Leaf architecture of *Bidens* (*Asteraceae*) in Sana'a city and its taxonomical significance

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Abstract. There has been an erroneous identification of three *Bidens* taxa – *B. bipinnata*, *B. biternata* & *B. pilosa* – by earlier taxonomists, mainly due to qualitative leaf morphology. This study deals with the leaf architecture (qualitative and quantitative) characters of the three *Bidens* taxa grown in Sana'a city (*B. bipinnata*, *B. biternata* & *B. pilosa*) and its taxonomical significance in distinguishing between these taxa. Fifty-three (32 qualitative and 21 quantitative) morphological leaf characters have been observed. Of these, four qualitative morphological characters can be used to distinguish between the three *Bidens* taxa, another three quantitative morphological characters of the terminal lobe are greatly significant for distinguishing those three taxa from each other.

Keywords: *Bidens bipinnata, B. biternata, B. pilosa,* leaf architecture

Introduction

The genus *Bidens* L. (*Asteraceae*, Heliantheae, Coreopsidineae) comprises approximately 230 widespread species, especially in subtropical, tropical and warm-temperate regions, including Africa, the New World, Polynesia, and Eurasia to Australia (Sherff 1937; Tadesse 1993 and Abedin & Al-Said 2000). All members of this genus are annual or perennial herbs or shrubs, with stems usually erect and branched; leaves usually cauline, opposite or seldom whorled, occasionally alternate. Blades simple to deeply and irregularly 2–3 pinnatisect or pinnately compound, segments linear to broadly ovate. Capitula solitary and terminal or arranged in lax corymbiform or paniculiform cymes (Tadesse 1993; Boulos & Hind 2002 and Kadereit & Jeffrey 2006).

According to Dubie & al. (1993), Dubie (1995), Wood (1997) and Al Khulaidi (2013), only three species of *Bidens*, belong to the section Psilocarpaea, namely *B. bipinnata* L., *B. biternata* (Lour.) Merr and *B. pilosa* L. were recorded in Sana'a city. Taxonomic treatment of those three *Bidens* species has varied from time to time and the understanding of their relationship is still unclear, which may be due to the phenotypic variability caused by a limited gene exchange, which poses a serious difficulty to taxonomists (Sherff 1937 and Dakshini & Prithipal 1984).

In 1989, Stace mentioned that the morphological leaf properties play an important role in distinguishing the different taxa when the floral properties are not helpful. Furthermore, Hickey (1973) stated that the term leaf architecture classification includes an almost infinite number of features such as position,

shape, structure, venation pattern, marginal configuration, glandular position, and other morphological features of the leaves. Those features were evaluated by studying their distribution among the different taxa and only the significant features were used to separate and distinguish between the various taxa, from ordinal to specific level (Inamdar & Murth 1978; Inamdar & al. 1983; Sun & al. 1991; Shanmuka & Narmada, 1994 and Jessica & al. 2014).

On the other hand, Chavan & Oza (1961) and Babu (1977) pointed out that the leaf morphology characters had not been generally helped in identification of the three above-mentioned *Bidens* species (*B. bipinnata; biternata* & *B. pilosa*), while Wood (1997) made a taxonomical key to distinguish between them in the flora of Yemen, based on the organization of leaf properties (lamina component) and floral characters. Therefore, the present study was undertaken to get a comprehensive description of the leaf architecture and to evaluate its taxonomical significance in distinguishing between the three *Bidens* species growing in Sana'a city, as a step toward understanding the role of leaf architecture in plant taxonomy.

Material and methods

1. Plant material

The three *Bidens* L. taxa belonging to the section Psilocarpaea (Fig.1) were collected from different localities in Sana'a city (Table 1), from April to August 2019. The specimens were identified by Prof. Abdul Nasser Al-Gifri, Department of Biology, Faculty of Education, University of Aden, Yemen and by using the available taxonomic and floristic literature (Sherff 1937; Wood 1997; Collenette 1999; Abedin & Al-Said 2000 and Boulos & Hind 2002). Furthermore, the material was compared with herbarium specimens (*B. bipinnata*- BHSS 678, *B. biternata*- BHSS 692 & *B. pilosa*- BHSS 654) stored in the Herbarium of the Faculty of Science of Sana'a University.

2. Morphological investigation

Achenes of each collected and identified taxa were planted in the experimental farm of the Faculty of Science, Sana'a University in August 2019, under uniform nursery conditions. Six subpopulations (each taxon was represented by two subpopulations and each subpopulation included 15 individuals) were produced. Leaf architecture characters of the three taxa were investigated in specimens of the subpopulations.

About 53 (32 qualitative and 21 quantitative) morphological leaf characters (Tables 2, 3) of sixty mature and well unfolded leaves (two leaves from every individual in the two subpopulations of each taxon) were investigated to record the leaf architecture characters of each species.

