ARTICLE

Phytomedicine 101: Plant Taxonomy for Preclinical and Clinical Medicinal Plant Researchers

Bradley C. Bennett, PhD, and Michael J. Balick, PhD

Plants are the primary source of medicine for most of the world. The most fundamental step in the scientific study of medicinal plants is establishing their botanical identity. Many studies lack voucher specimens, which serve as permanent records of scientific investigations. This omission makes positive identification impossible and hinders reproducibility. Even when vouchers are cited, scientific names are often mishandled. A random survey of titles and abstracts of 100 publications revealed 20 with taxonomic errors. Mistakes included a lack of author citations, misspellings, and use of older synonyms instead of currently accepted names. A seemingly minor orthographic error makes it impossible to search electronic databases for information about a species. Medicinal plant manuscripts and National Institutes of Health proposals commonly lack scientific rigor in dealing with botanical names and documentation. This article examines common taxonomic problems relevant to medicinal plant research and provides a basic guide to plant taxonomy for medicinal plant researchers. Voucher specimens and their preparation, plant identification, and botanical nomenclature are discussed. References and other resources to assist investigators are cited.

Key words: *binomials, botanical nomenclature, medicinal plants, plant identification, synonyms, voucher specimens*

Before a plant can be developed into an allopathic therapy, researchers must address several issues, including the plant's botanical identity, traditional use, chemical constituents, active components, safety, efficacy, and mechanism of action. Here we examine the botanical identity issue, which is the domain of plant taxonomy or systematics. Taxonomy has two primary objectives. The first is practical: the identification of the diversity of life. The second is cognitive: understanding relationships among organisms. Both are relevant to medicinal plant studies. Unless a plant under investigation can be unambiguously identified, there is no certainty about reproducibility, the fundamental underpinning of science. Understanding evolutionary relationships among species also is germane to the study of plant medicines. Whereas primary metabolites are similar across broad taxonomic categories, secondary metabolites (more accurately plant natural products) exhibit significant qualitative and quantitative variation.

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Problems

Answering the question "What is it?" requires two elements: a preserved specimen deposited in a properly curated collection and assignment of the correct name to that specimen. Botanical specimens, known as vouchers or voucher specimens, are deposited in herbaria. Herbaria (singular, herbarium) are collections of dried plants that are labeled, mounted on archival quality paper, and arranged systematically for scientific study and documentation. Some studies cite vouchers,[1–3] but many recent investigations fail to do so.[4–6]

Another problem is the frequent misuse of binomials in medicinal plant publications. In reviewing recent publications on medicinal plants in *PubMed*, we found 20 errors in the titles or abstracts of 100 publications (Table 1). An inexcusable error is to misspell binomials. One publication rendered the genus for pineapple as *Ananus* instead of the correct spelling, *Ananas*. The generic name *Boerhavia* contained an extract vowel; *Securidaca* contained an extra consonant. The specific epithet of *Xylopia langsdorfiana* St.Hilaire & Tulasne was spelled with an extra letter. Without correct orthography, researchers cannot adequately search the literature or electronic databases.

Another frequent error in the medicinal plant literature is the lack of author citations for binomials. Their inclusion is mandatory for publications in systematics and ethnobotany. For example, *Pluchea carolinensis* (Jacq.) G. Don is a common medicinal plant in the Caribbean.[3,7] The homonym *Pluchea carolinensis* (Jacq.) Sweet is a nomenclatural synonym of *Conyza carolinensis* Jacq. (a homonym duplicates a previously published name for a name of the same rank based on a different type of specimen). Most publications on this medicinal plant have failed to include the author citation. Therefore, it is unclear as to which taxon they refer. A lack of proper identification can confound clinical studies and their interpretation, thus reducing their value tremendously. We frequently recommend that journal editors reject manuscripts because of inadequate botanical documentation.

