

**[1] Laboratory of Development and Valorization of Plant Genetic Resources, Department of Plant Biology, Mentouri Brothers University of Constantine 1, Route de Ain El Bey, Constantine 25017, Algeria.**
**[2] Biodiversity and Biotechnology Techniques of Plant Resources Valorization Laboratory, SNV Department, Faculty of Sciences, University of M'sila, 28000, Algeria.**
**[3] Department of Nature and Life Sciences, Faculty of Sciences, University of Msila, Msila 28000, Laboratory of Ethnobotany and Natural Substances, Department of Natural Sciences, Ecole Normale Supérieure (ENS), Alger 16308, Algeria.**

***Correspondence to:** T. Hadji, Laboratory of Development and Valorization of Plant Genetic Resources, Department of Plant Biology, Mentouri Brothers University of Constantine 1, Route de Ain El Bey, Constantine 25017, Algeria.
**Email:** tokahad@gmail.com

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## Abstract

Wheat from the Algerian Saharan oases represent important breeding material for the development of genotypes resistant to environmental stress and climate change. This study was conducted on six Saharan oases bread wheat (*Triticum aestivum* L.) landraces using complete randomized block design. It evaluated their morphological, agronomical, physiological and phenological performance, and their related estimates of genetic variability and heritability under semi-arid conditions during the 2020/2021 growing season. Data were analyzed for correlation coefficient, path coefficient analysis, principal component analysis and cluster analysis. The results revealed the existence of significant variations in all measured traits. High heritability and high genetic advance were recorded for yield, yield-related traits, and most morphological traits including plant height, peduncle length, spike length, number of nodes, and flag leaf area.

Additionally, analyses of correlation coefficients showed grain yield to be significantly correlated to yield-related traits, chlorophyll content, days to first leaf, days to booting and days to heading. Furthermore, path coefficient analysis showed direct positive effects of number of grains per spike, weight of thousand grain and days to booting on grain yield. Multivariate analysis enabled the study of the relationship between different traits while simultaneously aiding in the classification and selection of the highest yielding and best adapted landraces.

**Keywords:** Oasis wheat, Phenological traits, Agro-morphological traits, Heritability, Path analysis.

# تقييم التنوع، تحليل التوريث والترابط للصفات المتعلقة بالتكيف والإنتاج في سلالات محلية من حنطة الخبز من واحات الصحراء الجزائرية

**معاذ بولعسل [1] تقى حاجي [1]* غناي عواطف [1] مروة حاجي [2] عبد الحميد بلحبيب [1]**

**نبيلة صويلح [1] حمدي بن ضيف [3]**

**[1] مختبر تطوير وتثمين الموارد النباتية، كلية بيولوجيا النبات، جامعة قسنطينة 1 الإخوة منتوري، طريق عين الباي، قسنطينة، 25017، الجزائر**

**[2] مختبر التنوع الحيوي وتقنيات البيوتكنولوجيا لتثمين الموارد النباتية، كلية علوم الطبيعة والحياة، جامعة المسيلة، 2800، الجزائر**

**[3] كلية علوم الطبيعة والحياة-جامعة المسيلة، 28000. مختبر الانتوبوتانيك والمواد الطبيعية، كلية العلوم الطبيعية، المدرسة العليا للأساتذة، الجزائر 16308، الجزائر**

***المراسلة الى:** تقى حاجي، مختبر تطوير وتثمين الموارد النباتية، كلية بيولوجيا النبات، جامعة قسنطينة 1 الإخوة منتوري، طريق عين الباي، قسنطينة، 25017، الجزائر.

**البريد الالكتروني:** tokahad@gmail.com

## الخلاصة

يمثل قمح الواحات الصحراوية الجزائرية مادة تربية مهمة لتطوير أصناف مقاومة للإجهاد البيئي وتغير المناخ. أجريت هذه الدراسة على ستة أصناف محلية للقمح الناعم (*Triticum aestivum* L.) من واحات الصحراء باستخدام تصميم القطاعات العشوائية الكاملة. هدفت إلى تقييم أدائها المورفولوجي والزراعي والفسيولوجي والفينولوجي، وتقديرات التباين الوراثي ونسبة التوريث في ظل الظروف شبه الجافة خلال موسم النمو 2021/2020. تم تحليل البيانات لمعامل الارتباط، وتحليل معامل المسار، وتحليل المكونات الرئيسية. كشفت النتائج عن وجود تباين كبير في جميع الصفات المقاسة. تم تسجيل نسبة توريث عالية وتقدم وراثي عالٍ

للمحصول والصفات المرتبطة بالمحصول، ومعظم الصفات المورفولوجية بما في ذلك ارتفاع النبات، طول عنق السنبلة، طول السنبلة، عدد العقد، ومساحة الورقة العلمية. بالإضافة إلى ذلك، أظهر تحليل معاملات الارتباط أن محصول الحبوب يرتبط ارتباطًا كبيرًا بالصفات المرتبطة بالحاصل، محتوى الكلوروفيل، عدد الأيام حتى ظهور الورقة الأولى، عدد الأيام حتى الانتفاخ، وعدد الأيام حتى الإسبال. علاوة على ذلك، أظهر تحليل معامل المسار تأثيرًا إيجابيًا مباشرًا لعدد الحبوب في السنبلة، ووزن الألف حبة، وعدد الأيام حتى الانتفاخ على محصول الحبوب. مكّنت التحليلات متعددة المتغيرات من دراسة العلاقة بين الصفات المختلفة وساعدت في تصنيف واختيار الأصناف المحلية ذات المحصول الأعلى والأكثر تكيفًا في آن واحد.

**كلمات مفتاحية:** قمح الواحات، فينولوجيا، الخصائص الزراعية والمورفولوجية، نسبة التوريث وتحليل المسار.

## Introduction

Wheat farming covers vast expanses of agricultural land in Algeria spanning approximately 1.9 million hectares, mostly in its Mediterranean region and high plateaus, coastal plains, and sublittoral plains (15). However, wheat production in the region is subject to various challenges of irregular annual rainfall distribution, intermittent droughts, and urbanization (36). This highlights the importance of leveraging and utilizing the phytogenetic resources found in the oases of the Sahara which possess much potential in boosting wheat cultivation and production in Algeria.

