

REVISED NOMENCLATURE OF COMPOUND LEAVES AS AN AID IN FIELD IDENTIFICATION OF TROPICAL TREES AND OTHER WOODY PLANTS

HUMBERTO JIMÉNEZ-SAA¹

Abstract. After offering Tropical Dendrology courses for the last seventeen years in Costa Rica, the author has detected deficiencies in the botanical terminology related to compound leaves of tropical woody plants. He suggests several new terms and new leaf classification categories. Four basic compound leaf categories are proposed, for which diagrams are presented, namely: monofoliolate, bifoliolate, palmate, and pinnate. The palmate-compound leaf category is classified as monopalmate, trifoliolate-monopalmate, bipalmate, trifoliolate-bipalmate, tripalmate, and trifoliolate-tripalmate. Correspondingly the pinnate-compound leaf category is classified as monopinnate, bipinnate, and tripinnate. The monopinnate-compound leaf category is further classified as parimonopinnate, imparimonopinnate, and trifoliolate-monopinnate. The bipinnate-compound leaf category is further classified as paribipinnate, and imparibipinnate. Also, the terms foliole versus pinnae, and foliate versus foliolate are discussed. The term ternate is considered as synonymous of palmate with three folioles. Other uncommon compound leaf categories are described, namely: bipalmate, distally monopinnate and tripinnate, distally bipinnate.

Resumen. Después de dictar cursos de Dendrología Tropical en Costa Rica durante los últimos diecisiete años, el autor ha detectado deficiencias en la terminología botánica relacionadas con las hojas compuestas de las plantas leñosas del trópico. El autor sugiere nuevos términos y nuevas categorías de clasificación de las hojas compuestas. Se proponen cuatro categorías básicas de hojas compuestas y se presentan diagramas de las mismas, a saber: monofoliolada, bifoliolada, palmada, y pinnada. La categoría hoja palmati-compuesta se clasifica en monopalmada, monopalmada-trifoliolada, bipalmada, bipalmada-trifoliolada, tripalmada, y tripalmada-trifoliolada. Correspondientemente la categoría hoja pinnati-compuesta se clasifica como monopinnada, bipinnada, y tripinnada. A su vez, la categoría hoja compuesta monopinnada se clasifica como parimonopinnada, imparimonopinnada, y monopinnada-trifoliolada. La categoría hoja compuesta bipinnada se clasifica como paribipinnada e imparibipinnada. También se analizan los términos foliolo versus pinna, y foliado versus foliolado. El término hoja ternada se considera como sinónimo de hoja palmada con tres foliolos. Se describen otras categorías de hojas compuestas poco comunes, a saber: hoja bipalmada, distalmente monopinnada y hoja tripinnada, distalmente bipinnada.

Keywords: terminology, compound leaves, plant identification, morphology, taxonomy.

TABLE OF CONTENTS

1. Current nomenclature of compound leaves	p. 2
1.1. Palmate-compound leaves.....	p. 2
1.2. Pinnate-compound leaves.....	p. 2
1.2.1. Pinnate-compound leaves.....	p. 2
1.2.2. Bipinnate-compound leaves.....	p. 2
1.2.3. Tripinnate-compound leaves	p. 2
1.3. Ternate and trifoliolate leaves	p. 2
2. Deficiencies in using botanical terminology related to compound leaves.....	p. 3
2.1. Pinnate-compound leaves.....	p. 3
2.2. Ternate and trifoliolate leaves	p. 3
2.3. Folioles and pinnae.....	p. 3
2.4. Trifoliolate vs. trifoliolate	p. 3
3. New terms proposed for compound leaf categories.....	p. 3
3.1. Monofoliolate-compound leaves.....	p. 3
3.2. Bifoliolate-compound leaves.....	p. 5
3.3. Palmate-compound leaves.....	p. 5
3.3.1. Monopalmate-compound leaves.....	p. 5

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¹ Centro Científico Tropical, San José, Costa Rica. Email: hjimenez@racsa.co.cr

3.3.2. Bipalmate-compound leaves	p. 6
3.3.3. Tripalmate-compound leaves.....	p. 7
3.4. Pinnate-compound leaves.....	p. 7
3.4.1. Monopinnate-compound leaves.....	p. 7
3.4.1.1. Imparimonopinnate leaves	p. 8
3.4.1.2. Parimonopinnate leaves	p. 8
3.4.2. Bipinnate-compound leaves.....	p. 8
3.4.3. Tripinnate-compound leaves	p. 9
3.5. Foliolae and pinnae.....	p. 10
3.6. Trifoliolate vs. trifoliolate	p. 10
3.7. Ternate leaves as a compound leaf category.....	p. 11

The author has led courses in Tropical Dendrology in Costa Rica since 1993 (www.hjimenez.org), partially sponsored by the Tropical Science Center (www.cct.or.cr). Through permanent interaction with students the author has observed some deficiencies in using botanical terminology related to compound leaves of mainly dicotyledonous woody

plants (Jiménez-Saa 2010). In this article a short description is made of current nomenclature (Section 1, p. 2), followed by a short revision of deficiencies found in common terminology (Section 2, p. 3). Finally, several new leaf terms and new leaf classification categories are suggested (Section 3, p. 3).

