

## Agro-morphological characterization of *Allium sativum* L. cultivars grown under semi-arid conditions

Caracterización agro-morfológica de cultivares de *Allium sativum* L. cultivados en condiciones semiáridas

Caracterização agro-morfológica de cultivares de *Allium sativum* L. cultivados em condições semiáridas

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### Crop production

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### Abstract

Garlic (*Allium sativum* L.) is a vegetable and medicinal crop with significant genetic diversity in Mediterranean regions. The valorization of this condiment is necessary to meet production demands. An experiment was conducted at ITCMI of Sidi Bel Abbes, Algeria, to evaluate the variation of agro-morphological properties of 10 garlic cultivars during the 2023/2024 growing season. The morphological evaluation revealed significant variety effects on leaves, bulbs, and cloves. The varieties Rose de Chine, Rouge Local, and Germidour showed important leaf length dimensions (52.79, 53.23 and 52.1 cm) and leaf surface area (97.61, 88.48 and 86.26 cm<sup>2</sup>), respectively. Regarding bulbs and cloves, the varieties Messidrômes and Mocta Bulgare indicated better performance in weight (54.45 and 6.9 g) and diameter (52.69 and 22.71 mm), respectively. The Fructidor variety had the highest number of cloves per bulb (14.16). These results highlight the potential of selected cultivars for specific end uses: foliage-vigorous varieties for biomass-oriented programs, and high-yielding bulb varieties for commercial production under semi-arid conditions. The identified agro-morphological diversity provides a valuable basis for varietal selection, breeding programs, and the conservation of locally adapted garlic germplasm.

## Resumen

El ajo (*Allium sativum* L.) es un cultivo hortícola y medicinal con importante diversidad genética en las regiones mediterráneas. La valorización de este condimento es una necesidad para satisfacer la demanda de producción. Se llevó a cabo un experimento en el ITCMI de Sidi Bel Abbes, Argelia, para evaluar la variación de las propiedades agro-morfológicas de 10 cultivares de ajo durante la campaña agrícola 2023/2024. La evaluación morfológica reveló efectos significativos de la variedad sobre hojas, bulbos y dientes. Las variedades Rose de Chine, Rouge Local y Germidour mostraron dimensiones importantes de longitud foliar (52,79; 53,23 y 52,1 cm) y superficie foliar (97,61; 88,48 y 86,26 cm<sup>2</sup>), respectivamente. En cuanto a bulbos y dientes, las variedades Messidrômes y Mocta Bulgare indicaron mejor rendimiento en peso (54,45 y 6,9 g) y diámetro (52,69 y 22,71 mm), respectivamente. La variedad Fructidor presentó el mayor número de dientes por bulbo (14,16). Estos resultados destacan el potencial de los cultivares seleccionados para usos específicos: variedades de follaje vigoroso para programas orientados a la biomasa, y variedades de alto rendimiento en bulbo para la producción comercial en condiciones semiáridas. La diversidad agromorfológica identificada constituye una base valiosa para la selección varietal, los programas de mejoramiento genético y la conservación del germoplasma de ajo adaptado localmente.

**Palabras clave:** ajo, diversidad genética, características cuantitativas, cultivar, evaluación de germoplasma.

## Resumo

O alho (*Allium sativum* L.) é uma cultura hortícola e medicinal com importante diversidade genética nas regiões mediterrânicas. A valorização deste condimento é uma necessidade para satisfazer a demanda de produção. Foi realizado um experimento no ITCMI de Sidi Bel Abbes, Argélia, para avaliar a variação das propriedades agromorfológicas de dez cultivares de alho durante a safra 2023/2024. A avaliação morfológica revelou efeitos significativos da variedade sobre folhas, bulbos e dentes. As variedades Rose de Chine, Rouge Local e Germidour apresentaram dimensões importantes de comprimento foliar (52,79; 53,23 e 52,1 cm) e área foliar (97,61; 88,48 e 86,26 cm<sup>2</sup>), respectivamente. Quanto aos bulbos e dentes, as variedades Messidrômes e Mocta Bulgare indicaram melhor desempenho em peso (54,45 e 6,9 g) e diâmetro (52,69 e 22,71 mm), respectivamente. A variedade Fructidor apresentou o maior número de dentes por bulbo (14,16). Estes resultados destacam o potencial dos cultivares selecionados para usos específicos: variedades de folhagem vigorosa para programas orientados à biomassa, e variedades de alto rendimento em bulbo para a produção comercial em condições semiáridas. A diversidade agromorfológica identificada constitui uma base valiosa para a seleção varietal, os programas de melhoramento genético e a conservação do germoplasma de alho localmente adaptado.