Based on the terminology in the *Approaches to Identification of Angiosperm Leaf Remains* (Dilcher 1974) and *Manual of Leaf Architecture* (Leaf Architecture Working Group 1999), the following qualitative characters were determined: leaf arrangement; composition and orientation; lamina characters – shape (form), area, balance, apex, base, texture, margin, venation, adaxial surface and color, abaxial surface and color; lobe characters (number of lobes, shape, symmetry, and incision), and petiole characters (general shape and cross-section,

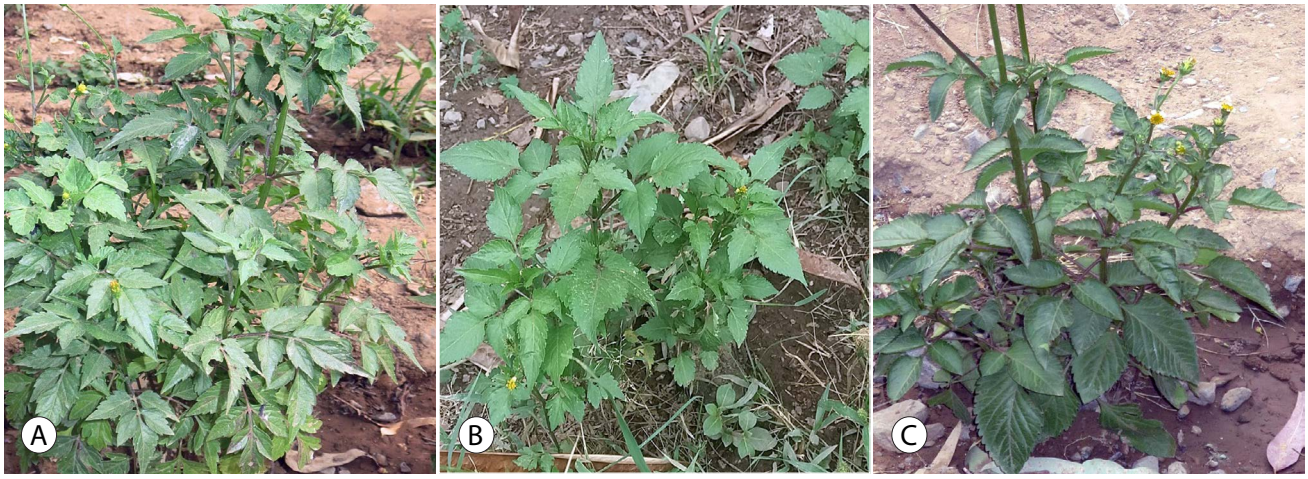

Fig. 1. *Bidens* taxa habit. **A** – *B. bipinnata*, **B** – *B. biternata*, **C** – *B. pilosa*.

Table 1. Locality (coordinates and altitude), collection date and herbarium number of the investigated *Bidens* taxa.

Location	Date	Coordinates		Altitude	*Bidens* taxa/ herbarium No.
		Longitude	Latitude		
Al- Dairy Str., Maeen District	24-5-019	44°11'19.64"E	15°21'6.55"N	2269m asl.	*B. pilosa* BHSS:1516
Al-Zeraa Str., Al-Tahreer District	25-7-019	44°11'28.73"E	15°21'12.75"N	2267m asl.	*B. biternata* BHSS:1534
Hayl Str., Maeen District	5-4-019	44°11'4.84"E	15°21'17.45"N	2274m asl.	*B. pilosa* BHSS:1502
Jawlat Sabaa, Shu'ub District	6-6-019	44°12'21.34"E	15°22'14.83"N	2248m asl.	*B. bipnnata* BHSS:1520
Jawlat Al-Habary, Shu'ub District	28-6-019	44°12'48.97"E	15°22'50.26"N	2242m asl.	*B. bipnnata* BHSS:1527
Old Campus of Sana'a University, Al-Tahreer District	4-4-019	44°11'27.78"E	15°20'58.50"N	2296masl.	*B. pilosa* BHSS:1501
New Campus of Sana'a University, Maeen District	1-8-019	44°11'12.51"E	15°22'5.32"N	2263m asl.	*B. biternata* BHSS:1536

Table 2. List of the investigated qualitative morphological leaf characters of the three *Bidens* taxa recorded in Sana'a city.

	Qualitative Leaf Characters			
Lamina Characters	1/ Leaf arrangement	Opposite decussate [1]	Not so [2]	
	2/ Leaf composition	Pinnatisect [1]	Not [2]	
	3/ Orientation	Apical [1]	Not so [2]	
	4/ Lamina shape (form)	Very wide ovate to ovate [1]	Very wide ovate to narrow ovate [2]	
	5/ Type of lamina area	Microphyll to mesophyll [1]	Not so [2]	
	6/ Entire lamina balance	Symmetrical [1]	Not so [2]	
	7/ Adaxial surface	Glabrescent on vein islet and pubescent on veins [1]	Pubescent on vein islet and pubescent on veins [2]	
	8/ Abaxial surface	Glabrous on vein islet and pubescent on veins [1]	Glabrous to glabrescent on vein islet and pubescent on veins [2]	
	9/ Adaxial surface color	Green to dark-green [1]	Dark-green [2]	
	10/ Abaxial surface color	Green [1]	Not so [2]	
	11/ Texture	Coriaceous [1]	Chartaceous [2]	
	12/ Venation	Pinnate -craspedodormous mixed [1]	Not so [2]	
	13/ Lamina apex	Acuminate -mucronate [1]	Acute-mucronate [2]	
	14/ Lamina margin	Serrate [1]	Not so [2]	
	15/ Lamina margin surface	Glabrescent ciliolate [1]	Pubescent ciliolate [2]	Pubescent to villus Ciliolate [3]
	16/ Tooth spacing	Regular [1]	Irregular [2]	
	17/ Tooth sinus	Angular [1]	Not so [2]	
	18/ Margin apex	Acute-mucronate [1]	Not so [2]	
	19/ Lamina base	Decurrent [1]	Not so [2]	
	20/ Terminal lobe symmetry	Asymmetrical [1]	Not so [2]	
	21/ Terminal lobe shape (form)	Narrow ovate to lanceolate [1]	Widely ovate to lanceolate [2]	Very widely ovate to lanceolate [3]
	22/ Lateral lobe symmetry	Asymmetrical [1]	Not so [2]	
	23/ Lateral lobe shape (form)	Narrow ovate to ovate [1]	Narrow ovate to widely ovate [2]	
	24/ Lateral lobe apex	Acute-mucronate [1]	Not so [2]	
	25/ Lower lateral lobes incision	Simple [1]	Pinnatifid [2]	
Petiole Characters	26/ General shape and cross-section	Inflated with a grove at the adaxial [1] surface	Not so [2]	
	27/ Base	Swollen [1]	Not so [2]	
	28/ Adaxial surface color	Red [1]	Red to reddish-green [2]	Reddish- green [3]
	29/ Abaxial surface color	Green with red stripes [1]	Green with reddish stripes [2]	
	30/ Adaxial surface	Glabrescent, grooved, with fimbrilla on the groove margin [1]	Glabrescent to pubescent, grooved, with fimbrillae on the groove margin [2]	Glabrousent to pubescent, grooved, without fimbrillae at the groove margin [3]
	31/ Abaxial Surface	Glabrous – glabrescent [1]	Glabrescent – pubescent [2]	
	32/ Position of petiole attachment	Marginal [1]	Not so [2]	