1. CURRENT NOMENCLATURE OF COMPOUND LEAVES

Leaves of tropical woody angiosperms are normally grouped into two basic classes: simple and compound. The compound leaves are, in turn, grouped into: palmate-compound (also called digitately compound) and pinnate-compound.

1.1. Palmate-compound leaves

In palmate-compound leaves, folioles (or leaflets) are attached at the end of the petiole. Each foliole has a petiolule. Technically, there is no rachis in palmate-compound leaves

There seems to be a non-declared or tacit agreement among some authors to consider that palmate-compound leaves have four or more folioles. To name palmate-compound leaves with three folioles, two special categories are commonly used: trifoliolate leaf and ternate leaf. There is no special category for palmate-compound leaves having four, five, or more folioles.

Moreno (1984) reported the terms bipalmate-compound leaf and tripalmate-compound leaf, which are explained below in sections 3.3.2. and 3.3.3. In the tropics, there are few, if any, bipalmate or tripalmate leaves among trees and shrubs.

1.2. Pinnate-compound leaves

The literature further divides pinnate-compound leaves into pinnate, bipinnate, and tripinnate (Moreno 1984; Harrington 1985).

1.2.1. Pinnate-compound leaves

Pinnate-compound leaves are currently classified

in two groups: paripinnate (when ending in two folioles [leaflets]) and imparipinnate (when ending in one foliole [leaflet]). In the pinnate-compound leaf category, we distinguish—as in simple leaves—the petiole and the blade. The blade divides into segments, called folioles (leaflets), disposed along a rachis, each foliole having its own slender stalk or petiolule. Folioles of pinnate-compound leaves may be opposite or alternate.

1.2.2. Bipinnate-compound leaves

In bipinnate leaves, the blade divides into segments called pinnae, consisting of second order folioles along a rachilla. Such second order folioles are also called foliolules.

1.2.3. Tripinnate-compound leaves

There are a few dicotyledonous tree species with tripinnate leaves having second order pinnae and third order folioles. Such second order pinnae are also called pinnules. Pinnae of bipinnate and tripinnate leaves may be opposite or alternate.

1.3. Ternate and trifoliolate leaves

Ternate is a term applied to leaves with three folioles. The terms biternate and triternate are also employed in the literature. These latter two groups of leaves are found mostly in climbers. In the literature, trifoliolate also has been applied as a category of leaves with three folioles no matter whether imparipinnate or palmate.

2. DEFICIENCIES IN USING BOTANICAL TERMINOLOGY RELATED TO COMPOUND LEAVES

The Greek prefixes *mono*, *di*, *tri*, *tetra*, *penta*, *hexa*, etc., and their corresponding Latin prefixes *uni*, *bi*, *tri*, *quadr*, *quinque*, *sex*, etc., are broadly used in botany to express the number of parts. The prefix “tern” (from Latin *ternatus*) is used as a synonym for “tri” (a set of three). Such prefixes are partially used both to establish leaf classification categories and to describe the leaf morphology of plant individuals.

The Greek prefix *mono* is not used in all cases as it should in relation to the number of segments in leaves (Jiménez-Saa 2010). Attempts have been made to partially solve such terminological deficiency using equivalent terms, such as simple pinnate, once-pinnate, 1 time pinnate, as follows: Gentry (1993) used the term simply pinnate in the same sense as our *monopinnate*, described below in Section 3.4.1. The “Discover Life” initiative (<http://www.discoverlife.org/>) uses the following categories: compound pinnate 1 time, compound pinnate 2 times, and compound pinnate over 2 times (http://www.discoverlife.org/mp/20q?guide=Neotropical_flora). Some fern specialists use the term monopinnate in fossil frond descriptions (Archangelsky 1983).

2.1. Pinnate-compound leaves

The author considers that we should not use the term pinnate-compound leaf as a classification category for the once pinnate-compound leaves, because it is highly convenient to take into account the Greek and Latin prefixes *mono* or *uni*, respectively. The term **monopinnate-compound leaf** should be used consistently to designate once pinnate-compound leaves. The more general term **pinnate** should be used only to describe the group of “feather-like” compound leaves as opposed to “hand-like” or palmate-compound leaves. This will be revisited in Section 3.4.1.

2.2. Ternate and trifoliolate leaves

Historically, compound leaves having three folioles (leaflets) have been described in two categories: **ternate** (applied mostly for leaves of dicotyledonous climbers), and **trifoliolate** (applied mostly for leaves of dicotyledonous non-climbing plants). The term *ternado* in Spanish is registered as a synonym of *trifoliolado* (Font Quer 1980).

According to Moreno (1984) and Harrington (1985), the term **trifoliolate-compound** should be applied both to trifoliolate-palmate and to trifoliolate-pinnate. The present author agrees with this. It is unfortunate, however, that some authors are increasingly using the term trifoliolate alone, without accompanying it with the descriptors palmate or pinnate. By doing this, they cause confusion and a loss of valuable information

2.3. Folioles and pinnae

Classical botanists accepted the terms foliole and pinna as synonymous (Font Quer 1980). When such synonymy is applied to some compound leaves of tropical plants, misunderstandings can arise. For instance, the compound leaf in Fig. 3 could be termed bifoliolate (which is correct), because it has two folioles; but it also could be termed bipinnate, because it has two pinnae (which is incorrect, because foliole and pinna are not synonymous).

2.4. Trifoliolate vs. trifoliolate

It is becoming popular to apply the term **trifoliolate** for leaves having three folioles (leaflets) instead of using the term **trifoliolate**. This is incorrect as will be discussed in Section 3.6.