**Palavras-chave:** alho, diversidade genética, características quantitativas, cultivar, avaliação de germoplasma.

## Introduction

The genus *Allium* comprises major vegetable crops worldwide and is characterized by high genetic and geographic diversity. Garlic

(*Allium sativum* L.) is one of the most important species in terms of production, consumption, and therapeutic value. According to FAO (2025), it is the second most produced vegetable crop after onion (*Allium cepa* L.), with significant global economic importance related to its culinary, medicinal, and aromatic properties (El-Fiki and Adly, 2020). Global garlic production exceeds 30 million tons annually, with Asia contributing nearly 90 % and China accounting for over 75 % of world output (Aslam *et al.*, 2025).

Garlic is a bulbous species of the Amaryllidaceae family, native to Central Asia and widely cultivated in Mediterranean regions since 1550 BC (Lim, 2015). Although it reproduces exclusively by vegetative propagation (Egea *et al.*, 2017), garlic shows considerable phenotypic diversity. Genomic studies indicate that this diversity has accumulated over thousands of years of cultivation, leading to distinct genetic subpopulations worldwide (Jia *et al.*, 2023), likely driven by natural mutations under diverse environmental and cultural conditions (Parreño *et al.*, 2023).

Phenotypic variability in garlic mainly involves bulb, clove, and leaf traits (Benke *et al.*, 2020; Karaman *et al.*, 2022). Morphological and biochemical traits generally display higher phenotypic than genotypic variation, highlighting the strong influence of environmental factors on trait expression (Pasupula *et al.*, 2024). Evaluating this variability is therefore essential for breeding programs aiming to improve or develop new genotypes (Polyzos *et al.*, 2019). Accordingly, this study aimed to agronomically and morphologically characterize ten garlic cultivars grown under semi-arid conditions in the Sidi Bel Abbes region of Algeria.

## Materials and methods

### Experiment location and climatic conditions

The experiment was conducted during the 2023/2024 agricultural season at the Technical Institute for Vegetable and Industrial Crops (ITCMI) in Sidi Bel Abbes, Algeria (35°10'25.20" N, 0°40'22.32" W, altitude 490 m). The region has a semi-arid climate characterized by wet and cold winters and dry and hot summers. During the growing period, maximum temperatures ranged between 15.86 °C and 31.22 °C, while minimum temperatures varied between 11.51 °C and 18.55 °C. Maximum precipitation was recorded in December (84.44 mm.month<sup>-1</sup>) and minimum in February (6.42 mm.month<sup>-1</sup>).

### Plant material

Ten *Allium sativum* L. varieties from the ITCMI collection were evaluated, comprising genotypes of diverse geographic origins (Table 1). The collection was introduced approximately 35 years ago and is therefore considered well adapted to local conditions. Sowing was carried out in mid-November 2023.

**Table 1. List of studied genotypes and their origins.**

Index	Denomination	Origin
V1	Rouge Local	France
V2	Thermidrome	France
V3	Germidour	France
V4	Fructidor	France
V5	Rouge d'Iran	Iran
V6	Rouge d'Espagne	Spain
V7	Simple Californie	USA
V8	Mocta Bulgare	Bulgaria
V9	Messidrome	France
V10	Rose de Chine	China

### Experimental design

The experimental design was completely randomized with four replications for each variety, totaling 40 microplots of 10 m long by 4 m wide (40 m<sup>2</sup>), with a total area of 1,913.5 m<sup>2</sup>.