base, position of petiole attachment, adaxial and abaxial surface and color).

On the other hand, the quantitative characters were measured as follows: lamina length (from base to apex, petiole not included); lamina width (across the lamina at the widest point in the region between apex and leaf base); petiole length and total leaf length; length of lobes (terminal and lateral lobes); width of lobes (terminal and lateral lobes). The measurements were done by a ruler, in millimeters, and an Image J software program, version 1.50i, was used for the lamina apex angle. Furthermore, based on the terminology of Dilcher (1974) (*Approaches to Identification of Angiosperm Leaf Remains*) and the Leaf Architecture Working Group (1999), the following characters were also obtained: lamina size, form, length-to-width ratio, leaf area and size, percentage of lamina length to total length of the leaf, percentage of petiole length to total length of the leaf, percentage of petiole length to lamina length, lobes (terminal and lateral lobes) length-to-width ratio and size.

3. Statistical analysis

Taxonomical value of the quantitative morphological leaf characters was determined by one-way Anova test using Graph Pad Prism 6.01 program. If $P < 0.05$, then the quantitative leaf features were significantly different. Dissimilarity between the three *Bidens* taxa recorded in Sana'a city has been demonstrated as a dendrogram based on the obtained morphological leaf data (Table 2, 3) by creating a data matrix for numerical analysis (unweighted pair group mathematical average clustering – UPGMA) by Primer 5 software version: 5.2.2

Results

The qualitative and quantitative leaf characteristics of the three *Bidens* taxa recorded in Sana'a city (Figs 2, 3, 4) were studied in detail and the range of variation of these characters is summarized in Table 4 and 6, respectively.

Eighteen qualitative morphological leaf characters coincided in all three *Bidens* taxa. However, five qualitative morphological leaf features (lamina adaxial surface color and texture; apex and lateral lobes shape) separated *B. biternata* from the two other taxa, *B. bipinnata* & *B. pilosa* (Table 4 and Figs 2, 3). Furthermore, three qualitative morphological leaf characters (marginal tooth spacing, lamina lower lobes incision and petiole abaxial surface color) differentiated *B. bipinnata* form *B. biternata* and *B. pilosa* (Table 4 and Figs 2, 4). However, two qualitative morphological leaf characters (lamina abaxial surface and petiole abaxial surface) separated *B. pilosa* form *B. bipinnata* and *B. biternata* (Table 4 and Figs 3, 4). Four qualitative morphological characters (lamina margin surface, terminal lobe shape (form), adaxial petiole surface, and color) could be used to separate these species from each other (Table 4 and