Plant Taxonomy for Medicinal Plant Researchers

Vouchers

Voucher specimens are the sine qua non of medicinal plant studies. Plant vouchers are important for scientific documentation and identification, as well as for studies of variability within plant taxa. It is crucial, but insufficient, to know the botanical identity of a medicinal plant. Preparation of vouchers is a crucial step for ''good botanical practices'' in studies of plant medicines.[8] Every

Table 1. Incorrect Binomial, Misspelled Names, and Author Citation Problems in Recent Publications on Medicinal Plants

Name Citation	*Accepted Name Citation*	*Source*	*Problem*
Acalypha wilkesiana	*Acalypha amentacea* Roxb.	25, 26	Synonym, no author citation
Acanthopanax gracilistylus	*Eleutherococcus nodiflorus* (Dunn) S.Y. Hu	26	Synonym, no author citation
Ananus comosus	*Ananas comosus* (L.) Merr.	26	Misspelled generic name, no author citation
Artocarpus communis	*Artocarpus altilis* (Parkinson) Fosb.	27	Synonym, no author citation
Boerhaavia diffusa	*Boerhavia diffusa* L.	28	Misspelled generic name, no author citation
Cajanus indicus	*Cajanus cajan* (L.) Millsp.	29	Synonym, no author citation
Euphorbia fischeriana	*Euphorbia fischeriana* Steud.	30	No author citation
Geranium palustre Torner Cent	*Geranium palustre* L.	31	Erroneous author citation
Ipomoea arborescens	*Ipomoea wolcottiana* Rose subsp. *wolcottiana*	32	Synonym, no author citation
Leonurus heterophyllus	*Leonurus japonicus* Houtt.	33	Synonym, no author citation
Mentha piperita (Linn)	*Mentha piperita* L.	34	Author citation cited incorrectly
Oldenlandia diffusa	*Hedyotis diffusa* Willd.	35	Synonym, no author citation
Peperomia dindygulensis	*Peperomia blanda* (Jacq.) Kunth	36	Synonym, no author citation
Platycodon grandiflorum	*Platycodon grandiflorus* (Jacq.) A. DC.	37	Orthographic change in epithet
Plectranthus barbatus	*Coleus forskohlii* (Willd.) Briq.	37	Synonym, no author citation
Plectranthus grandis	*Plectranthus comosus* Sims	37	Synonym, no author citation
Polygala tenuifolia	*Polygala rehmannii* Chodat	26	Synonym, no author citation
Securidacca longipedunculata	*Securidaca longipedunculata* Fresen.	38	Misspelled generic name, no author citation
Xylopia langsdorffiana	*Xylopia langsdorfiana* St.Hil. & Tul.	39	Misspelled specific epithet, no author citation

published study should reference a scientific specimen and indicate the herbarium in which it is deposited. The source of commercial botanical products should be vouchered as well. Reputable companies now do this to document their botanical products. A voucher is more important than a correct identification. An erroneous scientific name can be rectified or emended to reflect new taxonomic circumscriptions.

Because of infraspecific spatial and temporal variation in plant natural products, the geographic source and collection dates of medicinal plants should be cited both on the voucher label and in publications. For example, the sanguinarine content of *Sanguinaria canadensis* L. rhizomes, collected throughout the eastern United States, varied 18-fold and peaked in early spring.[9]

Preparing botanical specimens is part art and part science, and medicinal plant researchers should consult experienced botanists for help in such preparation. Techniques are described in most plant taxonomy texts[10] or field manuals.[11,12] Several Web sites also offer helpful information on preparing plant vouchers (Table 2).

Identification requires a well-prepared voucher specimen (ie, a fertile specimen with fruits or flowers attached to vegetative parts and good label information). A complete collection includes a section of stem with attached leaves and flowers or fruits. Without flowers or fruits, the fertile portion of the plants, it may be impossible to make a proper determination. Specimens also should contain roots of herbaceous taxa and bark, especially if that part of the plant is used as a botanical medicine.[8] Specimens should be representative of their populations.

Identification

A fundamental objective of ethnobotany is to link plant species to products derived from them. Vouchers serve as the vehicle to establish this link. Determining the correct scientific binomial (ie, identification) provides a universal link between a plant, products derived from it, and the scientific literature. In some cases, the process confirms the identity of a known taxon. In other cases, researchers must identify unknown taxa.

The most reliable way to establish the correct scientific name for a specimen is to send a duplicate specimen to a taxonomic specialist. Duplicates are specimens collected at the same time from the same individual (for woody and large herbaceous species) or from the same population (for small herbs) that bear a single collection number.

