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## NUMERICAL TAXONOMY OF THE GENUS *BRASSICA* L. CULTIVARS OF THE DIFFERENT SPECIES CULTIVATED IN NINEVEH GOVERNORATE, IRAQ

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### SUMMARY

The presented study carried out the numerical classification of eight cultivars belonging to five species of the genus *Brassica* L. (Brassicaceae), cultivated in Nineveh Governorate, Iraq. The morphological, pollen, and chemical properties obtained evaluation for the degree of equality and taxa classification. Thirty morphological qualitative and quantitative characters underwent cluster analysis. Moreover, the analysis of 11 chemical compounds supported taxonomic assessment. The coding of data succeeded numerically before analysis using SPSS software to generate equality indices and dendrograms. The polygon and the dendrogram demonstrated an apparent variation among the cultivars and their species, which supports the validity of species and selected properties of cultivars. The degree of equality among the cultivars ranged from 0.5% to 68.7%, depending on morphological and physiological features, while equality values based on the chemical compounds ranged between 6.9% and 82.8%. The analysis divided the genus *Brassica* L. cultivars into six groups and confirmed the effectiveness of the numerical taxonomy in portraying taxonomic relationships. The results emphasized the importance of integrating qualitative traits of leaves, pollen grains, and chemical features to improve the classification and understanding of *Brassica* cultivation.

**Keywords:** Brassicaceae, cluster analysis, cultivars, degree of equality, genus *Brassica* L., morphological and chemical features, numerical taxonomy, species

**Key findings:** *Brassica* cultivation exhibited broad morphological and chemical diversity, with equality indices ranging from 0.5% to 82.8%. Numerical analysis that integrates morphological, pollen, and chemical features divided eight cultivars into six groups. The results confirmed the effectiveness of the numerical taxonomy to improve classification and support breeding and conservation strategies.

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## INTRODUCTION

The Brassicaceae (Cruciferae) family, often known as the mustard family, is one of the most important plant families grown worldwide. It includes numerous species of economic value, such as *Brassica oleracea* (cabbage, cauliflower, and broccoli), *B. rapa* (cabbage root), and *B. nigra* (black mustard). These plant species incur extensive growing as food crops, in addition to their use as the source of natural products with medical, industrial, and antimicrobial activities (Al-Moussawi, 1987; Rasheed *et al.*, 2024; Taher *et al.*, 2025). The said family has more than 338 genera and 3,709 species around the globe (Gharb, 2014). In Iraq, the flora has more than 75 genera and 18 species (Al-Katib, 2000).

The study based on morphological features has had long usage for plant classification and has served as the primary basis for identifying and classifying cultivars and species of crop plants. Despite the rapid growth of molecular and chemical methods, the use of morphological features based on the stems, leaves, flowers, and fruits was basically favorable due to their accessibility, clinical significance, and differences in taxa (Sneath and Sokal, 1973; Radford *et al.*, 1974; Al-Jawari *et al.*, 2018).

With the promotion of biometrical methods, numerical classification has proven to be an effective tool to assess the different ratios found in taxa. This approach primarily depends on coding morphological and chemical signs in a numerical matrix and analyzing them to determine the equality indices and cluster patterns (Sneath and Sokal, 1973). Recent studies have emphasized the importance of integrating different morphological and chemical features into numerical analysis to solve taxonomic ambiguities and provide more reliable and stable classification (Al-Masoud and Al-Shammary, 2017; AL-Mathidy *et al.*, 2023).

Recent research in Iraq and neighboring countries has shown the utility of numerical classification to clarify the categories of different plant groups. These past studies combined the morphological and chemical

features for the reliable cataloging structure (Aloush, 2024; Al-Ma'thidy and Shehab, 2021). Additionally, the study on radish and celery applied the combinations of taxonomic, morphological, and chemical markers (Atiyah and Saeed, 2025; Taher *et al.*, 2025).

Therefore, based on the above discussion, the subsequent study aimed to employ the numerical classification of eight cultivars belonging to five species of the genus *Brassica* L. cultivated in the Nineveh Governorate, Iraq. By integrating morphological, pollen, and chemical characters, the scrutiny of equality traits ensued among the genus *Brassica* L. cultivars and constructed the dendrogram showing their taxonomic relationship. In this perspective, the classification of cultivars can contribute to a full understanding of *Brassica* diversity under local environmental conditions.