3. NEW TERMS AND RECOMMENDATIONS FOR COMPOUND LEAF CATEGORIES

In this section the author proposes a new set of terms for compound leaf categories with special attention given to the use of the Greek and Latin prefixes *mono*, *bi*, and *tri* as mentioned in first paragraph of Section 2. The system can be easily visualized by studying Fig. 1. Notice that accompanying every new term suggested, the word **compound** is added. However, this will not always be necessary when the context is clear. The intention

is to encourage more botanists to participate in a free discussion, in order to define a clear and sound morphological classification system applied to plant leaves.

3.1. Monofoliolate-compound leaves

The author proposes that the traditional term **monofoliolate compound leaf**—when the species *consistently* exhibits a single foliole (Fig. 2)—be

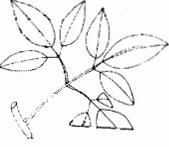
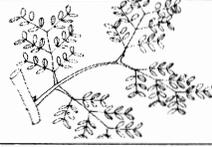
A. Simple leaves (The blade is <u>NOT</u> divided into <u>individual segments</u> .)					
B. Compound leaves (The blade is <u>divided into individual segments</u> with <u>petiolules</u> .) →	B1. Monofoliolate compound leaves (The blade has just one foliole.)				
	B2. Bifoliolate compound leaves (The blade has two folioles. Sometimes there is a tendril in between the folioles.)				
	B3. Palmate compound leaves (The blade appears divided in segments — <u>folioles</u> or <u>foliolules</u> —which <u>occur grouped</u> at the end of a petiole or a petiolule.) →	B3a. Monopalmate compound leaves (Folioles are grouped at the end of the petiole.)			
		B3b. Bipalmate compound leaves (Folioles are grouped at the end of a first order petiolule.)			
		B3c. Tripalmate compound leaves (Folioles are grouped at the end of a second order petiolule.)			
	B4. Pinnate compound leaves (The blade appears divided into folioles or pinnae which are <u>borne along</u> a rachis or a rachilla.) →	B4a. Monopinnate (The blade appears divided into <u>folioles</u> , borne along a rachis.) →	B4a.(1). Parimonopinnate (At the end of the rachis there are <u>2 folioles</u> [one pair].)		
			B4a.(2). Imparimonopinnate (At the end of the rachis there is 1 foliole.)		
		B4b. Bipinnate (The blade appears divided into <u>pinnae</u> , which are normally borne along a rachis.) →	B4b.(1). Paribipinnate (At the end of the rachis there are <u>2 pinnae</u> [one pair].)		
B4b.(2). Imparibipinnate (At the end of the rachis there is a single pinna.)					
B4c. Tripinnate (The blade appears divided into <u>second order pinnae</u> , which are normally borne along a rachilla.)					

Fig. 1. Main leaf classes commonly occurring among dicotyledons. Illustrations: LGB.

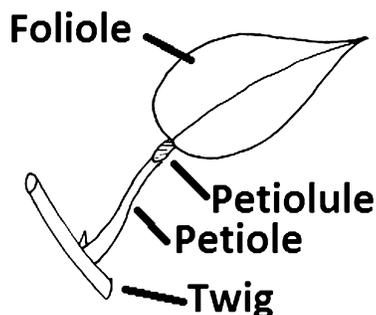


FIG. 2. Monofoliolate-compound leaf. Illustration: LGB.

considered as an independent compound leaf category (see also Fig. 1). Examples of species exhibiting such morphology include: *Citrus* L. spp., *Zanthoxylum monophyllum* (Lam.) P. Wilson, *Stauranthus perforatus* Liebm., and *Swartzia simplex* (Sw.) Spreng.).

3.2. Bifoliolate-compound leaves

The author proposes that the traditional term **bifoliolate-compound leaf**—when the species *consistently* has two folioles—be considered as an independent compound leaf category (see also Fig. 1). Some examples of this category are found in Fabaceae-Caesalpinioideae (e.g., *Hymenaea* L., *Peltogyne* Vogel, *Cynometra* L., and *Macrolobium* Schreb.) and Bignoniaceae (e.g., *Anemopaegma* Mart. ex Meisn. and *Pyrostegia* C. Presl.; Fig. 3).

There are some species (mostly in the climber group of Bignoniaceae) with bifoliolate leaves which have a tendril as in *Pyrostegia venusta* (Ker Gawl.) Miers (Krings & Braham 2005; Fig. 4). See also the fourth paragraph of section 3.4.1.

3.3. Palmate-compound leaves

The group of the palmate-compound leaves can be classified following the same basic principles used for the group of the pinnate-compound leaves (see Section 3.4.), as follows.

3.3.1. Monopalmate-compound leaves

Monopalmate-compound leaves show folioles attached together or grouped at the end of the petiole. Each foliole has a petiolule (Fig. 5).

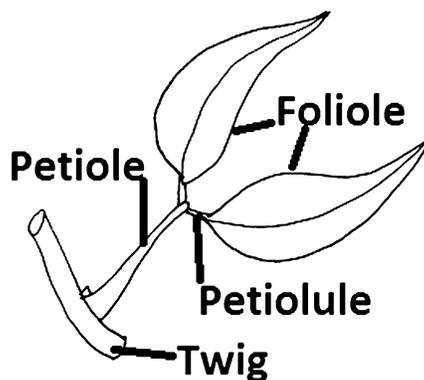


FIG. 3. Bifoliolate-compound leaf. Illustration: LGB.