Which specialists should be consulted? One possibility is to consult a taxonomist familiar with the flora from the collection site. Better yet is a taxonomic specialist who studies the plant group of interest. Locating the appropriate taxonomic specialist necessarily requires the preliminary determination of the family or genus. Herbaria at universities or botanical gardens are good choices for finding taxonomic experts. Specialists also can be located by consulting the *Index Herbariorum* (<http://sciweb.nybg.org/science2/IndexHerbariorum.asp>). Most taxonomists are very willing to identify a well-prepared fertile voucher.

Taxonomic keys also may be employed to identify specimens. The most widely employed types are dichotomous keys. Polyclaves (multiaccess keys, which can tolerate missing data) using punch cards became common in the 1970s. These identification devices and many others are now computer based.[13,14] Which key should be used?

Table 2. Web Sites Providing Information on the Preparation of Plant Vouchers

Web Site	*Organization*
http://www.flmnh.ufl.edu/herbarium/voucher.htm.	Florida Museum of Natural History
http://www.cieer.org/faqs/Eb006/	Center for International Ethnomedicinal Research and Education
http://herbarium.usu.edu/OpenHerbarium/plant%20collecting.htm	Utah State University, Open Herbarium
http://hua.huh.harvard.edu/FNA/Outreach/coll_prep_plant.shtml	The Flora of North America, The Outreach Resources
http://www.mobot.org/MOBOT/Research/Library/liesner/tpage.html	Missouri Botanical Garden
http://www.eman-rese.ca/eman/ecotools/protocols/terrestrial/plantcoll/plant_collections.html	Environment Canada, Ecological Monitoring and Assessment Network

This is another question best answered by taxonomic experts. Keys are not available for all taxa or for all geographic regions (see Frodin[15] for available floras). The best keys are those in comprehensive floras or taxonomic monographs. What should not be used are field guides that include only part of the area's flora. An unknown specimen may key out, even if it is not included in the treatment. Users of keys should follow several steps:

1. Read the introductory comments about the key. It may contain notes on its use and perhaps its limitations.
2. Read both leads in a couplet (of a dichotomous key) before making a selection (eg, leaves shiny on their upper surface versus waxy). If not certain, follow one lead first and then the other. For polyclaves, use only information that is certain.
3. Use a glossary to check the meaning of unknown terms. Useful glossaries of taxonomic terms include *Plant Identification Terminology: An Illustrated Glossary*[16] and the *Angiosperm Phylogeny* Web site glossary (<http://www.mobot.org/MOBOT/research/APweb/>).
4. Measure parts when lengths and widths are given and realize that sometimes plant dimensions are not always within the parameters provided by the keys.
5. Examine more than one diagnostic plant part. In other words, do not measure a single leaf or count the number of stamens on a single flower.
6. Verify preliminary identifications by reading descriptions of taxa and their habitats and geographic range.
7. If possible, compare the specimen to an annotated herbarium specimen. If access to herbaria is limited, consult a virtual herbarium (eg, <http://sciweb.nybg.org/Science2/VirtualHerbarium.asp>).

In the absence of taxonomic experts and keys, the alternative is to compare specimens to annotated vouchers in a herbarium. Annotated specimens are those that have been identified by an expert in that group of plants or in general plant taxonomy. The feasibility of using herbaria depends on their size. It would be extremely difficult to compare a completely unknown plant against the 7,200,000 specimens at The New York Botanical Garden. However, a small regional herbarium, with 5,000 to 10,000 specimens, could be searchable. Preliminary determinations make the task easier. For example, if the specimen is known to be a member of Moringaceae, a family with 12 species, it would be possible to examine all specimens, even in a large herbarium.

Herbaria

Herbaria (singular herbarium) are excellent resources for identifying plants and finding experts to assist with taxonomic questions. The New York Botanical Garden (NY), Harvard University (A, AMES, ECON), Smithsonian's United States National Herbarium (US), Missouri Botanical Garden (MO), Field Museum of Natural History (F), and University of California at Berkeley (UC, JEPS) are major US herbaria. The acronyms in parentheses are used to refer to the herbaria (some institutions have more than one herbarium). Major US herbaria are listed in Table 3. For a complete list of the world's herbaria, researchers should consult the aforementioned *Index Herbariorum* Web site or printed volume.[17,18]