## MATERIALS AND METHODS

### Plant material

Eight cultivars belonging to five different taxa of genus *Brassica* L. (Brassicaceae) (*B. oleracea* var. *capitata* 'Kirmizi' and 'Rosse,' *B. oleracea* var. *botrytis* 'Palla' and 'Turkey,' *B. oleracea* var. *italica* 'Turkey' and 'Calabrese,' *B. rapa* 'Local', and *B. nigra* 'Local'), succeeded in studying and cultivation during the winter of 2024–2025 at the University of Mosul, Mosul, Iraq.

### Morphological characters

Thirty morphological and anatomical features obtained selection for taxonomic evaluation numerically. These characters included vegetative features, such as stem color and leaf (petiole, blade, margin, and apex), in addition to reproductive features, including flower characteristics, pollen grain ornamentation, fruit size and shape, and seed shape. Each trait, coded numerically, received distinct symbols assigned to the different states of each character, producing a dataset suitable for statistical analysis.

## Chemical characters

Eleven phenolic compounds were options as chemical markers for chemotaxonomic evaluation. The presence and absence of each chemical compound underwent determination and recording using a binary coding system. Afterward, the integration of this chemical dataset with the morphological dataset helped enhance the discriminatory resolution of the analysis.

## Data matrix and statistical analysis

The coded data based on the morphological and chemical features sustained standardization and transformation into similarity matrices. Similarity coefficients' calculation among the genus *Brassica* L. cultivars relied on both datasets independently. Statistical analyses performed used SPSS software (version 20), with cluster analysis conducted using the average linkage method between the groups.

## Dendrogram construction

The resulting similarity coefficients attained numerical data representation before their placement in a numerical matrix that sustained statistical analysis by computer using the SPSS 20 program. There, selecting the cluster analysis method helped illustrate the relationship among the genus *Brassica* L.'s different cultivars. Morphological and chemical features achieved separate analyses, allowing comparison of the clustering patterns derived from each type of data.

## RESULTS

### Morphological variations

The comparative analysis of 30 morphological characteristics demonstrated clear and considerable variations among the studied cultivars of the genus *Brassica* L. The diagnostic differences were visible in stem

color, petiole shape, basal and cauline leaf morphology, seed shape, and flowers and micromorphological characteristics of pollen grains. The features' coding provided a comprehensive dataset for numerical evaluation (Table 1). Based on the morphological dataset, the cluster analysis produced similarity coefficients ranging between 0.5% and 68.7% (Table 2). The highest similarity was evident between the cultivars *B. oleracea* var. *botrytis* 'Palla' and *B. oleracea* var. *capitata* 'Kirmizi,' while the lowest similarity appeared between the cultivars *B. nigra* 'Local' and *B. oleracea* var. *capitata* 'Rosse.' These relationships attained illustration in the dendrogram derived from morphological data (Figure 1). As for the analysis of the data related to the morphological characters of the studied genus species, which included 30 variables (Table 1), their numerical analysis (Table 2) succeeded in dividing them into two clusters. The first cluster included *B. oleracea* var. *capitata* 'Kirmizi,' *B. oleracea* var. *botrytis* 'Palla,' *B. oleracea* var. *botrytis* 'Turkey,' *B. oleracea* var. *italica* 'Turkey,' and *B. oleracea* var. *italica* 'Calabrese.' The second cluster comprised *B. oleracea* var. *capitata* 'Rosse,' *B. rapa* 'Local,' and *B. nigra* 'Local.'

### Chemical composition

The chemical screening revealed significant differences among the genus *Brassica* L. cultivars for phenolic compounds. Eleven compounds, when investigated, had quercetin and kaempferol as the most widely distributed, whereas rutin and catechin were only in a few cultivars (Table 3). Based on chemical markers, the similarity coefficients ranged from 6.9% to 82.8% (Table 4). The highest similarity (82.8%) emerged between the cultivars Rosse (*B. oleracea* var. *capitata*) and Local (*B. nigra*), while the lowest similarity occurred between the distantly related cultivars. The dendrogram constructed from the chemical features' data reflects their relationships (Figure 2).

**Table 1.** Morphological features with symbols used in the numerical taxonomy for drawing the dendrogram in the genus *Brassica* L. cultivars.