### Morphological characterization

Morphological characterization was performed using biometric measurements based on UPOV and IPGRI descriptors. Quantitative traits were assessed on ten plants per variety and included leaf number, length, and surface area, as well as bulb and clove weight and dimensions. Leaf traits were measured 190 days after planting: leaf number was counted directly per plant, leaf length was measured from the ligule to the tip using a graduated ruler, and leaf surface area was estimated from digital photographs analyzed with Digimizer software (v. 5.6.0). At harvest, bulb and clove weight were recorded using a precision balance (KERN PFB 1200-2, accuracy  $\pm 0.01$  g), while bulb diameter, bulb height, clove diameter, and clove height were measured with a digital caliper (Mitutoyo 500-196-30, accuracy  $\pm 0.02$  mm).

### Statistical analysis

Statistical analyses were performed using XLSTAT version 2021.3.1.1174 and CoStat version 6.400 software. One-way analysis of variance (ANOVA) was applied to evaluate the variety effect on quantitative characteristics ( $P \leq 0.05$ ). Mean comparison was performed using the LSD test, which was selected due to the balanced experimental design and the relatively small number of varieties compared ( $n = 10$ ), conditions under which its Type I error rate remains acceptable. Pearson correlation coefficients between agro-morphological traits were computed and visualized as a correlogram using the Python programming language (version 3.13) with the matplotlib and seaborn libraries. Significance levels are indicated as follows: \*  $P \leq 0.05$  and \*\*  $P \leq 0.01$ .

## Results and discussion

Analysis of variance revealed significant varietal differences for most traits, except bulb height (Table 2), indicating substantial diversity among the evaluated garlic varieties, in agreement with previous reports (Tesfaye *et al.*, 2023; Popa and Cosmulescu, 2024).

**Table 2. Mean squares from analysis of variance for quantitative morphological variables.**

Variable	Variety (df=9)	Error (df=40-90)	Significance
Leaf number	1.85	0.27	***
Leaf length (cm)	35.39	6.48	***
Leaf surface (cm <sup>2</sup> )	277.42	82.25	**
Bulb weight (g)	192.89	60.52	**
Bulb height (mm)	26.40	15.07	ns
Bulb diameter (mm)	37.69	7.94	***
Clove number	11.71	5.41	*
Clove weight (g)	5.40	2.44	*
Clove height (mm)	37.72	8.34	***
Clove diameter (mm)	47.07	3.76	***

\*\*\*:  $P < 0.001$ ; \*\*:  $P < 0.01$ ; \*:  $P < 0.05$ ; ns: not significant; df: degrees of freedom.

For leaf characteristics (Table 3), the variety Rose de Chine had the highest leaf number ( $9.4 \pm 0.52$ ), while Rouge Local recorded the lowest ( $7.9 \pm 0.32$ ). This variation could be due to the different genetic

constitution of genotypes or to physiological processes influenced by environmental factors (Pasupula *et al.*, 2024). Given the direct relationship between leaf number and the plant's photosynthetic capacity, genotypes with a greater number of leaves are likely to demonstrate enhanced physiological performance (Aslam *et al.*, 2025). Regarding leaf length, Rouge Local obtained the highest value ( $53.23 \pm 2.03$  cm) and Fructidor the lowest ( $45.03 \pm 2.04$  cm). For leaf surface area, Rose de Chine recorded the maximum ( $97.61 \pm 0.59$  cm<sup>2</sup>) and Rouge d'Iran the minimum ( $72.05 \pm 4.91$  cm<sup>2</sup>).