Historically, wheat landraces from Saharan oases have garnered attention from travelers, although early descriptions were often vague. Notably, (17 and 19) were among the first to recognize their significance, focusing primarily on the morphology of spikes and grains, as well as systematic botany, genetic diversity, and origin (8 and 13). (17 and 46) observed high tolerance to salinity, drought, and heat in certain oasis landraces, while (19) highlighted landraces with superior bread-making qualities. These findings underscore the potential of Saharan Oasis wheat landraces for future breeding programs.

Despite recent studies such as on the diversity of Saharan oasis wheat landraces and their potential tolerance to abiotic stress by (49), and the survey by (39) evaluating their morphological diversity, concerns persist regarding the disappearance of traditional crop varieties from their native regions due to the introduction of modern cultivars, land restoration efforts, and urbanization (30 and 31). (19 and 49) have highlighted the risk of genetic erosion facing Saharan wheat landraces.

The primary objective of this investigation is to assess the genetic diversity present among a selection of oasis bread wheat landraces and to evaluate their agronomic performance when cultivated outside of their native environments. Specifically, the study aims to analyze various morphological, phenological, physiological, and yield-related traits to classify the landraces into distinct groups and identify their most promising characteristics. Moreover, it seeks to elucidate the associations between these diverse attributes and their direct and indirect impacts on grain yield, as determined through path analysis. The findings on these key relationships will inform the identification of superior-performing landraces that can be strategically incorporated into future wheat breeding initiatives.

## Materials and Methods

This investigation used six bread wheat (*Triticum aestivum* L.) landraces sourced from the Saharan oases of Algeria (Table 1). The experiment was carried out during the 2020/2021 growing season at the Chaabat Erassas experimental station in the University of Constantine 1, Algeria. The experimental design employed a complete randomized block arrangement with four replications. The soil at the site exhibited a clay-loam texture, comprising 67.4% clay, 19.7% silt, 6.97% fine sand, and 5.81% coarse sand. Additionally, the soil had a pH of 8.16, an electrical conductivity of 813.66 $\mu s.cm^{-1}$, and a total limestone content of 22.1%. Standard agronomic practices, including fertilization, weed control, and pest and disease management, were meticulously observed throughout the study, from planting to harvest.

**Table 1: Saharan oases bread wheat landraces studied.**

| Landrace | Code | Source |
|---|---|---|
| Oum Rokba El Baida | L1 | Touat |
| Chater | L2 | Touat |
| Oum Rokba Elhamra | L3 | Touat |
| Khellouf | L4 | Oued Righ |
| Tazi | L5 | Touat |
| Zeghlou | L6 | Touat |

Five plants from each replication were randomly chosen and data recorded for plant height (pH, cm), peduncle length (PL, cm), spike length without awns (SL, cm), awns length (AL, cm), ear density (N/L where N is the number of spikelets and L the length of the rachis, mm) number of nods (Nb N), number of spikelets (NS), flag leaf area (FLA, $cm^2$), number of herbaceous tillers (Nb HT), number of spike tillers (Nb ST), number of grains per spike (Nb G/S), spikes number per $m^2$ (Nb S/$m^2$), thousand grains weight (TGW, g), and grain yield (GY, $q.h^{-1}$). Chlorophyll content was estimated using the SPAD-502 meter (Chl, SPAD) and relative water content (RWC, %) was determined according to method (6). Fresh leaves were weighed, saturated in distillated water for 24 h, then dried to a constant mass. The resulting fresh, turgid, and dry weights were used to compute RWC using a standard formula: RWC % = ((FW-DW)) / ((TW-DW) × 100.

For phenology, this study opted for the external morphological approach to ensure consistency in the number of sown plants for subsequent evaluation. Phenological data were collected by recording the number of days from sowing until 50% of plants attained the following growth stages: emergence of the first leaf D1stL (first true leaf emerged from the soil surface, Zadoks growth stage 09), emergence of the 4$^{th}$ leaf D4thL (4$^{th}$ leaf fully expanded, Zadoks growth stage 14), booting stage DBT (the sheath of the last leaf has fully developed, and the ear is enlarged but not yet visible, Zadoks growth stage 45), heading DH (first spikelet of inflorescence just visible, Zadoks growth stage 51), flowering DFLW (mature anthers visible, Zadoks growth stage 61), grain filling DGF (grain expansion, Zadoks growth stage 71), and grain ripening DGR (caryopsis hard and straw dead, Zadoks growth stage 91), with each stage quantified in days.

Statistical analysis was carried out using XLSTAT 2016 V1.0 (v18) statistical package (XLSTAT Addinsoft Inc., New York, NY, United States). The collected data were analyzed for descriptive statistics. The data for each trait underwent individual analysis of variance to assess significance among varieties, followed by Fisher's least significant difference (LSD) test at a 5% significance level. Components of variance were determined using the following formula suggested by (11 and 43):

$$\sigma_g^2 = \frac{MS_g - MS_e}{r}; \sigma_g^2 = \frac{MS_g - MS_e}{r}; \sigma_g^2 = \frac{MS_g - MS_e}{r}.$$

where, $\sigma^2_g$, $\sigma^2_e$, $\sigma^2_p$ are the genotypic variance, environmental and phenotypic variance, respectively; and

$MS_g$, $MS_e$, and r, are the mean squares of genotypes, mean squares of error and number of blocks, respectively.

The genetic parameters were derived using variance components following (11 and 45), as follows:

$$GCV(\%) = \frac{\sqrt{\sigma_g^2}}{x} \times 100; GCV(\%) = \frac{\sqrt{\sigma_g^2}}{x} \times 100; GCV(\%) = \frac{\sqrt{\sigma_g^2}}{x} \times 100.$$

where, GCV, PCV, ECV, and x are the genetic coefficient of variation, phenotypic coefficient of variation, environmental coefficient of variation, and the grand mean of each trait.

GCV and PCV were classified as low at values of less than 10%, moderate at 10-20%, and high when above 20% (14).

Heritability was calculated according to (3 and 12) as:

$h_{bs}^2(\%) = \frac{\sigma_g^2}{\sigma_p^2} \times 100$. It was classified as low (<40%), moderate (40-60%), and high (>60%) according to (44).

The expected genetic advance was calculated according to (28) as follows:

$$GA = \frac{\sigma_g^2}{\sigma_p^2} \times k \times \sigma_p;$$

where, k is a constant 2.06 assuming that the selection intensity is 5%, and GA is the genetic advance.