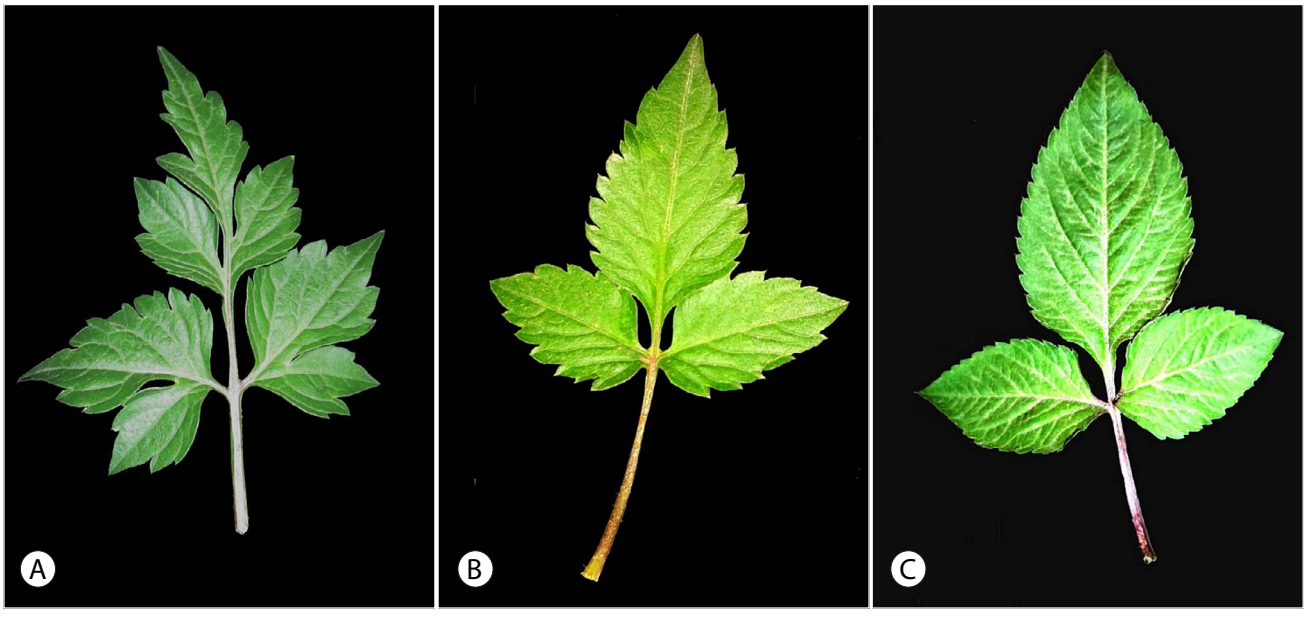

Fig. 2. Leaves of the *Bidens* taxa. **A-B**. *bipinnata*; **B** – *B. biternata* Leaf, **C** – *B. pilosa*.

Figs 2, 3, 4). On the other hand, according to Table 6, the ratio of lamina length-to-width; petiole length; leaf length (lamina length and petiole length); leaf apex angle and mean width of lateral lobes were all greatly significant in distinguishing between *B. pilosa* and the other two taxa, *B. bipinnata* & *B. pilosa*. The total number of lobes and size of the terminal lobe were very significant in separating *B. bipinnata* from the other two taxa, *B. biternata* & *B. pilosa***.** Only one quantitative leaf character (Table 6) – the mean ratio of lateral lobes length-to-width was highly significant in distinguishing *B. biternata* from *B. bipinnata* and *B. pilosa.* Furthermore, the length and width of the terminal lobe and the length-to-width ratio of terminal lobe could be used to separate those species from each other (Table 6).

Taxonomical key based on the qualitative leaf characters

1. Lamina lower lobes are simple, lamina with serrate regular tooth spacing.

   \+ Adaxial petiole surface with fimbrillae on the groove margin ..... *B. biternata.*

   – Adaxial petiole surface without fimbrillae on the groove margin ..... *B. pilosa.*

2. Lamina lower lobes are pinnatisect, lamina with serrate irregular tooth spacing ..... *B. bipinnata.*

Table 3. List of the investigated quantitative leaf characters.

		Quantitative leaf characters
Entire leaf	1/	Lamina length (mm)
	2/	Lamina width (mm)
	3/	Ratio L:W
	4/	Lamina size (mm^2)
	5/	Leaf area (mm^2)
	6/	Petiole length (mm)
	7/	Leaf length (mm)
	8/	Leaf size (mm^2)
	9/	Length of lamina to total length of the leaf %
	10/	Length of petiole to total length of the leaf %
	11/	Length of petiole to lamina length%
	12/	Apex angle
	13/	Total number of lobes
Terminal lobe	14/	Length (mm)
	15/	Width (mm)
	16/	Ratio L:W
	17/	Size (mm^2)
Lateral lobes	18/	Mean length of the lateral lobes (mm)
	19/	Mean width of the lateral lobes (mm)
	20/	Mean ratio L:W
	21/	Mean size of the lateral lobes (mm^2)

Numerical study

Based on 53 leaf morphological features (32 qualitative and 21 quantitative), the dendrogram (Fig. 5) resulting from the UPGMA method illustrates the relationship among the three recorded *Bidens* taxa in Sana'a city and divides them into two groups.