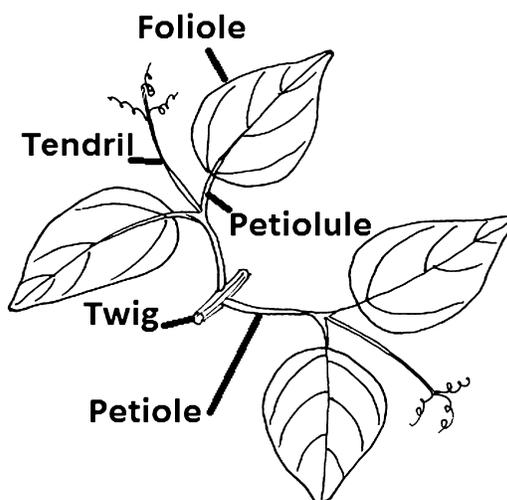


FIG. 4. Bifoliolate-compound leaves with a tendril between the folioles (*Pyrostegia venusta*). Illustration: Krings & Braham (2005). Reprinted with permission of John Wiley & Sons, Inc. (Copyright, 2005).

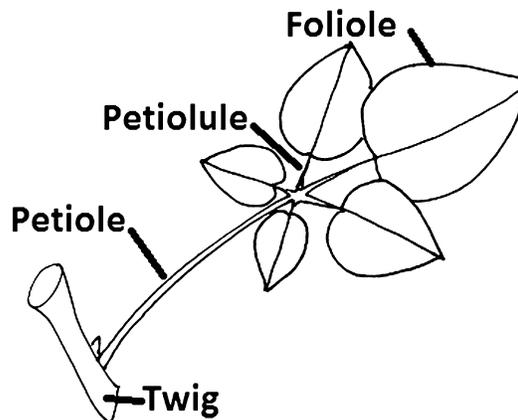


FIG. 5. Monopalmate-compound leaf (penta-foliolate). Illustration: LGB.

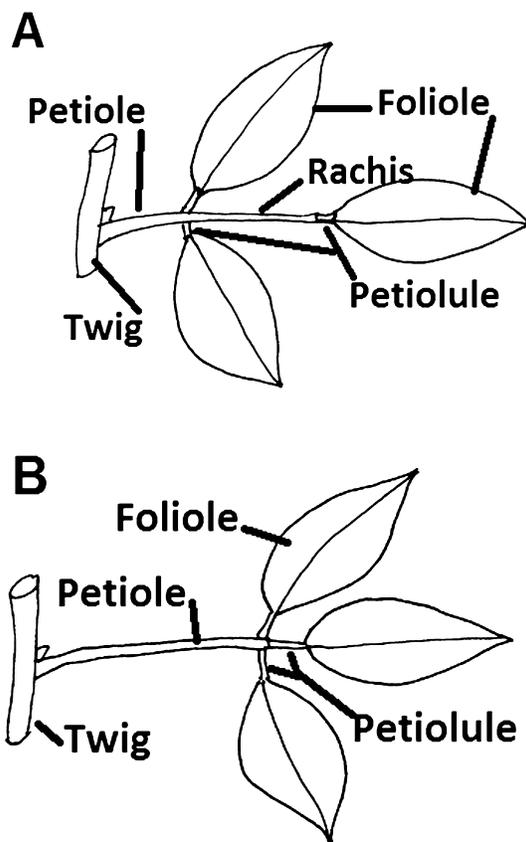


FIG. 6. Two types of trifoliolate-compound leaves, commonly referred to as “ternate” in the literature: A, trifoliolate-monopinnate; B, trifoliolate monopalmate. Illustrations: LGB.

There are several species (mostly in the Fabaceae-Papilionoideae and in the climber group of Sapindaceae) with monopalmate leaves, which *consistently* exhibits three folioles. It is thus convenient to give a special treatment to this case for which the author proposes the term **trifoliolate-monopalmate** (Fig. 6B). This category also serves to establish the difference between this group and that of the trifoliolate-monopinnate leaf, as discussed in Section 3.4.1.

It is also convenient to include the number of folioles in certain unusual cases as in the monopalmate leaf shown in Fig. 7. The author suggests monopalmate-compound leaf, tetrafoliolate with a tendril between two of the folioles.

3.3.2. Bipalmate-compound leaves

Bipalmate-compound leaves exhibit foliolules grouped *at the end of petiolules*. Each foliolule has a

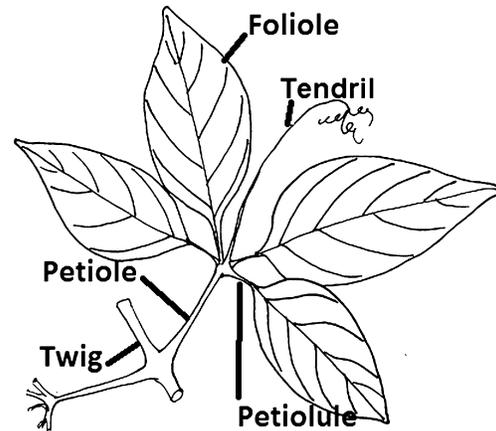


FIG. 7. Monopalmate-compound leaf, tetrafoliolate with a tendril between two of the folioles (*Anemopaegma orbiculatum*). Illustration: Krings & Braham (2005). Reprinted with permission of John Wiley & Sons, Inc. (Copyright, 2005).