The genetic advance as percentage of mean was estimated as follows:

$GAM\ (\%) = \frac{GA}{x} \times 100$. It was classified high at above 20%, moderate (10 to 20%), and low (less than 10%) (28).

Pearson's coefficient correlation was performed to assess the association of different traits among themselves and with yield. Furthermore, significant correlation coefficients with yield were subjected to path coefficient analysis to separate them into direct and indirect effects. Principal component analysis (PCA) was conducted using a correlation matrix.

## Results and Discussion

Analysis of variance: The results of the analysis of variance and mean performance for 23 measured traits are shown in Table 2. ANOVA showed no significant block effect for all measured traits except for ED and Nb S $m^{-2}$. All the agro-morphological, physiological and phenological traits exhibited a highly significant difference ($P < 0.0001$) among the six studied landraces except for NB $S.m^{-2}$, which was just significant ($P < 0.01$).

Mean performance of agro-morphological and physiological traits: The highest Ph values were recorded in L4 and L5 with 77.86 cm and 78.37cm, respectively, while lowest values were found in L2 with 62.21cm and L6 with 58.81cm. PL values ranged from 8.76 cm in L2 to 16.39 cm in L4, SL from 6.03cm in L6 to 8.29 cm in L4, AL from 0.78 cm in L4 and 0.96 cm in L3 to 5.61cm in L5. On the other hand, ED ranged from 2.55 mm and 2.56 mm in L5 and L4, to 3.38 mm and 3.58 mm in L1 and L6, respectively. Landraces L1, L2, and L6 exhibited high ear density values (above 3mm). Additionally, Nb N varied from 3.65 in L1 to 5.80 in L4, and Nb S was high in all landraces, varying from 19.75 in L2 to 22.05 in L3. Also, the largest FLA was observed in L2 with 38.63 $cm^2$, while L3 achieved the smallest value of 23.37 $cm^2$.

The results showed that L4 and L6 produced the highest Nb HT at 1.00 and 0.88 tiller $plant^{-1}$, respectively while L1, L5, L3 and L2 produced the lowest at 0.56, 0.50, 0.38, and 0.38. On the other hand, the highest Nb ST at 1.44 tiller $plant^{-1}$ was produced by L4, while L2 and L3 produced the lowest at 0.5. Accordingly, the highest Nb $S.m^{-2}$ was achieved by L4 at 339.5 and the lowest by L3 at 200.6. Besides, the highest mean value of Nb $G.S^{-1}$ belonged to L1 at 51.68 $G.S^{-1}$, and the lowest for L5 at 39 $G.S^{-1}$. In addition, WTG values varied from 21.89 g in L4, to 36.47 g in. L1, L2 and L4 exhibited the highest values for GY, with 39.62, 38.78, and 37.93 $q.h^{-1}$, respectively, followed by L3 with 32.13 $q.h^{-1}$, and finally, L6 and L5, which exhibited the lowest GY values, of 24.50 and 23.69 $q.h^{-1}$ respectively.

Physiologically, the chlorophyll content ranged from 33.71 SPAD in L6, to 44 SPAD in L2. The highest RWC value was observed in L4 at 92.25% and 88.43% in L5.

**Table 2: Mean values and standard deviation of the agro-morphological and physiological traits of the six oasis bread wheat landraces.**

| | L1 | L2 | L3 | L4 | L5 | L6 | Pr>F | LSD 5% |
|---|---|---|---|---|---|---|---|---|
| **Ph** | 68.15 ±4.62$^{b}$ | 62.21 ±3.00$^{c}$ | 71.50 ±5.18$^{b}$ | 77.86 ±5.34$^{a}$ | 78.37 ±5.12$^{a}$ | 58.81 ±6.41$^{c}$ | *** | 3.43 |
| **PL** | 13.165 ±1.83$^{bc}$ | 8.76 ±2.23$^{d}$ | 12.47 ±2.68$^{c}$ | 16.39 ±1.13$^{a}$ | 14.29 ±1.57$^{b}$ | 13.62 ±3.21$^{bc}$ | *** | 1.676 |
| **SL** | 6.70 ±0.24$^{c}$ | 6.86 ±0.55$^{c}$ | 7.49 ±0.53$^{b}$ | 8.29 ±0.31$^{a}$ | 7.53 ±0.39$^{b}$ | 6.03 ±0.30$^{d}$ | *** | 0.219 |
| **AL** | 3.78 ±0.68$^{b}$ | 1.76 ±0.52$^{d}$ | 0.96 ±0.42$^{e}$ | 0.78 ±0.43$^{e}$ | 5.61 ±0.50$^{a}$ | 2.08 ±0.38$^{c}$ | *** | 0.29 |
| **ED** | 3.38 ±0.30$^{ab}$ | 3.20 ±0.29$^{bc}$ | 3.00 ±0.23$^{c}$ | 2.56 ±0.16$^{d}$ | 2.55 ±0.24$^{d}$ | 3.58 ±0.47$^{a}$ | *** | 0.349 |
| **Nb N** | 3.65 ±0.49$^{e}$ | 4.00 ±0.00$^{d}$ | 3.85 ±0.37$^{dd}$ | 5.80 ±0.41$^{a}$ | 5.00 ±0.00$^{c}$ | 5.30 ±0.73$^{b}$ | *** | 0.179 |
| **Nb S** | 20.30 ±0.66$^{cd}$ | 19.75 ±1.07$^{d}$ | 22.05 ±0.69$^{a}$ | 20.15 ±1.57$^{cd}$ | 20.65 ±1.57$^{bc}$ | 21.30 ±0.66$^{b}$ | *** | 0.683 |
| **FLA** | 25.00± 3.80$^{d}$ | 38.63±3.51$^{a}$ | 23.37±0.44$^{e}$ | 34.29±1.13$^{b}$ | 26.33±0.98$^{d}$ | 29.91±1.75$^{c}$ | *** | 1.546 |
| **Nb HT** | 0.56±0.51$^{b}$ | 0.38±0.50$^{b}$ | 0.38±0.50$^{b}$ | 1.00 ±0.73$^{a}$ | 0.50 ±0.52$^{b}$ | 0.88 ±0.62$^{a}$ | *** | 0.244 |
| **Nb ST** | 0.75 ±0.45$^{bc}$ | 0.50 ±0.52$^{bc}$ | 0.50 ±0.52$^{c}$ | 1.44 ±0.89$^{a}$ | 0.81 ±0.54$^{bc}$ | 0.94 ±0.77$^{b}$ | ** | 0.401 |
| **Nb G.S$^{-1}$** | 51.68± 6.83$^{a}$ | 49.75 ±8.31$^{ab}$ | 48.18 ±6.76$^{b}$ | 50.56±4.59$^{ab}$ | 39.00 ±2.07$^{c}$ | 40.87 ±1.78$^{c}$ | *** | 3.41 |
| **Nb S.m$^{-2}$** | 221.1±5.21$^{c}$ | 2016.1±10.8$^{cd}$ | 200.6 ±5.3$^{d}$ | 339.5 ±7.8$^{a}$ | 246.9 ±11.3$^{b}$ | 246.9 ±12.4$^{b}$ | *** | 0.95 |
| **WTG** | 34.22 ±0.93$^{b}$ | 36.47 ±0.58$^{a}$ | 31.58 ±0.54$^{c}$ | 21.89 ±0.48$^{e}$ | 23.93 ±0.12$^{d}$ | 23.54 ±0.29$^{d}$ | *** | 0.978 |
| **GY** | 39.62 ±0.75$^{a}$ | 38.78 ±4.10$^{a}$ | 32.13 ±2.36$^{b}$ | 37.93 ±2.13$^{a}$ | 23.69 ±1.27$^{c}$ | 24.50 ±1.24$^{c}$ | *** | 4.019 |
| **Chl** | 35.61 ±0.73$^{c}$ | 44.00 ±1.08$^{a}$ | 40.30 ±0.84$^{b}$ | 39.60 ±1.45$^{b}$ | 36.42 ±0.57$^{c}$ | 33.71 ±2.62$^{d}$ | *** | 1.226 |
| **RWC** | 88.79 ±2.20$^{c}$ | 91.61 ±1.41$^{ab}$ | 90.62 ±1.03$^{b}$ | 92.25 ±1.50$^{a}$ | 88.43 ±1.31$^{c}$ | 90.45 ±0.73$^{b}$ | *** | 1.347 |