**Table 3. Mean values of leaf characteristics for the ten evaluated varieties.**

Variety	Leaf number	Length (cm)	Surface (cm <sup>2</sup> )
Rouge Local	$7.9 \pm 0.32$ e	$53.23 \pm 2.03$ a	$88.48 \pm 9.9$ ab
Thermidrome	$8.6 \pm 0.7$ bc	$51.94 \pm 3.21$ abc	$83.64 \pm 10.53$ bcde
Germidour	$8.3 \pm 0.67$ cde	$52.1 \pm 2.15$ abc	$86.26 \pm 5.31$ abc
Fructidor	$8.9 \pm 0.57$ b	$45.03 \pm 2.04$ e	$73.80 \pm 2.45$ de
Rouge d'Iran	$8.3 \pm 0.48$ cde	$47.51 \pm 2.86$ de	$72.05 \pm 4.91$ e
Rouge d'Espagne	$8.1 \pm 0.32$ de	$49.76 \pm 2.98$ bcd	$83.14 \pm 14.66$ bcde
Simple Californie	$8.4 \pm 0.52$ cd	$49.11 \pm 2$ cd	$82.66 \pm 8.92$ bcde
Mocta Bulgare	$8.4 \pm 0.52$ cd	$48.43 \pm 1.21$ d	$76.77 \pm 8.29$ cde
Messidrome	$8.2 \pm 0.42$ cde	$48.14 \pm 4.23$ de	$84.28 \pm 13.84$ bcd
Rose de Chine	$9.4 \pm 0.52$ a	$52.79 \pm 1.04$ ab	$97.61 \pm 0.59$ a

Different letters indicate significant differences ( $P < 0.05$ ) according to LSD test.

Regarding bulb and clove characteristics (Table 4), the variety Messidrome stood out with the highest bulb weight ( $54.45 \pm 8.75$  g), while Rose de Chine had the lowest ( $42.17 \pm 11.52$  g). According to Jia *et al.* (2023), bulb weight is among the most important agronomic traits in garlic, showing significant genetic architecture with multiple associated SNPs. Bulb weight variation can also be explained by the greater photosynthetic area resulting from higher leaf number and larger leaf surface, which enhances carbon assimilation and promotes biomass accumulation that is subsequently translocated to the bulb (Goyal *et al.*, 2025). However, in Rose de Chine, despite its good foliage vigor, bulb weight was the lowest recorded, which may reflect a preferential allocation of assimilates toward vegetative organs rather than storage structures, a source-sink partitioning pattern previously reported in garlic genotypes with high leaf area index (Parreño *et al.*, 2023). Bulb diameter varied from  $48.27 \pm 3.62$  mm (Mocta Bulgare) to  $52.69 \pm 3.99$  mm (Messidrome), values consistent with those reported by Karaman *et al.* (2022) in Turkish garlic genotypes. Clove weight ranged from  $4.69 \pm 0.8$  g (Rouge d'Espagne) to  $7.19 \pm 2.86$  g (Rouge Local). The number of cloves per bulb varied from  $9.83 \pm 1.72$  (Rouge Local) to  $14.17 \pm 2.93$  (Fructidor), a difference probably due to specific genes of each cultivar (Tesfaye *et al.*, 2023).

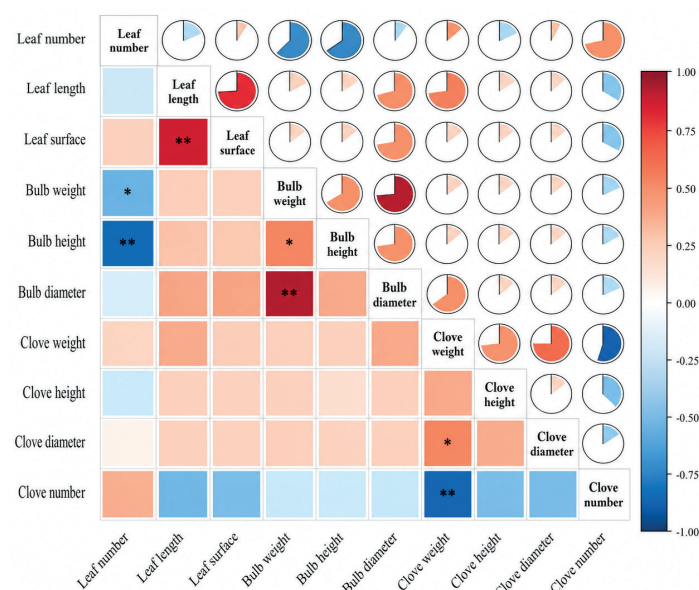
### Correlation analysis among agro-morphological traits of garlic cultivars