Nomenclature

Plant nomenclature is governed by the International Code of Botanical Nomenclature (ICBN). The code is amended every 6 years at the International Botanical Congress and is commonly referred to by the name of the host city. The latest is the Vienna Code, which is available at <http://ibot.sav.sk/icbn/main.htm>. The ICBN has several principles. The following are among those most relevant to medicinal plant researchers:

> Principle IV: "Each taxonomic group with a particular circumscription, position, and rank can bear only one correct name, the earliest that is in accordance with the Rules, except in specified cases." In other words, there is only one accepted name for a taxon in any system of classification.
>
> Principle V: "Scientific names of taxonomic groups are treated as Latin regardless of their derivation." All names must be in Latin form, written in the alphabet, and subject to the rules of Latin.

Common names need not follow a single classification system and, therefore, are inadequate labels. In Brazil, *Plectranthus* species (Lamiaceae) are known as boldo.[19] In Chile, boldo refers to *Peumus boldus* Molina (Monimiaceae). Common names for *Pluchea carolinensis* include bushy fleabane, cough bush, cure-for-all, Indian tobacco, la choige, salvia de la playa, saab, salvia cimarrona, Santa Maria, shrubby fleabane, sour bush, tabac diable, tabac zombie, wild tobacco. The most frequently used moniker is salvia.[3] However, salvia or its variants also refer to *Austroeupatorium inulifolium* (Kunth) R.M. King & H. Rob., *Chromolaena odorata* (L.) R.M. King & H. Rob., *Hyptis suaveolens* (L.) Poit., *Neurolaena lobata*

Table 3. Major US Herbaria

Institution	*Acronym(s)*	*Location*
Academy of Natural Sciences	PH, PENN, ANSP	Philadelphia, PA
Bishop Museum	BISH	Honolulu, HI
California Academy of Sciences	CAS	San Francisco, CA
Carnegie Museum of Natural History	CM	Pittsburgh, PA
Cornell University	BH, CU, CUP	Ithaca, NY
Duke University	DUKE	Durham, NC
Field Museum of Natural History	F	Chicago, IL
Harvard University	A, AMES, ECON	Cambridge, MA
Michigan State University	MSC	East Lansing, MI
Missouri Botanical Garden	MO	St. Louis, MO
New York Botanical Garden	NY	Bronx, NY
Ohio State University	OS	Columbus, OH
Rancho Santa Ana Botanical Garden		Claremont, CA
United States National Herbarium	US	Washington, DC
University of California at Berkeley	UC, JEPS	Berkeley, CA
University of Michigan at Ann Arbor	MICH	Ann Arbor, MI
University of Minnesota	MIN	St. Paul, MN
University of North Carolina Chapel Hill	NCU	Chapel Hill, NC
University of Texas at Austin	TEX, LL	Austin, TX
University of Washington	WTU	Seattle, WA
University of Wisconsin-Madison	WIS	Madison, WI

(L.) Cass., *Salvia divinorum* Epling & Játiva, *Salvia officinalis* L. (culinary sage), *Vernonanthura patens* (Kunth) H. Rob., and many others.

Supraspecific Names

Supraspecific names are uninomials (ie, names composed of a single word). Generic and higher-level names are capitalized. Generic names also are italicized. The suffixes of suprageneric names indicate their rank (Table 4). Plant families end in the suffix ''aceae.'' There are exceptions to this orthography and to Principle IV for eight plant families.[20] These families can be designated by their recommended name, which ends in ''aceae,'' or by a conserved name (Table 5). Finding information about these families often requires searches with both names.

Table 4. Suffixes for Plant Taxa by Rank

Rank	*Ending*
Division	-phyta
Class	-opsida
Order	-ales
Family	-aceae
Subfamily	-oideae
Genus	—
Species	—

Species Names

Species names are binomials, composed of the generic name and a specific epithet, along with the author citation (eg, *Catharanthus roseus* (L.) G. Don). The generic name in a binomial may be abbreviated once it has been fully cited (e.g., *C. roseus*) if its use is unambiguous. Species can not be designated solely by a specific epithet (eg, *roseus*).