Mean performance of phenological traits: The results for the mean days to different phenological stages of the studied landraces are shown in Table 3. The average for seedling emergence to formation of the first leaf ranged from 14.25 days in L4 to 16.75 days in L5 and L6, while that to 4th leaf varied from 68.75 days in L3 to 77.75 days in L1. The average days to booting ranged from 129.75 days in L6 to 116.75 days in L2.

**Table 3: Mean values and standard deviation of phenological traits in the six oasis bread wheat landraces.**

| | L1 | L2 | L3 | L4 | L5 | L6 | Pr>F | LSD 5% |
|---|---|---|---|---|---|---|---|---|
| **D1$^{st}$L** | 15.5±0.58$^{b}$ | 15.25 ±0.50$^{b}$ | 15.75±0.50$^{b}$ | 14.25 ±0.50$^{c}$ | 16.75±0.50$^{a}$ | 16.75±0.50$^{a}$ | *** | 0.763 |
| **D4$^{th}$L** | 77.75±0.50$^{a}$ | 74.50 ±0.58$^{c}$ | 68.75±0.50$^{e}$ | 76.75 ±0.50$^{ab}$ | 73.25±0.96$^{d}$ | 76.50±1.00$^{b}$ | *** | 1.05 |
| **DBT** | 121.75±0.50$^{d}$ | 116.75±0.50$^{f}$ | 118 ±0.00$^{e}$ | 127.75 ±0.5$^{c}$ | 129.00±0.00$^{b}$ | 129.75±0.50$^{a}$ | *** | 0.606 |
| **DH** | 126.00±0.00$^{d}$ | 122.5 ±0.58$^{e}$ | 121.75±0.50$^{f}$ | 133.50±0.58$^{c}$ | 134.75±0.50$^{b}$ | 137.50±0.58$^{a}$ | *** | 0.743 |
| **DFLW** | 135.00±0.00$^{d}$ | 129.00±0.00$^{e}$ | 128.00±0.00$^{f}$ | 147.75±0.50$^{a}$ | 142.00±0.82$^{c}$ | 144.50±0.58$^{b}$ | *** | 0.678 |
| **DGF** | 152.25±0.50$^{d}$ | 148.25±0.50$^{e}$ | 147.5 ±0.58$^{f}$ | 169.00±0.00$^{a}$ | 160.50±0.58$^{c}$ | 162.25±0.50$^{b}$ | *** | 0.722 |
| **DGR** | 162.50±0.50$^{d}$ | 158.25±0.43$^{e}$ | 158.25±0.43$^{e}$ | 176.25±0.43$^{a}$ | 169.00±0.71$^{c}$ | 171.25±0.43$^{b}$ | *** | 0.858 |

For DH, the results show that L3 was the earliest averaging 121.75 days and L6 the latest at 137.5 days. The average number of days to FLW varied from 128 days in L3 to 147.75 days in L4. Additionally, DGF varied from 147.5 days in L3 to 169 days in L4. For DGR, the shortest life cycle, averaging 158.25 days, was recorded in L2 and L3 while the longest was for L4 at 176.25 days.

Genetic parameters: Genetic variability parameters of the recorded agro-morphological, physiological and phenological traits are displayed in Table 4. While phenotypic variance ranged from 0.09 to 74.61, genotypic variances were from 0.06 to 74.42. Also, the environmental variance varied from 0.01 to 6.21, whereas the estimates of phenotypic variance were higher than the corresponding genotypic variance in all traits, although with a small difference. However, the values of heritable fraction were higher than the non-heritable fraction in all traits except ED. The phenotypic coefficient of variation ranged from 4.42 to 74.84. High PCVs were registered in PL, AL, ED FLA, Nb HT, Nb ST, Nb S.m $^{2}$. Furthermore, moderate PCVs were recorded for PH, SL, Nb N, WTG, and GY while phenological and physiological traits exhibited a low PCV.

The genotypic coefficient of variation fluctuated between 1.58 and 74.48. High GCVs were expressed in AL, Nb HT, Nb ST, Nb S.m$^{-2}$, moderate in PH, PL, SL, ED, Nb N, FLA, WTG, GY, and low in physiological and phenological characters. On the other hand, the environmental coefficient of variation, ranged 0.28 from 47.26.