No.	Characteristics	Specifications	Symbol
1	Stem color	Violet	1
		Red	2
2	Petiole shape	Winged triangle	2
		Crescent	2
3	Cauline leaves	Sessile	1
		Petiolate	2
4	Basal leaf blade shape	Ovate	1
		Broad Ovate	2
		Elliptic Oblong	3
		Sub-circular	4
		Obovate	5
5	Shape of the tip of the basal leaf blade	Acute	1
		Obtuse	2
6	Shape of the margin of the basal leaf blade	Lobed	1
		Undulate	2
		Dentate	3
		Smooth	4
		Crenate	5
7	Length of the basal leaf blade	Less than 10	1
8	Length of the basal leaf petiole	More than 10	2
		Less than 10	1
9	Indumentum of basal leaves	More than 10	2
		Glabrous	1
10	Cauline leaf blade shape	Scaly	2
		Ovate-Elliptic	1
11	Cauline leaf blade margin shape	Broad ovate	2
		Triangular-lanceolate	3
		Elliptic	4
		Sub-circular	5
		Ovate-Oblong	6
		Undulate	1
12	Cauline leaf blade base shape	Dentate	2
		Fine dentate	3
		Connate Perfoliate	1
13	Cauline leaf blade apex shape	Oblique	2
		Obtuse	1
14	Cauline leaf blade length	Acute	2
		Less than 10	1
15	Cauline leaf petiole length	More than 10	2
		Less than 5	1
16	Indumentum of cauline leaves	More than 5	2
		Glabrous	1
17	Peduncle length	Scaly	2
		Less than 5	1
18	Color of sepals	More than 5	2
		Violet	1
19	Length of claw	Green	2
		Less than 5	1
20	Petals color	More than 5	2
		Dark yellow	1
21	Fruit beak length	Light yellow	2
		Less than 10	1
22	Length of fruit	More than 10	2
		Less than 40	1
23	Number of seeds in fruit	More than 40	2
		Less than 20	1
24	Color of seed	More than 20	2
		Dark Brown	1
25	Seed shape	Light Brown	2
		Circular - Subcircular	1
26	Seed configuration	Board ovate	2
		Ovate - Ovate oblong	3
		Reticulate	1
27	Pollen grain shape in polar view	Fine- Reticulate	2
		Sub-spherical	1
		Spherical-triangular	2
28	Pollen grain shape in equatorial view	Triangular	3
		Spherical	1
		Sub-spherical	2
29	Upper epidermal cells shape of leaves	Ovate prolate	3
		Straight curved	1
30	Lower epidermal cells shape of leaves	Undulate	2
		Straight curved	1
		Undulate	2

**Table 2.** Matrix of similarity and difference ratios in *Brassica L.* cultivars.

Cultivars	1	2	3	4	5	6	7	8
1	1.000							
2	0.220	1.000						
3	0.687	0.507	1.000					
4	0.681	0.127	0.551	1.000				
5	0.482	0.210	0.116	0.572	1.000			
6	0.340	0.285	0.355	0.331	0.237	1.000		
7	0.134	0.603	0.546	0.079	0.350	0.034	1.000	
8	0.031	0.005	0.104	0.125	0.016	0.044	0.020	1.000

1) Kirmizi, 2) Rosse, 3) Palla, 4) Turkey, 5) Turkey, 6) Calabrese, 7) Local, and 8) Local.