A significant negative correlation was observed between bulb weight and leaf number ( $r = -0.762$ ) (Figure 1), indicating that during the garlic life cycle, when bulb maturation begins, foliage regression occurs. A significant negative correlation was also found between clove number and weight ( $r = -0.832$ ) (Figure 1), meaning that increased clove weight leads to a decrease in number, in agreement with Polyzos *et al.* (2019) and Pasupula *et al.* (2024). The significant positive correlation between clove weight and diameter ( $r = 0.640$ ) (Figure 1) indicates that larger clove size leads to higher weight.

**Table 4.** Mean values of bulb and clove characteristics for the ten evaluated varieties.

Variety	Bulb weight (g)	Bulb diameter (mm)	Clove weight (g)	Clove no.
Rouge Local	53.98 ± 7.4 a	51.78 ± 2.91 ab	7.19 ± 2.86 a	9.83 ± 1.72 c
Thermidrome	47.7 ± 7.2 abc	48.39 ± 2.88 bc	4.71 ± 0.87 c	12.33 ± 0.52 abc
Germidour	52.72 ± 5.52 ab	51.6 ± 2.53 abc	5.67 ± 1.17 abc	11.5 ± 2.43 abc
Fructidor	46.81 ± 8.06 bc	51.74 ± 5.22 ab	4.69 ± 0.8 c	14.17 ± 2.93 a
Rouge d'Iran	53.68 ± 5.59 ab	51.95 ± 3.79 a	5.79 ± 1.17 abc	11 ± 1.67 bc
Rouge d'Espagne	49.04 ± 6.08 abc	50.23 ± 3.13 abc	4.7 ± 1.21 c	13.17 ± 2.86 ab
Simple Californie	52.22 ± 8.05 ab	52.26 ± 3.56 a	5.18 ± 0.9 c	13.17 ± 0.75 ab
Mocta Bulgare	44.05 ± 7.99 c	48.27 ± 3.62 c	6.9 ± 2.5 ab	11 ± 2.83 bc
Messidrome	54.45 ± 8.75 a	52.69 ± 3.99 a	5.33 ± 0.79 bc	13.83 ± 3.13 a
Rose de Chine	42.17 ± 11.52 c	49.5 ± 5.83 abc	5.66 ± 1.71 abc	12.67 ± 2.66 ab

diam.: bulb diameter; Clove no.: number of cloves per bulb; g: grams; mm: millimeters. Different letters within the same column indicate significant differences ( $P < 0.05$ ) according to the Least Significant Difference (LSD) test.



**Figure 1.** Pearson correlation heatmap of agro-morphological traits measured in ten garlic (*Allium sativum* L.) cultivars grown under semi-arid conditions.

## Conclusions

The agro-morphological evaluation of ten garlic cultivars grown under semi-arid climate in Algeria reveals significant genetic variability dependent on genetic constitution and agroclimatic conditions. The varieties Rose de Chine, Rouge Local, and Germidour stand out for their foliage vigor, representing a potentially interesting trait for further valorization studies. The variety Messidrome shows better performance in bulb weight and diameter, making it economically advantageous for producers. Mocta Bulgare presents the best clove dimensions and weight, highlighting its interest for culinary and commercial purposes. This morphological characterization constitutes a starting point for selection and breeding programs, as well as for the regeneration and conservation of local garlic germplasm adapted to semi-arid conditions through modern techniques such as in vitro culture.

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