In the studied landraces, broad sense heritability estimates ranged from 7.79% to 99.04%. High values were observed for all traits except ED and Nb ST, which exhibited low and moderate heritability values of 56.38 and 68.85, respectively. Genetic advance as a percentage of mean varied from 2.71% to 152.7%. High heritability was noted to be associated with high genetic advance as the percentage of mean in PH, PL, SL, AL, Nb N, FLA, Nb HT, Nb S.m$^{-2}$, WTG, and GY. High heritability was also coupled with moderate GAM in Nb G.S$^{-1}$, Chl, D 1st L, DH, D FlW, and DGF, and with low values in Nb S, RWC, D 4thL, D BT and DGR. Moderate heritability value was accompanied by high GAM in Nb ST and low GAM in ED.

**Table 4: Genetic parameters of 23 measured traits in the oases bread wheat varieties.**

| | Mean | SD | $\sigma^2_g$ | $\sigma^2_e$ | $\sigma^2_p$ | PCV | GCV | ECV | $H^2_{bs}$ | GA | GAM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **PH** | 69.48 | 8.02 | 62.78 | 6.21 | 68.98 | 11.95 | 11.40 | 3.59 | 91.00 | 15.57 | 22.41 |
| **PL** | 13.11 | 2.52 | 6.04 | 1.23 | 7.27 | 20.55 | 18.74 | 8.44 | 83.13 | 4.61 | 35.19 |
| **SL** | 7.15 | 0.78 | 0.61 | 0.03 | 0.64 | 11.18 | 10.96 | 2.23 | 96.02 | 1.58 | 22.12 |
| **AL** | 2.498 | 1.86 | 3.46 | 0.03 | 3.50 | 74.84 | 74.48 | 7.34 | 99.04 | 3.81 | 152.70 |
| **ED** | 3.04 | 0.44 | 0.17 | 2.07 | 2.24 | 49.22 | 13.74 | 47.26 | 7.79 | 0.24 | 7.90 |
| **Nb N** | 4.60 | 0.88 | 0.78 | 0.01 | 0.79 | 19.35 | 19.20 | 2.47 | 98.37 | 1.80 | 39.22 |
| **Nb S** | 20.70 | 0.84 | 0.67 | 0.17 | 0.84 | 4.42 | 3.95 | 2.00 | 79.63 | 1.50 | 7.25 |
| **FLA** | 29.58 | 5.90 | 34.57 | 1.20 | 35.77 | 20.21 | 19.87 | 3.70 | 96.65 | 11.90 | 40.24 |
| **Nb HT** | 0.61 | 0.26 | 0.06 | 0.03 | 0.09 | 48.92 | 41.10 | 26.54 | 70.57 | 0.43 | 71.12 |
| **Nb ST** | 0.83 | 0.34 | 0.10 | 0.07 | 0.17 | 49.49 | 37.16 | 32.69 | 56.38 | 0.47 | 57.48 |
| **Nb G/S** | 46.67 | 5.37 | 6.13 | 0.27 | 6.40 | 5.42 | 5.31 | 1.11 | 95.83 | 4.99 | 10.70 |
| **Nb S/m$^2$** | 11.92 | 2.41 | 5.79 | 0.11 | 5.90 | 20.38 | 20.18 | 2.80 | 98.12 | 4.90 | 41.19 |
| **WTG** | 28.60 | 6.24 | 29.13 | 0.36 | 29.49 | 18.98 | 18.87 | 2.09 | 98.79 | 11.05 | 38.63 |
| **GY** | 32.78 | 7.22 | 38.15 | 3.98 | 42.13 | 19.80 | 18.85 | 6.09 | 90.55 | 12.10 | 36.94 |
| **Chl** | 38.27 | 3.74 | 13.83 | 0.66 | 14.49 | 9.94 | 9.72 | 2.12 | 95.44 | 7.48 | 19.55 |
| **RWC** | 90.36 | 1.50 | 2.05 | 0.93 | 2.97 | 1.91 | 1.58 | 1.06 | 68.85 | 2.44 | 2.71 |
| **D 1st L** | 15.70 | 0.95 | 0.83 | 0.31 | 1.14 | 6.80 | 5.81 | 3.53 | 72.99 | 1.60 | 10.23 |
| **D 4thL** | 74.58 | 3.29 | 10.74 | 0.39 | 11.13 | 4.47 | 4.39 | 0.84 | 96.51 | 6.63 | 8.89 |
| **DBT** | 123.83 | 5.75 | 33.07 | 0.18 | 33.25 | 4.66 | 4.64 | 0.34 | 99.47 | 11.81 | 9.54 |
| **DH** | 129.33 | 6.76 | 45.67 | 0.28 | 45.95 | 5.24 | 5.23 | 0.41 | 99.40 | 13.88 | 10.73 |
| **DFLW** | 137.70 | 8.28 | 68.51 | 0.22 | 68.73 | 6.02 | 6.01 | 0.34 | 99.68 | 17.02 | 12.36 |
| **DGF** | 156.62 | 8.63 | 74.42 | 0.19 | 74.61 | 5.51 | 5.51 | 0.28 | 99.75 | 17.74 | 11.33 |
| **DGR** | 165.91 | 7.40 | 54.71 | 0.34 | 55.05 | 4.47 | 4.46 | 0.35 | 99.37 | 15.18 | 9.15 |

Pearson correlation coefficient: The analysis of the correlation between all possible trait pairs measured in the six landraces is shown in Figure 1. The most important positive correlations were between Nb N and WTG (-0.925); DFLW (0.907), DGF (0.944), and DGR (0.934); D BT and DH (0.981), DFLW (0.942), and

DGR (0.905); DH and D FLW (0.936); DFLW and DGF (0.983), and DGR (0.985); and DGF and DGR (0.994). The main negative correlations were between TGW and D BT (-0.918), DFLW (-0.902), DGF (-0.913), and DGR (-0.916). Grain yield showed a significant association with NS, WTG, Nb G.S-1, Chl, D 1st L, D BT, and DH. The highest association of GY were with Nb G.S-1 while a negative association of GY with D1stL was also detected.