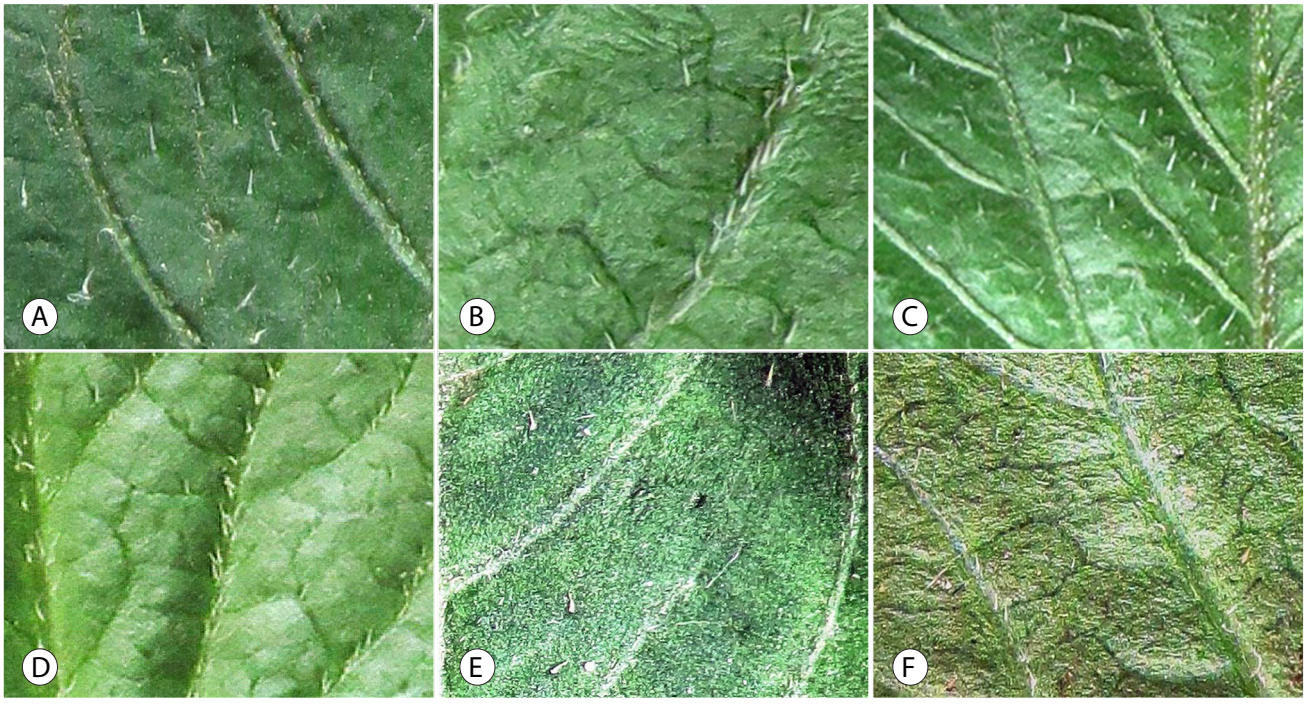

Fig. 3. Leaf surface of the *Bidens* taxa. **A-B** – *B. bipinnata*; **A** – adaxial surface, **B** – abaxial surface. **C-D** – *B. biternata*; **C** – adaxial surface, **D** – abaxial surface. **E-F** – *B. pilosa*; **E** – adaxial surface, **F** – abaxial surface.

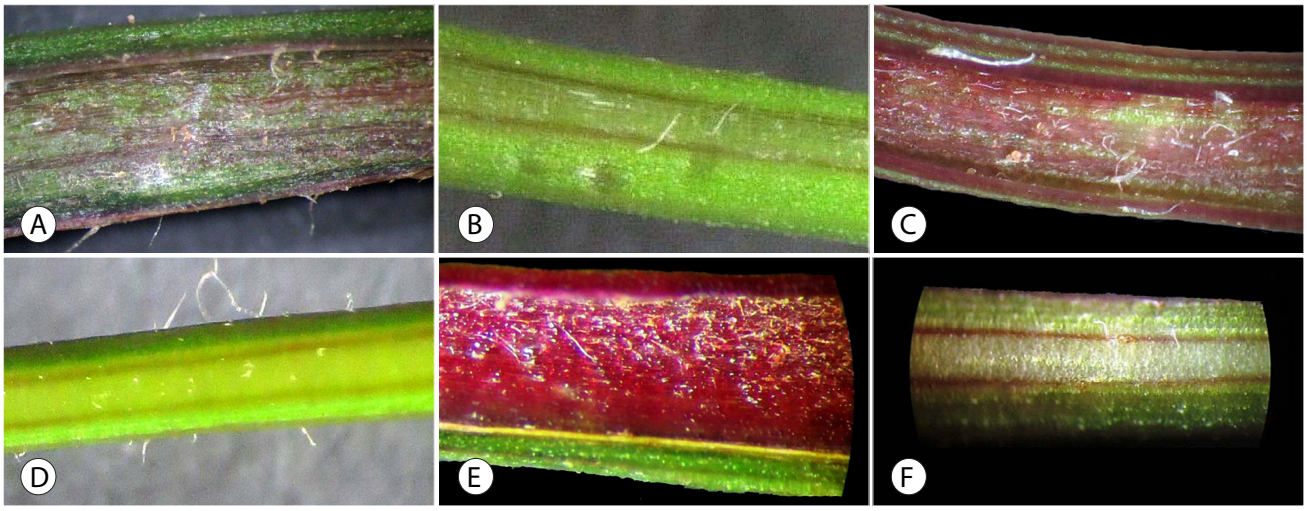

Fig. 4. Petiole surface of the *Bidens* taxa. **A-B** – *B. bipinnata*; **A** – adaxial surface, **B** – abaxial surface. **C-D** – *B. biternata*; **C** – adaxial surface, **D** – abaxial surface. **E-F** – *B. pilosa*; **E** – adaxial surface, **F** – abaxial surface.

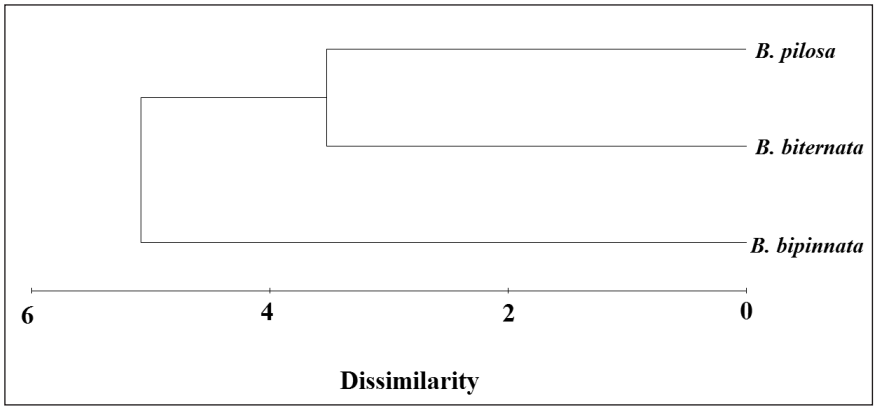

Fig. 5. Cluster analysis illustrating the relationship between the three recoded *Bidens* taxa in Sana'a city based on 53 morphological leaf features obtained by the UPGMA method.