Table 5. Families that May Be Referred to by Either of Two Names

Standard Name	*Accepted Conserved Name*
Arecaceae	Palmae
Apiaceae	Umbelliferae
Asteraceae	Compositae
Brassicaceae	Cruciferae
Clusiaceae	Guttiferae
Fabaceae	Leguminosae
Lamiaceae	Labiatae
Poaceae	Graminae

Infraspecific names are trinomial, comprising the species binomial and a subspecific epithet (eg, *Colubrina cubensis* var. *floridana* M.C Johnst.). Like generic names, specific and subspecific epithets are italicized. They are not capitalized unless their authors choose to do so when the epithets are derived from names of persons or when they are former generic names. Hybrid names may be indicated by formulae or by names. For example, the offspring of a cross between *Digitalis purpurea* L. and *Digitalis lutea* L. is indicated by *Digitalis purpurea* L. × *Digitalis lutea* L. Alternatively, *Musa* × *paradisiaca* L., the binomial for plants that produce bananas and plantains, indicates that it is of hybrid origin.

Author Citations

Names of species and subspecific taxa should include the author citation somewhere in the manuscript, preferably in the title or abstract. Author citations can be found in floras and in taxonomic databases (eg, International Plant Name Index, available at <http://www.ipni.org/index.html>; Missouri Botanical Garden's VAST (VAScular Tropicos) Nomenclatural Database, available at <http://mobot.mobot.org/W3T/Search/vast.html>; or the US Department of Agriculture's Germplasm Resources Information Network [GRIN] *Taxonomy for Plants*, available at <http://www.ars-grin.gov/cgi-bin/npgs/html/index.pl?language=en>). Print sources include Brummitt and Powell and Mabberley.[21,22] The latter reference is an excellent starting point for orthography and information on plant genera and families.

The simplest format for a citation is a single author. The "L." following *Geranium palustre* L. indicates that the species was named by Carolus Linnaeus, who developed the modern system of biologic nomenclature. *Xylopia langsdorfiana* St.Hilaire & Tulasne was named by Jean Saint-Hilaire and Edmond Tulasne and is sometimes abbreviated as St. Hil. & Tul. For *Euphorbia pallasii* Turcz. ex Ledeb.(synonym of *Euphorbia fischeriana* Steud.), Porphir Turczaninow suggested the epithet, but it was validly published by Carl Friedrich von Ledebour. Parenthetical authors are common in botanical nomenclature (eg, *Ananas comosus* (L.) Merr.). Linnaeus established the species *Bromelia comosa* L. Elmer Merrill later transferred the species to the genus *Ananas*. Some citations are complex. Medicinal plant researchers need only reproduce the citation from a reliable resource in its exact form.

Synonyms

The correct name for a species is the one that was first validly published on or after May 1, 1753—the publication date of Linnaeus's *Species Plantarum*. All other names applied to that taxon are called synonyms. Black cohosh is a well-known example of a common plant that has been recognized by two names: *Cimicifuga racemosa* (L.) Nutt. and *Actaea racemosa* L. Which is correct? Consider the taxonomic history of black cohosh. The binomial *Actaea racemosa* dates to 1753. In 1818, Thomas Nuttall transferred the species to the genus *Cimicifuga*. Compton and colleagues presented molecular data that suggested that *Cimicifuga* be included in *Actaea*.[23] However, the *Flora of North America* recognizes the two genera as distinct based on morphologic characteristics.[24] The choice of the name depends on the interpretation of the data by a given authority. In either case, a researcher needs to search under both names, as well as the common name. Searching *PubMed* using the three key terms *C. racemosa*, *A. racemosa*, and black cohosh singularly and in all possible combinations yielded a range of hits from 179 to 235. However, the differences are even more severe as the sets of hits are not nested. Careful research, therefore, requires that the investigator compile a list of relevant synonyms, as well as the accepted name.

Summary

Documentation of medicinal plant research requires a few simple yet essential steps (Figure 1). Medicinal plant research should begin with a vouchered plant sample that has been accurately identified. Vouchers should be deposited in recognized herbaria. We highly recommend that all papers cite voucher specimens. A lack of vouchers, misspelled names, and misapplied synonyms lead to confusion and a lack of reproducibility. They may also lead to the rejection of papers or grant proposals if a qualified botanist senses that the author of either has not addressed this topic professionally and with precision. Plant systematists at university or botanical garden herbaria can provide the expertise for research laboratories that lack taxonomic expertise, and they often are delighted to be part of a larger, interdisciplinary collaboration. We trust that, in the future, botanists will have an increasingly important role in complementary and alternative medicine, achieving greater recognition for their contributions to the multidisciplinary teams defining this important field of medicine.