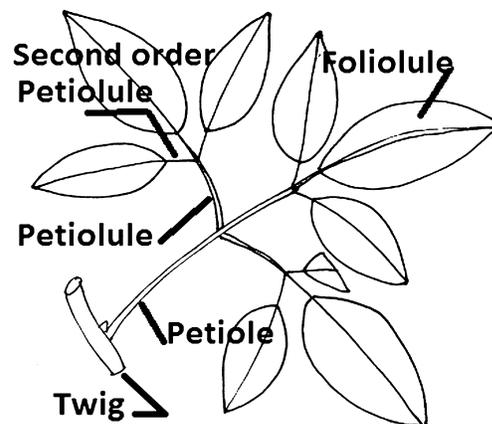


FIG. 8. Trifoliolate-bipalmate compound leaf (“biternate” sec. Harrington 1985). Illustration: LGB.

second order petiolule (Fig. 8). There are some species (mostly in the climber group of Bignoniaceae) with bipalmate-compound leaves which have a tendril, such as *Pleonotoma variabilis* (Jacq.) Miers and *Tourrettia lappacea* (L’Hér.) Willd. ex L.f. (Krings & Braham 2005).

Some leaves are bipalmate in their basal segments, but monopinnate (parimonopinnate or imparimonopinnate) in their distal segments. Examples of such species can be found in *Paullinia* L. spp. and others genera of Sapindaceae (Figs. 9 and 10). The author proposes the term **bipalmate-compound leaf, distally monopinnate** for such cases.

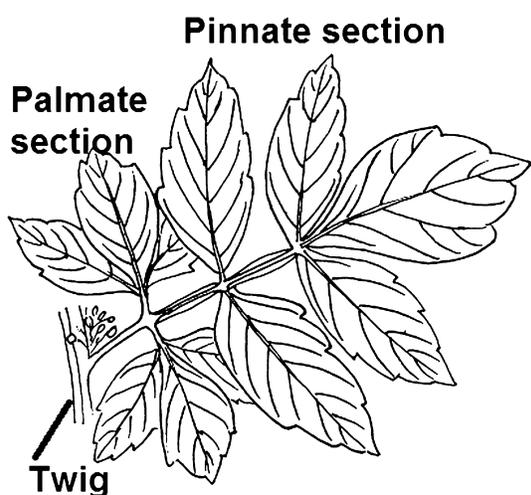


FIG. 9. Bipalmate-compound leaf, distally monopinnate (*Paullinia mallophylla*). Illustration: Krings & Braham (2005). Reprinted with permission of John Wiley & Sons, Inc. (Copyright, 2005).

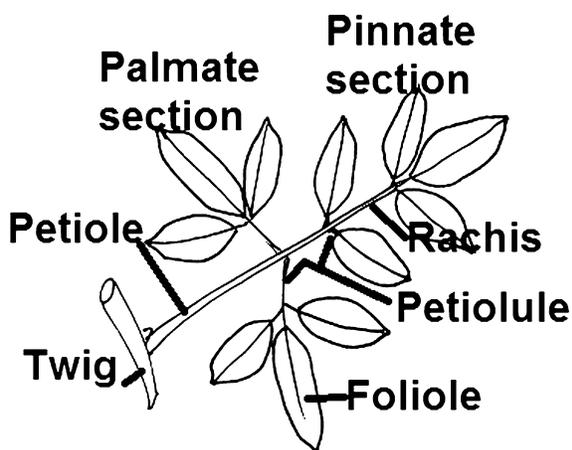


FIG. 10. Bipalmate-compound leaf, distally monopinnate (some species of *Paullinia* and *Memora*; "ternate-pinnate" or "intermediate between biternate and triternate" sec. Ribeiro et al. 1999). Illustration: LGB.

3.3.3. Tripalmate-compound leaves

The literature reports the category tripalmate-compound leaf which shows folioles grouped at the end of *second* order petiolules. Each foliole has a *third* order petiolule (Fig. 11).

When authors defined (literally and graphically) both bipalmate and tripalmate-compound leaves (mostly reported as biternate and triternate leaves),

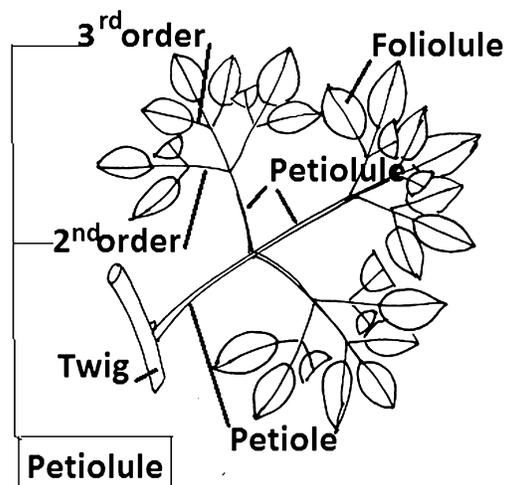


FIG. 11. Trifoliolate-tripalmate compound leaf ("triternate" sec. Harrington 1985). Illustration: LGB.

they typically showed them having groups of three folioles (e.g., Harrington 1985). Thus, it is also convenient to accord them special treatment and the terms **trifoliolate-bipalmate** compound leaf (Fig. 8) and **trifoliolate-tripalmate** compound leaf (Fig. 11) are proposed here.