Table 4. Comparative review of the leaf qualitative characters of the three *Bidens* taxa recorded in Sana'a city.

	Leaf quantitative Characters	*B. bipinnata*	*B. biternata*	*B. pilosa*
	Leaf arrangement:	Opposite - decussate	Opposite - decussate	Opposite - decussate
	Leaf composition:	Pinnaitsect	Pinnaitsect	Pinnaitsect
	Orientation:	Apical	Apical	Apical
	Lamina shape (Form):	Very wide ovate to narrow ovate	Very wide ovate to narrow ovate	Very wide ovate to ovate
	Type of Lamina Area:	Microphyll - Mesophyll	Microphyll - Mesophyll	Microphyll - Mesophyll
	Whole lamina Balance:	Asymmetrical	Asymmetrical	Asymmetrical
Lamina Characters	Lamina Adaxial Surface	Glabresent on vein islets and pubescent on veins	Pubescent on vein islet and pubescent on veins	Glabresent on vein islet and pubescent on veins
	Lamina Abaxial Surface	Glabrescent on vein islets and pubescent on veins	Glabrescent on vein islet and pubescent on veins	Glabrous to glabrescent on vein islet and pubescent on veins
	Color of lamina adaxial surface	Dark-green	Green to dark-green	Dark-green
	Color of lamina abaxial surface	Green	Green	Green
	Texture	Coriaceous	Chartaceous	Coriaceous
	Venation	Craspedodromous-mexid	Craspedodromous- mexid	Craspedodromous-mexid
	Lamina apex	Acute-mucronate	Acuminate-mucronate	Acute-mucronulate
	Lamina margin	Serrate	Serrate	Serrate
	Lamina margin surface	Pubescent to villus ciliolate	Pubescent ciliolate	Glabrescent Ciliolate
	Tooth spacing	Irregular	Regular	Regular
	Tooth sinus	Angular	Angular	Angular
	Margin apex	Acute-mucronate	Acute-mucronate	Acute-mucronulate

Table 4. Continuation.

	Leaf quantitative Characters	*B. bipinnata*	*B. biternata*	*B. pilosa*
Lamina Characters	Lamina Base	Decurent	Decurent	Decurent
	Terminal lobe symmetry	Asymmetrical	Asymmetrical	Asymmetrical
	Terminal lobe shape (form)	Wide ovate to Lanceolate	Narrow ovate to Lanceolate	Very wide ovate to Lanceolate
	Lateral lobe apex	Asymmetrical	Asymmetrical	Asymmetrical
	Lateral lobe apex	Narrow ovate to wide ovate	Narrow ovate to ovate	Narrow ovate to wide ovate
	Lateral lobe apex	Acute-Mucronulate	Acute-Mucronulate	Acute-Mucronulate
	Lower lateral lobes incision	Pinnatifid	Simple	Simple
Petiole Characters	General shape and cross-section	Inflated with a groove on the adaxial surface	Inflated with a groove on the adaxial surface	Inflated with a groove on the adaxial surface
	Base	Swollen	Swollen	Swollen
	Color of adaxial surface	Reddish-green	Red to reddish-green	Red
	Color of abaxial surface	Green with reddish stripes.	Green with red stripes	Green with red stripes
	Adaxial surface	Glabrescent, grooved, with fimbrillae on the groove margin	Glabrescent to pubescent, grooved, with fimbrillae on the groove margin	Glabrescent to pubescent, grooved, without fimbrillae on the groove margin
	Abaxial surface	Glabrous - glabrescent	Glabrous - glabrescent	Glabrescent - pubescent
	Position of petiole attachment	Marginal	Marginal	Marginal
Lamina Characters	Leaf arrangement:	Opposite - decussate	Opposite - decussate	Opposite - decussate
	Leaf composition:	Pinnaitsect	Pinnaitsect	Pinnaitsect
	Orientation:	Apical	Apical	Apical
	Lamina shape (Form):	Very wide ovate to narrow ovate	Very wide ovate to narrow ovate	Very wide ovate to ovate
	Type of Lamina Area:	Microphyll - Mesophyll	Microphyll - Mesophyll	Microphyll - Mesophyll
	Whole lamina Balance:	Asymmetrical	Asymmetrical	Asymmetrical
	Lamina Adaxial Surface	Glabresent on vein islets and pubescent on veins	Pubescent on vein islet and pubescent on veins	Glabresent on vein islet and pubescent on veins
	Lamina Abaxial Surface	Glabrescent on vein islets and pubescent on veins	Glabrescent on vein islet and pubescent on veins	Glabrous to glabrescent on vein islet and pubescent on veins
	Color of lamina adaxial surface	Dark-green	Green to dark-green	Dark-green
	Color of lamina abaxial surface	Green	Green	Green
	Texture	Coriaceous	Chartaceous	Coriaceous
	Venation	Craspedodromous-mexid	Craspedodromous- mexid	Craspedodromous-mexid
	Lamina apex	Acute-mucronate	Acuminate-mucronate	Acute-mucronulate
	Lamina margin	Serrate	Serrate	Serrate
	Lamina margin surface	Pubescent to villus ciliolate	Pubescent ciliolate	Glabrescent Ciliolate
	Tooth spacing	Irregular	Regular	Regular
	Tooth sinus	Angular	Angular	Angular
	Margin apex	Acute-mucronate	Acute-mucronate	Acute-mucronulate
	Lower lobes incision	Pinnatifid	Simple	Simple
Petiole Characters	General shape and cross-section	Inflated with a groove on the adaxial surface	Inflated with a groove on the adaxial surface	Inflated with a groove on the adaxial surface
	Base	Swollen	Swollen	Swollen
	Color of adaxial surface	Reddish-green	Red to reddish-green	Red
	Color of abaxial surface	Green with reddish stripes.	Green with red stripes	Green with red stripes
	Adaxial surface	Glabrescent, grooved, with fimbrillae on the groove margin	Glabrescent to pubescent, grooved, with fimbrillae on the groove margin	Glabrescent to pubescent, grooved, without fimbrillae on the groove margin
	Abaxial surface	Glabrous - glabrescent	Glabrous - glabrescent	Glabrescent - pubescent
	Position of petiole attachment	Marginal	Marginal	Marginal