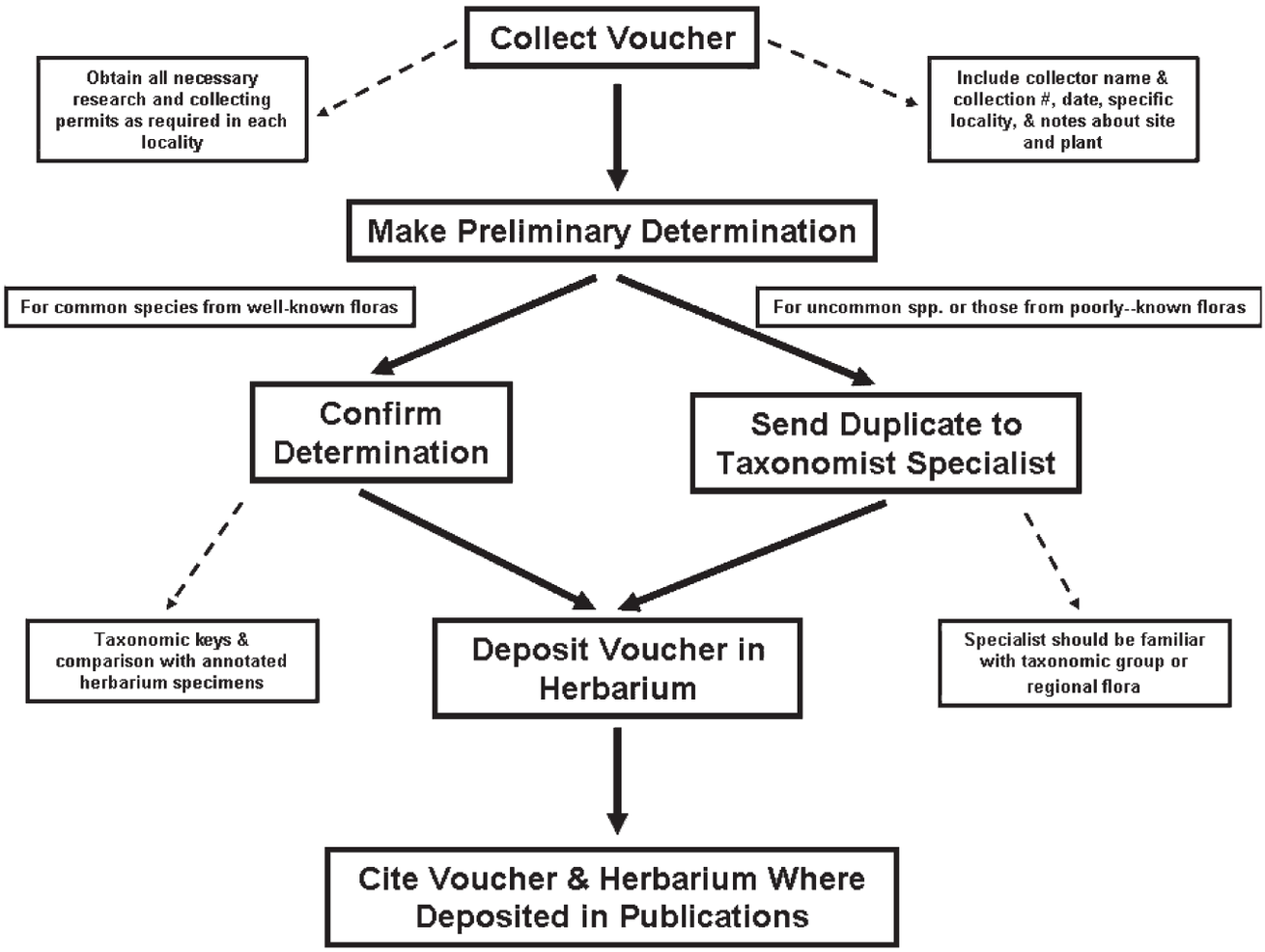

Figure 1. Flow chart for proper botanical documentation and identification.

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