3.4. Pinnate-compound leaves

The new category pinnate-compound leaf includes monopinnate-, bipinnate-, and tripinnate-compound leaves.

3.4.1. Monopinnate-compound leaves

The author proposes the collective term **monopinnate-compound leaf** as a substitute for the old collective term pinnate-compound leaf. Such substitution has the advantage of clarifying the classification and strengthening the relationship between this new proposed term and the traditional valid terms **bipinnate**, **tripinnate**, etc. The term imparipinnate should be turned into **imparimonopinnate**, and the term paripinnate into **parimonopinnate**, as described below in sections 3.4.1.1 and 3.4.1.2.

There are several species (mainly in the Fabaceae-Papilionoideae) with monopinnate leaves which *consistently* exhibit three folioles. Thus, it seems convenient to give special treatment to this case, for which the author proposes a new category using the term **trifoliolate-monopinnate** (Fig. 6A). This category also serves to establish the difference between this group and that of the trifoliolate

-monopalmate leaf, as discussed in Section 3.3.1.

On the basis of such substitutions, we should use the collective or generic term *pinnate* to mean *the group of* the monopinnate, the bipinnate and the tripinnate leaves, as stated above in the introductory paragraph of Section 3.4.

In some monopinnate leaves, the rachis does not end in one or two folioles, but in prolongations. Some examples of this include: (1) species of *Vicia* L. (Fabaceae-Papilionoideae) and *Cobaea* Cav. (Polemoniaceae), in which leaves terminate in a branched tendril (Fig. 12), (2) several species of Sapindaceae, in which leaves end in a short somewhat stiff prolongation (Fig. 13), and (3) species of *Dipteryx* Schreb. (Fabaceae-Papilionoideae), in which leaves end in a long flexible prolongation (Fig. 14). See also the second paragraph of Section 3.2.

3.4.1.1. Imparimonopinnate leaves

Imparimonopinnate leaves have folioles attached along a rachis and end in a single foliole (Fig. 15). The number of folioles is not necessarily *consistent* in individuals of the same species; some species exhibit leaves with three, five, or more folioles in the same individual. Arrangement or phyllotaxis of the folioles can be opposite or alternate. See also the second paragraph of Section 3.4.1

3.4.1.2. Parimonopinnate leaves

Parimonopinnate leaves have folioles attached along a rachis and ending in two folioles (Fig. 16). This category includes those leaves having two or more pairs of folioles. The number of folioles is not necessarily *consistent* in individuals of the same species, and some species exhibit leaves with two, three, or more pair of folioles in the same individual. Arrangement or phyllotaxis of the folioles can be opposite or alternate (see also Section 3.2).

3.4.2. Bipinnate-compound leaves

In bipinnate-compound leaves, the blade divides into segments, called pinnae, which normally occur along a rachis. Each pinna consists of foliolules along a rachilla (Fig. 17). The number of pinnae is not necessarily *consistent* in individuals of the same species, and some species exhibit leaves with one, two, or more pair of pinnae in the same individuals. (see also the fourth paragraph in this section). Arrangement or phyllotaxis of the pinnae and of the foliolules can be opposite or alternate.

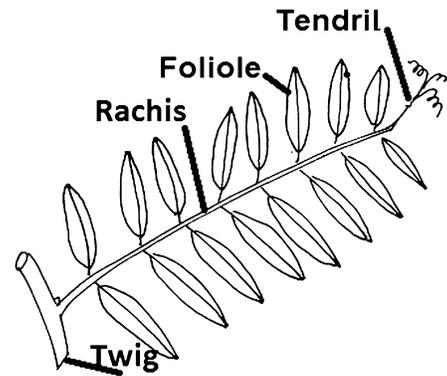


FIG. 12. Monopinnate-compound leaf ending in a tendril (*Vicia villosa*). Illustration: Krings & Braham (2005). Reprinted with permission of John Wiley & Sons, Inc. (Copyright, 2005).

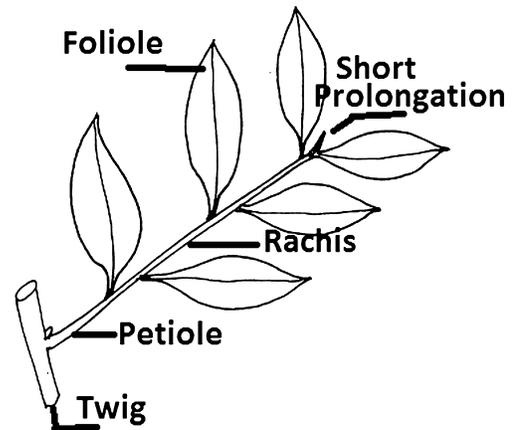


FIG. 13. Monopinnate-compound leaf ending in a short more or less stiff prolongation (common in several species of Sapindaceae). Illustration: LGB.