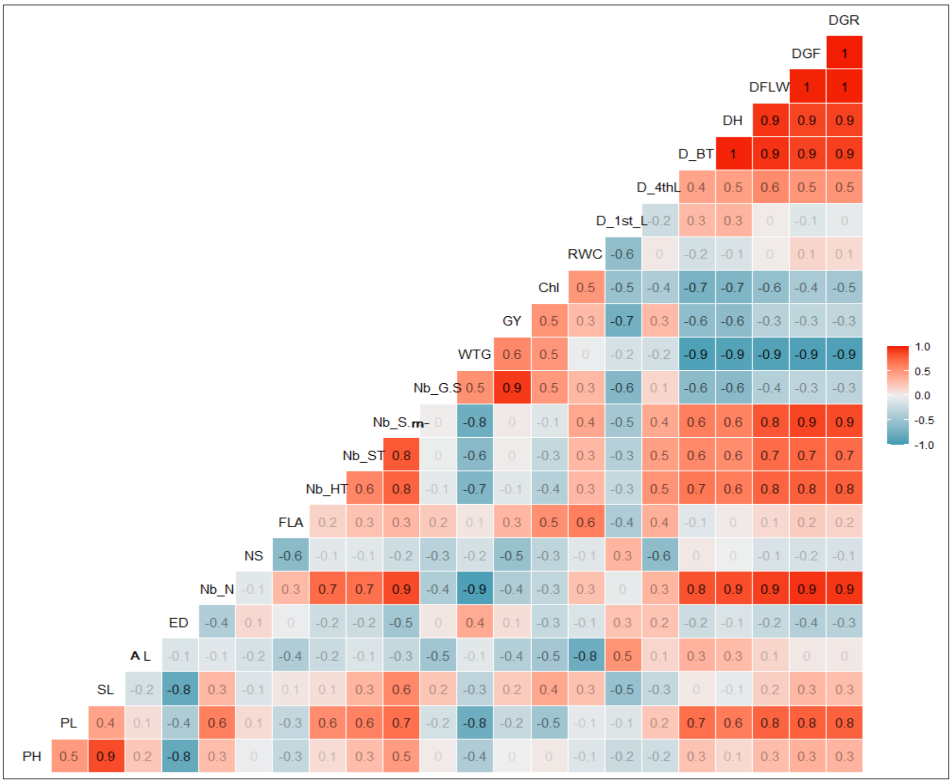


**Fig. 1. Pearson correlation plot of phenological, physiological and agro-morphological traits.**

Path coefficient analysis: Traits that showed statistically significant correlation coefficients with yield were separated into direct and indirect influences, as shown in Table 5. The highest positive direct effect on grain yield was registered in Nb G.S-1 (0.582), followed by WTG (0.315) and D BT (0.271). In contrast, the largest negative direct contribution to grain yield was recorded in D 1st L (-0.304) followed by NS (-0.217) and DH (-0.181). The direct effect of Chl on GY was negative and negligible (-0.084) despite the positive total correlation although positive and moderately high indirect effect via Nb G.S-1 (0.285), WTG (0.156), DH (0.122) and D 1st L (0.160) were mainly responsible for the final positive correlation coefficient.

**Table 5: Path coefficient analysis showing direct and indirect effects of some traits on grain yield of the oasis bread wheat landraces.**

| | NS | Nb G/S | WTG | Chl | D 1st L | DBT | DH |
|---|---|---|---|---|---|---|---|
| **NS** | **-0.217** | 0.073 | 0.035 | 0.063 | -0.072 | -0.008 | 0.001 |
| **Nb G/S** | -0.196 | **0.582** | 0.307 | 0.285 | -0.377 | -0.349 | -0.355 |
| **WTG** | -0.050 | 0.166 | **0.315** | 0.157 | -0.048 | -0.289 | -0.282 |
| **Chl** | 0.025 | -0.041 | -0.042 | **-0.084** | 0.044 | 0.060 | 0.057 |
| **D 1st L** | -0.100 | 0.197 | 0.046 | 0.160 | **-0.304** | -0.091 | -0.101 |
| **DBT** | 0.009 | -0.162 | -0.249 | -0.193 | 0.081 | **0.271** | 0.266 |
| **DH** | 0.001 | 0.111 | 0.162 | 0.122 | -0.060 | -0.178 | **-0.182** |
| **Total** | **-0.529** | **0.926** | **0.574** | **0.509** | **-0.737** | **-0.583** | **-0.596** |
| **Bold indicates direct effect; residual effect=0.105** | | | | | | | |

DBT demonstrated a positive direct effect as opposed to the exhibited negative total correlation coefficient. The negative correlation coefficient resulted from the negative indirect effects exerted through WTG (-0.289), $G.S^{-1}$(-0.349), and DH (-0.178). The indirect effect of all studied traits via NS and Chl was remarkably low, while the indirect contribution of all characteristics through $G.S^{-1}$ was the highest.

Principal component analysis: In the principal components analysis, the 23 traits were grouped into 5 components with eigen values higher than. The two primary components cumulatively accounted for 71.27% of the total variation (PC1: 46.78%; PC2: 24.49%), whereas the other 3 components combined comprised 28.74% of the total variation (PC3:13.90%, PC4:8.36%, PC5:6.45%). Thus, the latter 3 components were disregarded while the first two were considered sufficient to reflect the overall variation. The first component was contributed mostly by phenological traits: DBT (8.146%), DH (7.77%), DFLW (8.08%), DGF (9.14%), DGR (9.18%) and other agronomic traits, such as WTG (8.36%), Nb N (8.18%), Nb HT (7.01%), and Nb ST (7.79%). The second component was mainly contributed to by $D1^{st}L$ (16.78%), physiological traits, including Chl (8.66%), and RWC (11.12%), in addition to yield (11.57%) and Nb $G.S^{-1}$ (10.78%).

On the other hand, PC1 was highly loaded on reproductive phenological traits that included DBT, DH, DFLW, DGF, DGR, one morphological trait (PL), and agronomical traits of Nb N, Nb HT, Nb ST, and Nb $S.m^{-2}$ from its positive side, and WTG from its negative side. PC2 was highly loaded on AL, $D1^{st}$ L from the positive side, and FLA, Nb $G.S^{-1}$, GY, Chl, and RWC from the negative side. These characteristics are substantial in distinguishing the studied genotypes.

Based on these findings, it can be concluded that landraces with long reproductive stages, high PL, Nb N, Nb HT, Nb ST, and Nb $S.m^{-2}$, and with low WTG, can be found along PC1. Additionally, PC2 put in the picture genotypes that express short $D1^{st}$ L and AL with high FLA, Nb $G.S^{-1}$, GY, Chl, and RWC. The classification of the studied genotypes based on factor scores is presented in Figure 2. The dispersion on the two axes revealed four distinguished groups: Group 1 consisting of landraces characterized by dense ears and a high number of spikelets with short stem and peduncle, early heading period and relatively high yield; Group 2 comprising high yielding landraces with high Nb $G.S^{-1}$, high WTG and high Chl content; Group 3, as identified by landraces with best stress tolerance abilities, high tillering capacity and a relatively longer life cycle; and Group 4 included landraces marked by late heading and flowering, and ears with long awns.