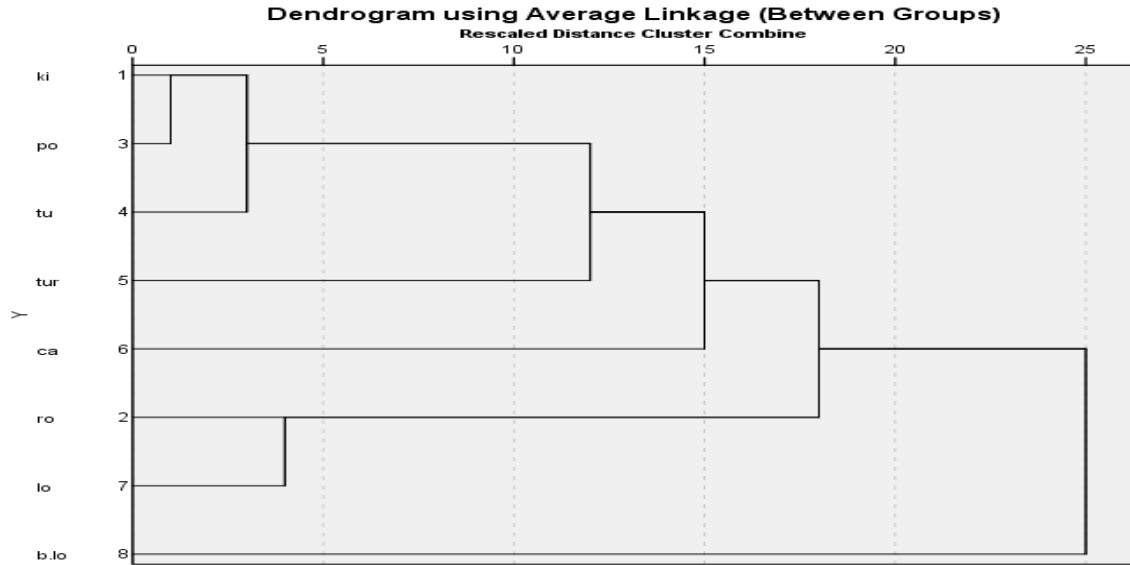
**Table 3.** Symbols of the chemical components used in the dendrogram of the genus *Brassica L.* cultivars.

No.	Chemical compounds	Plant compound content	Existence symbol
1	Quercetin	Exist	1
		Not exist	2
2	Rutin	Exist	1
		Not exist	2
3	Kaempferol	Exist	1
		Not exist	2
4	Galic acid	Exist	1
		Not exist	2
5	Ferulic acid	Exist	1
		Not exist	2
6	Caffeic acid	Exist	1
		Not exist	2
7	P-coumaric acid	Exist	1
		Not exist	2
8	Catechin	Exist	1
		Not exist	2
9	Vanillic acid	Exist	1
		Not exist	2
10	Apigenin	Exist	1
		Not exist	2
11	Ellagic acid	Exist	1
		Not exist	

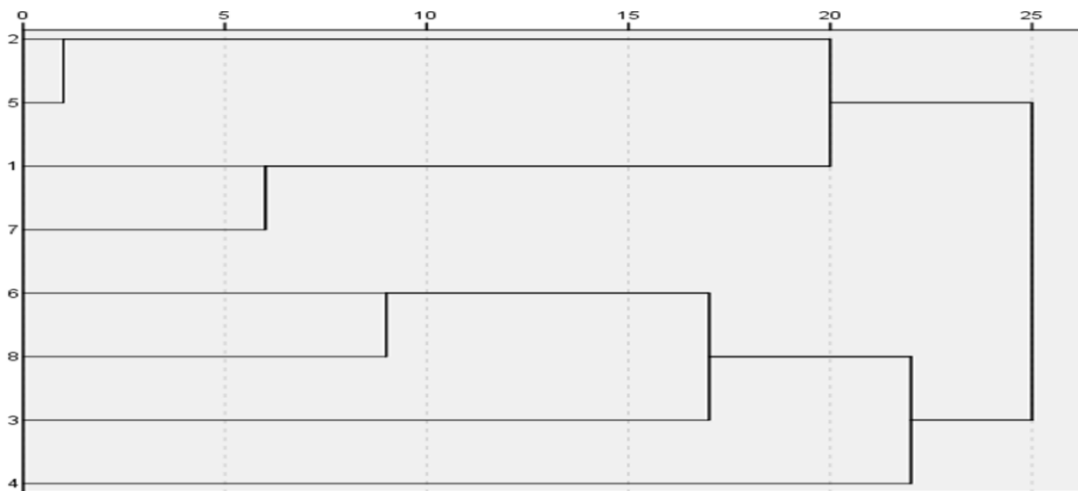
**Table 4.** The matrix of chemical compounds used in drawing the dendrogram of the *Brassica L.* cultivars.

Cultivars	1	2	3	4	5	6	7	8
1	1.000							
2	0.214	1.000						
3	0.311	0.069	1.000					
4	0.179	0.179	0.449	1.000				
5	0.449	0.828	0.100	0.311	1.000			
6	0.069	0.449	0.633	0.449	0.267	1.000		
7	0.690	0.311	0.100	0.449	0.467	0.100	1.000	
8	0.449	0.069	0.267	0.069	0.267	0.633	0.467	1.000

1) Kirmizi, 2) Rosse, 3) Palla, 4) Turkey, 5) Turkey, 6) Calabrese, 7) Local, and 8) Local.