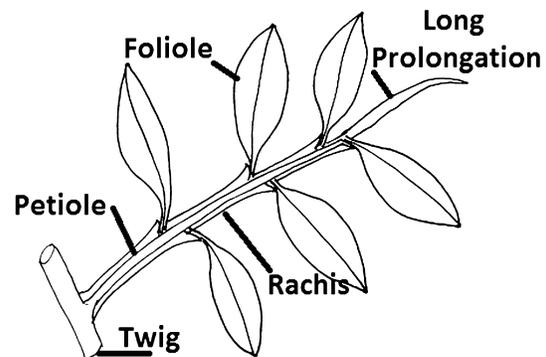


FIG. 14. Monopinnate-compound leaf ending in a flexible long prolongation (*Dipteryx* spp.). Illustration: LGB.

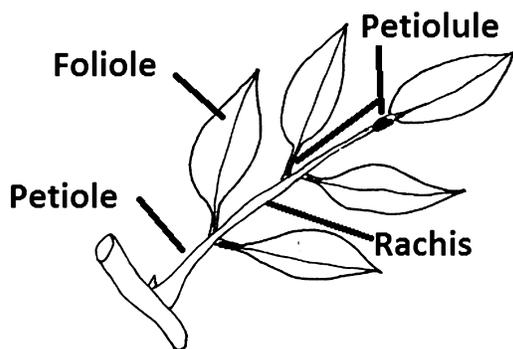


FIG. 15. Imparimonopinnate-compound leaf. Illustration: LGB.

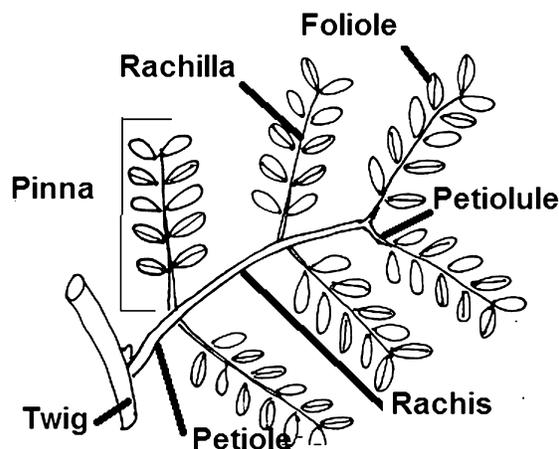


FIG. 17. Paribipinnate-compound leaf. Illustration: LGB.

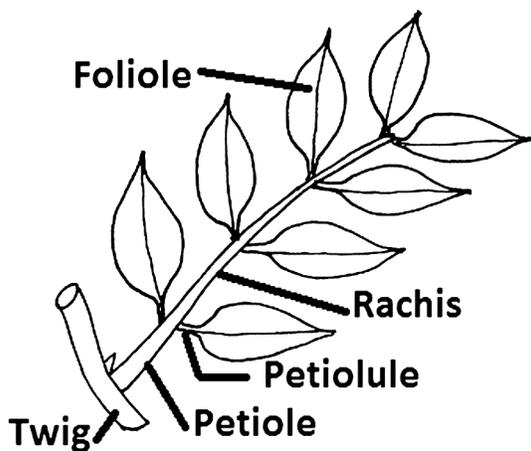


FIG. 16. Parimonopinnate-compound leaf. Illustration: LGB.

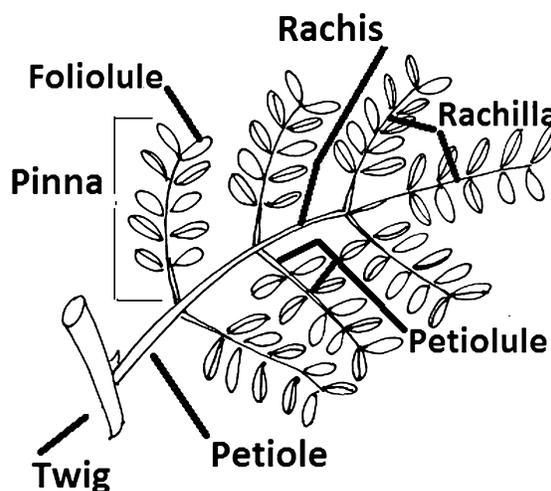


FIG. 18. Imparibipinnate-compound leaf. Illustration: LGB.

Most bipinnate-compound leaves end in two pinnae. The author suggests the category **paribipinnate leaf** for this case (Fig. 17).

In a few species, such as *Caesalpinia* L. (Fabaceae-Caesalpinioideae), the bipinnate-compound leaf consistently ends in one pinna. The author suggests the category **imparibipinnate leaf** for this case (Fig. 18).

There are several species (mostly in Fabaceae-Mimosoideae) that do not have a first order rachis because they *consistently* exhibit only one pair of pinnae. The author suggests that this group be kept within the category *bipinnate-compound leaf*, and that a descriptor be added, such as: **bipinnate leaves with just one pair of pinnae**. Exam-

ples of this morphology can be found in *Zygia* P. Browne, *Calliandra* Benth., and *Pithecellobium* Mart. (Figs. 19 and 20).

3.4.3. Tripinnate-compound leaves

In tripinnate-compound leaves, the blade appears divided into *second order pinnae which develop along a rachilla*. Such second order pinnae have pinnules (Fig. 21). Arrangement or phyllotaxis of the pinnae and that of the pinnules can be opposite or alternate.