Table 5. Data matrix of the qualitative morphological leaf characters and their states.

Leaf qualitative characters	Taxon	*B. bipinnata*	*B. biternata*	*B. pilosa*
Lamina Characters	Leaf arrangement	1	1	1
	Leaf composition	1	1	1
	Orientation	1	1	1
	Lamina shape (form)	2	2	1
	Type of lamina area	1	1	1
	Entire lamina balance	1	1	1
	Lamina adaxial surface	1	2	1
	Lamina abaxial surface	1	1	2
	Color of lamina adaxial surface	2	1	2
	Color of lamina abaxial surface	1	1	1
	Texture	1	2	1
	Venation	1	1	1
	Lamina apex	2	1	2
	Lamina margin	1	1	1
	Lamina margin surface	3	2	1
	Tooth spacing	2	1	1
	Tooth sinus	1	1	1
	Margin apex	1	1	1
	Lamina base	1	1	1
	Terminal lobe symmetry	1	1	1
	Terminal lobe shape (form)	2	1	3
	Lateral lobes symmetry	1	1	1
	Lateral lobes shape (form)	2	1	2
	Lateral lobe apex	1	1	1
	Lower lateral lobes incision	2	1	1
Petiole Characters	General shape and cross-section	1	1	1
	Base	1	1	1
	Color of adaxial surface	3	2	1
	Color of abaxial surface	2	1	1
	Adaxial surface	1	2	3
	Abaxial surface	1	1	2
	Position of petiole attachment	1	1	1

The first cluster includes *B. bipinnata* early separated from the other two taxa at 5.08 dissimilation distance. The lamina of this species is pinnatisect to three or more, up to nine lobes, and the lower lobes are also pinnatisect. The size of terminal lobe is up to 2077 mm^2; while the lamina of the other two species (*B. biternata* & *B. pilosa*) is pinnatisect to only three lobes (very seldom to five lobes in *B. biternata*) and the lower lobes are simple. The terminal lobe size is up to 3615.6 mm^2 and 6113 mm^2, respectively (Table 6).

The second cluster includes the other two species (*B. biternata* & *B. pilosa*) separated at 3.52 dissimilation distance. *B. biternata* leaves can be distinguished from those of *B. pilosa* by their green to dark-green adaxial surface, pubescent on the vein islet and on the veins, while the adaxial surface of *B. pilosa* leaves is dark-green and glabrescent on the vein islet and pubescent on veins (Table 4 and Fig. 3). The petiole adaxial surface in *B. biternata* is grooved, with fimbrillae on the groove margin, while in *B. pilosa* the petiole adaxial surface is grooved, without fimbrillae on the groove margin (Fig. 4). Furthermore, the terminal lobe of *B. biternata* is up to 100.8 mm in length, while the terminal lobe of *B. pilosa* is up to 116.2 mm long (Table 6).

Discussion

According to our results and earlier studies (Dilcher, 1974; Dakshini, K. M. & Prithipalsingh, 1984 and the Leaf Architecture Working Group, 1999), the lamina of the three taxa is pinnaitsect (the incision reaches to midrib and the lamina is lobed) and consists of lobes or segments. This disagrees with Wood (1997), who erroneously described the lamina of the three taxa as a pinnate compound lamina (the incision reaches to midrib and the lamina is divided into small leaflets).

Judging by Table 4, the qualitative morphological leaf characters do not generally help in distinguishing between the three *Bidens* species, which agrees with Chavan & Oza (1961) and Babu (1977). Only four qualitative characters – lamina margin surface, terminal lobe shape (form), adaxial petiole surface, and color – can be used in distinguishing between these taxa. It is sufficiently clear from Table 6 that the quantitative morphological leaf characters are highly significant in distinguishing between the three *Bidens* taxa, especially the quantitative features of the terminal lobe, which can be used to tell the three *Bidens* taxa apart.

On the other hand, the small dissimilation distance based on the morphological leaf features indicates that *B. bipinnata, B. biternata* and *B. pilosa* are closely related by their leaf morphology. This may give rise to misidentification among these species and agrees with Sheff (1937), who mentioned that the great similarity in leaf morphology had caused errors in identifying *B. bipinnata.* L. and *B. biternata* (Lour) Merr. by Hooker in the *Flora of British India*, where he treated *B. bipinnata.* L. as a variety of *B. pilosa,* and *B. biternata* (Lour) Merr as a synonym for *B. bipinnata* Santapua.

Table 6. Quantitative morphological leaf characters of the three *Bidens* taxa recorded in Sana'a city.