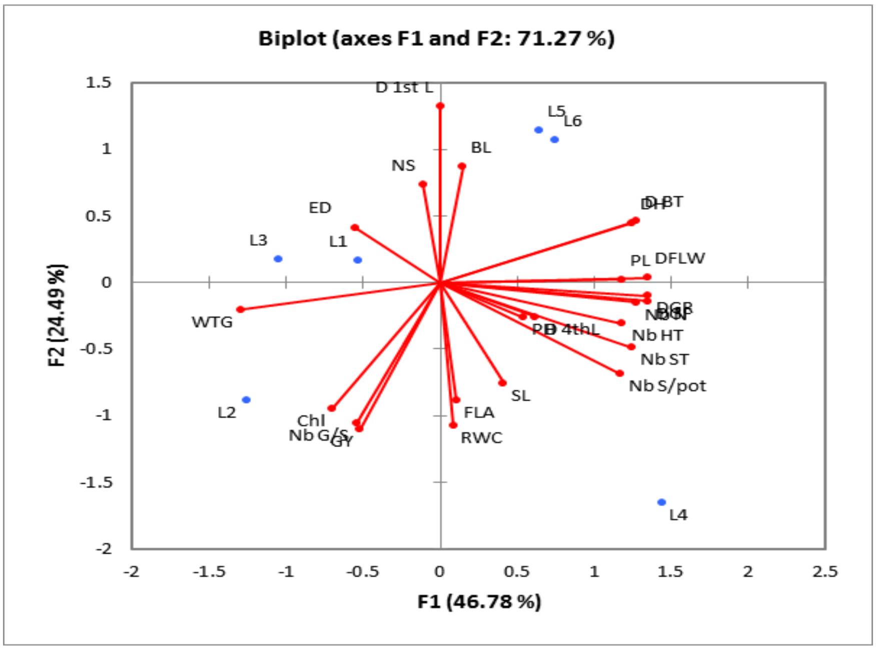


**Fig. 2. Biplot of measured agro-morphological, physiological and phenological traits of the studied landraces.**

Discussion: This research investigated the morphological, agronomical, physiological and phenological performances using multivariate analysis of six landraces of bead wheat (*Triticum aestivum* L.) from Algerian oases outside their environment of origin in order to select the best performers for later inclusion in a breeding program in the study area.

The study found significant genetic variations in all the four traits among the six landraces. These findings support those of (7, 10, 17 and 19). They indicate the presence of a wide diversity within the studied landraces, which can be attributed to their different origins (49). In fact, many civilizations have inhabited the Saharan oases across history, and each brought its own crops and agricultural practices to the region, which contributed to the diversity of this germplasm. The important variations in the traits can be exploited to generate appropriate selection criteria and identify promising genotypes for further improvement. The considerable variations encourage exploiting these landraces in their yields and abiotic stress potentials in future breeding programs.

The landraces studied had medium to short heights, a distinctive feature of bread wheat grown in the Saharan oases as mentioned by (49). ED values confirmed that they belong to the compacted type described earlier by (17). Similar results were verified by (10) who stated that landraces characterized by low ED are difficult to thresh because of the chaff's tight adherence to the grain, as exemplified by the Khellouf landrace. The morpho-physiological traits of the flag leaf are more apparent in Chater than other landraces. Chlorophyll content in the flag leaf is an important indicator of photosynthetic activity and yield potential of a given genotype (33 and 52) arguing that photosynthetic activity is responsible for 50% of the grain yield in wheat. Also, relative water content has significant value when screening for drought-tolerant wheat genotypes (2). The recorded high values in the studied landraces compared to those of (2) indicate their potential as a breeding material for addressing abiotic stress.

Monitoring crop growth can be properly achieved with proper knowledge of the different phenological growth stages of any given crop. Such knowledge can be beneficial in many respects. First, it contributes to yield-increasing as it helps in planning the different stages to coincide with the optimal seasonal conditions (16). In addition, it helps schedule different agricultural management practices like irrigation, fertilization, and pest control (24). It also provides an overview of the adaptation potential of a genotype and allows selection of the best adapted ones to the corresponding environment (27).

Results show that as the earliest emerging landrace Khellouf was able to better establish itself in the environment and compete successfully for resources. Early emerging seedlings have the advantage of earlier photosynthesizing allowing for an earlier accumulation of biomass that helps them compete for lighter and soil resources (35). Khellouf, Tazi and Zeghlou recorded the longest vegetative stages. In fact, studies indicate that a long vegetative stage is usually associated with higher grain yield in wheat as it allows a better accumulation of photosynthetic assimilates and the establishment of the growth and the vigor of the plants (43). Oum Rokba El Baida, Chater and Oum Rokba Elhamra manifested the earliest heading period.

Farmers and plant breeders in Mediterranean regions characterized by hot and dry summers as in Algeria are generally focused on early heading genotypes. The early emergence of the ear results in a longer post-heading stage enabling a longer period for grain filling. Further, it allows the completion of the life cycle of the plant before the end of the growing season when conditions are less favorable. Conversely, late heading accelerates leaf senescence, which impacts grain yield negatively. In parallel, the same landraces achieved the earliest flowering. This is a sensitive stage in wheat. Late flowering of crops grown in dry areas or environments that are exposed to high temperature stress can lead to reduced fertility by altering the morphology and the function of pollen and pistil, which subsequently impact grain yield (21 and 40). The findings of (4) support this as they reported a negative effect of the late flowering trait on grain weight and yield, concluding that early flowering genotypes achieve higher yield. Grain filling is the final growth stage through which starch and protein biosynthesis and accumulation take place. This stage is crucial since it determines both the size and the weight of the grain, which in turn influences final grain yield (38).