The author has observed that some tripinnate-compound leaves normally exhibit the tripinnate condition in their basal segments and a bipinnate

condition in their distal segments (see for example: *Memora flaviflora* (Miq.) Pulle of Bignoniaceae, *Myrrhidendron donnell-mithii* J.M. Coult. & J.N. Rose of Apiaceae, and *Sciadodendron excelsum* Griseb. of Araliaceae). For these cases, the author suggests using **tripinnate-compound leaf, distally bipinnate** (Fig. 22).

3.5. Foliololes and pinnae

Even though the term foliole comes from the Latin *foliolum* (meaning foliole or leaflet) and the

term *pinna* has a close relationship with the Latin *penna-ae* (feather), such terms were accepted as synonymous by some. However, there is a favorable tendency from a proportion of authors to disregard such synonymy (see Section 2.3). This tendency should be encouraged to avoid misunderstandings.

3.6. Trifoliolate vs. trifoliolate

As mentioned in section 2.4., some authors use the term **trifoliolate** for leaves having three folioles instead of using the term **trifoliolate**. This is not correct, because *foliate* comes from the Latin *folium*, meaning leaf, and *foliolate* comes from the Latin *foliolum*, meaning leaflet (Stearn 1967).

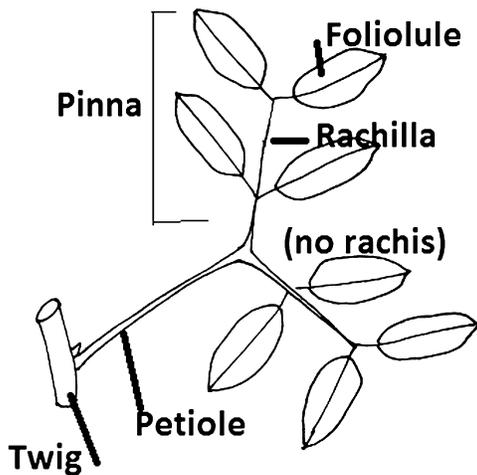


FIG. 19. Bipinnate-compound leaf with just one pair of pinnae. Illustration: LGB.

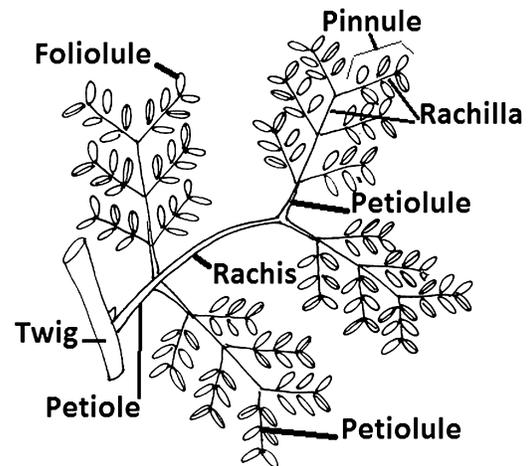


FIG. 21. Tripinnate-compound leaf. Illustration: LGB.

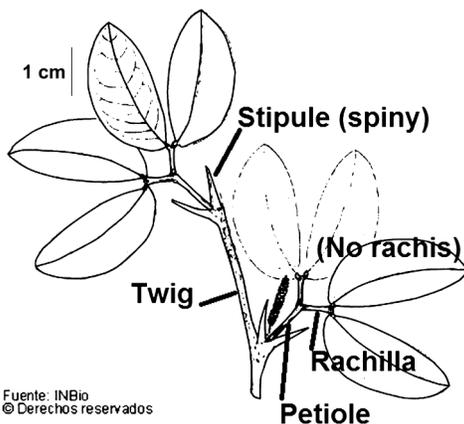


FIG. 20. Bipinnate-compound leaves with just one pair of pinnae (*Pithecellobium unguis-cati*). Illustration: Adapted with permission from: www.darnis.inbio.ac.cr).

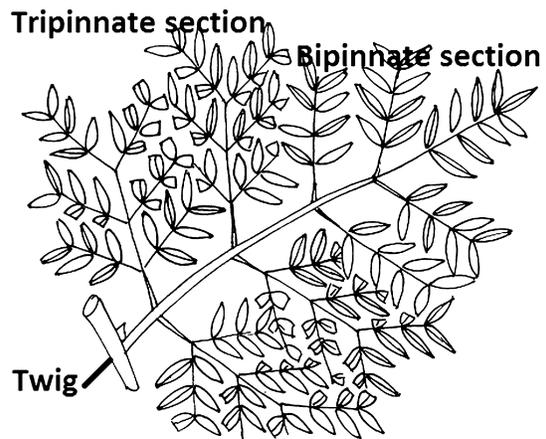


FIG. 22. Tripinnate-compound leaf, distally bipinnate. Illustration: LGB.

3.7. Ternate leaves as a compound leaf category

Based on the discussion in Section 2.2., it is suggested that the term *ternate* be disregarded, because it is not necessary as an explicit category of leaf classification. In some cases, botanists should include the terms trifoliolate, tetrafoliolate, pentafofoliate, etc., especially when dealing with palmate-compound leaves, as part of the description

of the species is being treated. The meaning of the terms ternate, biternate, and triternate (as used currently; Section 1.3.), is better expressed in the trifoliolate subcategories suggested for the palmate-compound categories: i.e., trifoliolate-monopalmate (Section 3.3.1.; Fig. 6B), trifoliolate-bipalmate, and trifoliolate-tripalmate (Section 3.3.3.; Figs. 8 and 11).

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