	Leaf quantitative characters	*B. bipinnata*	*B. biternata*	*B. pilosa*	P-value
Entire leaf	Lamina length mm Min (Mean ±SD) Max	33(75.2±21.7)138	43(77.2±12.1)101.9	28.1(67.4±20.3)119.7 ^{a*}	0.0104
	Lamina width mm Min (Mean ±SD) Max	29.2(69.2±21.4) 122.6	25.6 (73 ±16.8) 107.9	24.6(70.3±23.3)119.8	0.5868
	Ratio L:W	0.8(1.1±0.2) 2.7	0.8(1.1±0.2)1.7	0.7(1±0.2) 1.5 ^{a***,b**}	0.0005
	Lamina size mm^2 mm Min (Mean ±SD) Max	962.5 (5606.5±3356.7) 16912.2	1100.8 (5804.5±1983.7)10524.2	832 (5176 ±3074.2) 14342.9	0.4720
	Leaf area mm^2 Min (Mean ±SD) Max	641.7 (3737.7±2237.8) 11274.8	733.9 (3869.6±1322.5) 7016.2	554.7(3450.7±2049.5)9562	0.4720
	Petiole length mm Min (Mean ±SD) Max	6.02 (33±16.8) 73.9	12.6 (29.5±8.9)53.6	5 (22.5±10.4) 47.2 ^{a****,b**}	< 0.0001
	Leaf length mm Min (Mean ±SD) Max	40.6(108.1±35.3) 195.4	55.6 (106.7±18.6)148.4	48.2(89.9±26.1)151.9 ^{a**,b**}	0.0004
	Leaf size mm^2 Min (Mean ±SD) Max	1186.8 (8123±5076.7) 23949	1421.9 (8048 ±2895)16008.2	1183.7 (6873.5±4012.2) 18192.3	0.1752
	Length of lamina to total length of the leaf % Min (Mean ±SD) Max	52 (71 ±8.2) 88	60.2(72.8±4.8)80.2	51.5 (75.2±8.6)93.4 ^{a**}	0.0095
	Length of petiole to total length of the leaf % Min (Mean ±SD) Max	12 (29±8.2) 48	19.8 (27.2±4.8) 39.8	6.6 (24.8±8.6)48.6 ^{a**}	0.0095
	Length of petiole to lamina length% Min (Mean ±SD) Max	13.7(42.8±17.5)92.5	24.7(38 ±66)9.6	7.1(34.9±16.8)94.4 ^{a*}	0.0171
	Apex angle Min (Mean ±SD) Max	29.3 (46±9.9)74.5	24.1 (42.3±10.5) 66.4	28.4(66.7±15.4) 98.7 ^{a****,b****}	< 0.0001
	Total number of lobes Min (Mean ±SD) Max	3 (6± 1.1) 9	3 (3±0.4) 5 ^{a****}	3 ^{a****}	< 0.0001
Terminal lobe	Length mm Min (Mean ±SD) Max	14.7 (40.5±11.6)68.5	41.7(74.7±12.3)100.8 $^{a ****}$	25 (64±19.3)116.2 ^{a****,b***}	< 0.0001
	Width mm Min (Mean ±SD) Max	6.5 (19±5.1)31.7	15.6(27.6±4.6)39.9 ^{a****}	15.8 (32.6 ±9.8) 68.4 $^{a ****,b***}$	< 0.0001
	Ratio L:W Min (Mean ±SD) Max	1.4 (2.2±0.3) 3	2(2.7±0.3) 3.5 ^{a****}	1(2±0.4) 3 ^{a*,b****}	< 0.0001
	Size mm^2 Min (Mean ±SD) Max	101.7 (818.9±435.3)2077	652 (2097.9±607)3615.6 ^{a****}	446.7 (2223.2 ±1244.1) 6113 ^{a****}	< 0.0001
Lateral lobes	Mean length mm Min (Mean ±SD) Max	12.3 (31.5±9.6) 61.6	18.6 (39.8±8.4) 59.3 ^{a***}	14.3 (37.3±12.8) 67.3 ^{a**}	< 0.0001
	Mean width mm Min (Mean ±SD) Max	7.5 (18.2±5)33.1	8.2 (18.9±4.2) 29.7	10 (21.8 ±6.4) 35.9 ^{a***,b**}	0.0005
	Mean ratio L:W Min (Mean ±SD) Max	1.4 (1.8±0.2)2.3	1.6 (2.2±0.4)3.2 ^{a****}	1.3 (1.7 ±0.2) 2.6 ^{b****}	< 0.0001
	Mean size mm^2 Min (Mean ±SD) Max	97.7(658.9±397.8)1988.8	154.2 (776.8±275.5) 1521.7	151.4 (888.8 ±518.7)2423.9 ^{a**}	0.0100

Legend: **a** – Significant differences in species compared to *B. bipinnata*; **b** – Significant differences in species compared to *B. biternata*; * P<0.05; ** P<0.01; ***P<0.001 & **** <0.0001.

Conclusion

Dependence on leaf morphology (qualitative characters) has mainly given rise to erroneous identification of the three *Bidens* taxa by earlier scholars. However, our observations have shown that it is easy to distinguish between these three *Bidens* taxa by some qualitative morphological characters: lamina margin surface, terminal lobe shape (form), and petiole adaxial surface and color. Furthermore, the quantitative morphological leaf characters have proven taxonomically highly significant for distinguishing between these three taxa, especially the quantitative morphological characters of the terminal lobe: length and width and the ratio of terminal lobe length-to-width.

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