According to Wiegand and (43 and 48), early genotypes with long grain filling durations would be preferable in regions with extreme stress conditions, which allow more time for the accumulation of photo assimilates. Early-maturing (short-cycle) landraces like Oum Rokba El Baida, Chater, Oum Rokba Elhamra are often preferred by farmers and plant breeders because of their best adaptation and yield performances (1), especially in arid regions characterized by temporal rainfall distribution. (50) reported a high yield stability index in early maturing genotypes under heat stress. Contrastingly, some early-maturing genotypes have been reported by (1) to have unstable yield. Indeed, a recent study by (22) reported that some late-maturing wheat cultivars achieved significantly higher yield than the early-maturing ones in some growing seasons, while no significant differences in yield was recorded in other seasons. Unlike the findings of (10), the relatively low temperature of the study site compared to the high temperature in the Sahara led to an increase in the heading duration and life cycle of the studied landraces in general.

The study of genetic variability within germplasm is an integral part of any crop breeding program. It can be done through partitioning the variation into heritable and non-heritable components and, therefore, allow the identification of genetic properties of the corresponding germplasm. In this study, the genotypic variance was higher than the environmental variance indicating that it is the largest contributor to the total variation (phenotypic variance) in all the studied traits except for ED. The recorded high and moderate estimates of PCV and GCV suggest a great magnitude of genetic variability that could be exploited through selection for improvements to the studied morphological, yield and yield-related traits.

Moreover, phenological and physiological characters manifested low PCV and GCV indicating the existence of a limited selection range. PCV was higher than GCV but with very narrow difference in all traits except in PL, ED, Nb HT, Nb ST, meaning that the environment's impact on the traits is minimal which encourages the exploitation of these landraces to improve these traits outside their original environment. On the other hand, the expression of PL, ED, Nb HT, Nb ST is subjected to the influence of the environment and the process of selection based on these traits will be difficult because of their fluctuations. Phenological and physiological traits appear to be less influenced by the environment but also show low values of PCV and GCV, thus making their selection less effective and are not recommended.

The broad sense heritability of a trait is defined as the proportion of the total phenotypic variance that occurs due to the heritable genetic factors (20). It is often used by plant breeders to estimate the response of individuals within a population to the selection procedure (41). In the studied landraces, high to moderate estimates of heritability were registered in all traits except for ED. Nonetheless, relying on heritability alone for good selection might not be always sufficient because the genetic effect itself is composed of additive, dominance, and epistatic effects. Accompanying it with genetic advance is usually recommended to increase the predictability of the selection effect of a genotype with traits of interest. The results show that high heritability was coupled with high genetic advance in yield and yield-related traits, and most morphological traits, including PH, PL, SL, Nb N, and FLA. Some of these findings are in line with those of (18). This indicates that these traits are controlled by additive genes, and are thus are the best to consider in the selection of superior landraces.

The complexity of grain yield and its association with many other characteristics in wheat require studying the association between yield and these characteristics as well as among the characteristics themselves. This can be accomplished through calculating correlation coefficients. In fact, correlation studies are not limited to estimating the degree and direction of dependence, as they also help indirectly in selecting promising varieties based on a desirable trait or a number of traits (51).

Grain yield showed a significant correlation with NS, WTG, Nb G.S-1, Chl, D 1st L, D BT, and DH. This indicates that the selection of these traits may be beneficial to plant breeders in terms of grain yield improvement. Nonetheless, it is preferable to consider the direction of the correlation and its magnitude more than the significance of its values, as noted by (34). Nb G.S-1 recorded the strongest association with GY, meaning that it is more relevant than the other grain yield components. These results correspond with the findings of (5 and 26). The negative association of GY with D1stL indicates that the shorter the emergence period, the higher the grain yield. Short seedling emergence period resulting in high yield has been reported previously by Wanjura (23 and 47).

Path coefficient analysis informs on the direct and indirect influences of different characteristics on complex traits like grain-yield. In this study, Nb G.S-1, WTG and DBT registered the highest positive direct effects on GY. These correspond with (29) and match the above simple correlation coefficient analysis in terms of importance of the number of grains per spike and weight of thousand kernels as a selection criterion to generate high yielding genotypes. The direct positive effects imply that a small increase in any characteristic will produce a direct increase in grain yield and therefore, a direct selection of these traits will be highly effective to improve GY. Results revealed a negative direct effect on GY in the studied landraces, in line with the observations by (9 and 25). However, path coefficient analysis also showed contradictory results in other traits such as chlorophyll content and days to booting, in which the main effect on yield was indirect through weight of a thousand kernels, number of grains per spike and days to heading. In this case, selection for grain yield improvement should consider the traits with positive indirect effect instead (32).

Multivariate analysis enables the study of the relationship between different traits such as the phenological, yield-related, and adaptation-related ones. It helps classify and select the highest yielding and best adapted landraces simultaneously. The results in this work encourage the use and exploitation of the Algerian oasis wheat landraces in the breeding programs of the high plateau regions which are characterized by a semi-arid climate and to address the challenges posed by climate change facing the wheat culture there.

## Conclusions

This study revealed significant phenotypic diversity among Saharan oasis wheat landraces in traits crucial for productivity, adaptation, and phenology. These findings underscore the untapped potential of these landraces as valuable genetic resources for wheat improvement programs, particularly for developing varieties suited to challenging semi-arid environments such as in Algeria. Correlation analysis provides critical insights into trait associations, especially between grain yield and its components. The identified trade-off between spike density and individual grain weight offers a key consideration for refining selection strategies in breeding programs. Importantly, this research not only contributes to a scientific understanding of wheat diversity but also offers immediate practical applications. By exploiting these diverse landraces, breeders can develop more resilient and productive wheat varieties, directly addressing the pressing challenges of food security in stress-prone regions. This study lays a solid foundation for innovative wheat breeding approaches, paving the way for more sustainable and productive agricultural systems in semi-arid areas facing increasing environmental stress.

**Supplementary Materials:**

Supplementary Table 1.

**Author Contributions:**

Hadji T. performed the study, collected data, and wrote the manuscript. Boulacel M. developed the concept and design and supervised the study. Ghennai A. was involved in supervision, statistical analysis, and data interpretation. Benlahbib A. did the landraces collection while Souilah N. and Bendif H. reviewed and edited the paper.

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The study was conducted following the protocol authorized by the Head of the Ethics Committee, University of Constantine, Algeria Republic.

**Informed Consent Statement:**

No Informed Consent Statement.

**Data Availability Statement:**

Data will be provided upon reasonable request from the correspondence author.

**Conflicts of Interest:**

The authors declare no conflict of interest.

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