**Figure 1.** The dendrogram showing the degrees of similarity and difference between the genus *Brassica* L. cultivars as per their sequence in Table 2. 1) Kirmizi, 2) Rosse, 3) Palla, 4) Turkey, 5) Turkey, 6) Calabrese, 7) Local, and 8) Local.



**Figure 2.** The dendrogram showing the degree of similarity among the genus *Brassica* L. cultivars based on the chemical components, and according to their sequence in Table 4. 1) Kirmizi, 2) Rosse, 3) Palla, 4) Turkey, 5) Turkey, 6) Calabrese, 7) Local, and 8) Local.

**Cluster formation**

The joint analysis of the morphological and chemical datasets detailed both close affinities and marked distinctions among the cultivars. Morphological clustering grouped the cultivars 'Palla' and 'Kirmizi,' whereas chemical

clustering emphasized the affinity between the cultivars 'Rosse' and 'Local' (*B. nigra*). This integration highlighted the complementary role of morphological and chemical features in differentiating the cultivars and confirmed the wide diversity found within the studied *Brassica* species and their cultivars.

## DISCUSSION

The promising study revealed substantial morphological and chemical diversity among the eight *Brassica* cultivars. Variations in the vegetative and reproductive features, including leaf morphology, seed configuration, and flower and pollen grain structures, provided an essential criterion for cultivar differentiation. These results confirmed that traditional morphological and anatomical characters remain central and play a pivotal role in the taxonomic evaluation, even in the present era of molecular systematics (Sneath and Sokal, 1973; Radford *et al.*, 1974).

The analysis showed close affinities between certain cultivars of *B. oleracea*, such as cultivars Palla and Kirmizi, while other cultivars displayed wide genetic diversity, particularly the cultivars belonging to the *Brassica* species, *B. nigra* and *B. oleracea*. Reported similar morphological-based differentiation has also occurred in previous studies on Brassicaceae taxa in Iraq and neighboring regions, further supporting the reliability of numerical taxonomy in resolving cultivar relationships (Al-Jawari *et al.*, 2018; Al-Ma'thidy and Shehab, 2021).

Chemical evidence complemented these findings, as the phenolic compounds, such as quercetin and kaempferol, entailed wide distribution and served as stable chemotaxonomic markers in this study. In contrast, the chemical compounds like rutin and catechin were more restricted, highlighting their diagnostic value for specific taxa. Comparable patterns have had reports in recent studies on *Brassica rapa* and other related species, where chemical markers provided additional resolution beyond their morphological features (Lee *et al.*, 2023; Rasheed *et al.*, 2024; Zhou *et al.*, 2024).

The integration of morphological and chemical datasets produced a more comprehensive classification, revealing both the convergences and distinctions among the genus *Brassica* L. cultivars and their taxa. This integrative approach was greatly analogous to recent past recommendations for Brassicaceae taxonomy, which also emphasized the importance of combining morphological,

chemical, and molecular data to achieve more accurate classifications (Al-Shehbaz, 2023; Zhang *et al.*, 2024). Applying similar integrative frameworks has also been successful in other crop plants in Iraq, reinforcing their utility in clarifying taxonomic ambiguities (Atiyah and Saeed, 2025; Taher *et al.*, 2025).

Overall, the presented findings highlighted the effectiveness of numerical taxonomy as a tool for clarifying the relationship within *Brassica* L. species. The latest study provides a solid baseline for future research, including molecular analyses, breeding programs, and conservation strategies targeting *Brassica* genotypes under local diverse environmental conditions.

## CONCLUSIONS

The study highlighted the effectiveness of numerical classification in the evaluation of eight cultivars belonging to different *Brassica* taxa cultivated in Nineveh Governorate, Iraq. By integrating morphological, pollen, and chemical features, clear patterns of similarity and differentiation succeeded in their detection, where cultivars resulted in six separate groups. The results confirmed phenotypical and chemical markers proved to be valuable for discrimination at the cultivar level and complemented modern molecular approaches. The findings provide a solid baseline for classification and improvement through conservation and breeding strategies in *Brassica*.

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