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Review

Does the name really matter? The importance of botanical nomenclature and plant taxonomy in biomedical research

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ABSTRACT

Ethnopharmacological relevance: Medical research on plant-derived compounds requires a breadth of expertise from field to laboratory and clinical skills. Too often basic botanical skills are evidently lacking, especially with respect to plant taxonomy and botanical nomenclature. Binomial and familial names, synonyms and author citations are often misconstrued. The correct botanical name, linked to a vouchered specimen, is the *sine qua non* of phytomedical research. Without the unique identifier of a proper binomial, research cannot accurately be linked to the existing literature. Perhaps more significant, is the ambiguity of species determinations that ensues of from poor taxonomic practices. This uncertainty, not surprisingly, obstructs reproducibility of results—the cornerstone of science.
Materials and methods: Based on our combined six decades of experience with medicinal plants, we discuss the problems of inaccurate taxonomy and botanical nomenclature in biomedical research. This problems appear all too frequently in manuscripts and grant applications that we review and they extend to the published literature. We also review the literature on the importance of taxonomy in other disciplines that relate to medicinal plant research.
Results and discussion: In most cases, questions regarding orthography, synonymy, author citations, and current family designations of most plant binomials can be resolved using widely-available online databases and other electronic resources. Some complex problems require consultation with a professional plant taxonomist, which also is important for accurate identification of voucher specimens. Researchers should provide the currently accepted binomial and complete author citation, provide relevant synonyms, and employ the Angiosperm Phylogeny Group III family name. Taxonomy is a vital adjunct not only to plant-medicine research but to virtually every field of science.
Conclusions: Medicinal plant researchers can increase the precision and utility of their investigations by following sound practices with respect to botanical nomenclature. Correct spellings, accepted binomials, author citations, synonyms, and current family designations can readily be found on reliable online databases. When questions arise, researcher should consult plant taxonomists.

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1. Introduction

Medical research that involves natural products is necessarily an interdisciplinary endeavor. Taking a plant derived compound from the field to the pharmacy requires the expertise of ethnobotanists, plant taxonomists, phytochemists, pharmacologists, medicinal chemists, physicians and clinicians among others. We write from the perspective of botanists, who have dedicated our careers to documenting therapies from the plant kingdom. It has been our experience, in reviewing papers and grants, that many well respected and knowledgeable researchers are woefully deficient in their botanical skills. In one recent case, a grant review panel became quite contentious when one panel member asked why good botanical practices were necessary if the "science of the research projects was good." Another asked, "Does the [scientific] name [of the plant] really matter?" It is in that spirit that we respectfully title our essay with this very question, which deserves an answer, as it is pertinent to any study of medicinal plants. Moreover, accurate taxonomy is vital to every field of scientific research.

2. Common taxonomic errors

Taxonomic errors abound in the literature. Chan et al. (2012) discussed common problems, especially with respect to traditional Chinese medicine. Despite their admonitions, researchers and reviewers continue to pay too little attention to matters of taxonomy. Taxonomic errors are evident in almost every issue of every medicinal plant journal. In addition to erroneous author citations of binomials and incorrect family assignments, three other problems are frequent common in both proposals and published manuscripts: misspelled specific epithets, misspelled generic names, and use of synonyms instead of the currently accepted names. While a skilled taxonomist may be able to properly interpret misspellings, most researchers cannot. This means that their research cannot be connected to the body of published literature.

Consider one example found in a proposal: *Bacopa monnieri* misspelled as *Bacopa monieri*. An exact search (name in quotation marks) of PubMed generated 104 hits with the correct spelling but only one with the incorrect specific epithet. Some databases searches return close matches when an incorrect name is used. Other databases do not accommodate incorrect orthography. Free online databases now allow quick, easy and accurate verification of most plant binomials. Failure to do so reveals a lack of scholarship in preparing proposals and manuscripts.

Common names are important, but insufficient (Bennett and Balick, 2008; Chan et al., 2012; Obón et al., 2012). There are no rules for their use or formation and one common name can be used for many and often unrelated species, and they vary across languages and within languages. Salvia, for example may refer to one several dozen species in a least 3 different families. Conversely, a single binomial can equate to a near limitless number of common names. The only way to unambiguously document a species is to employ a scientific binomial that is linked to a botanical specimen or voucher. Without this documentation, there is little chance for reproducibility.

Wu et al. (2007) discuss the limitation of common names in Traditional Chinese Medicine. In some cases there was a one-to-one correspondence between the common names of plant products and their scientific names (guan mutong refers to the root of *Aristolochia manshuriensis*). In a case of over-differentiation, three common names referred to three different parts of *Aristolochia debilis*: *madouling* for the fruit, *qingmuxiang* for the root, and *tianxianteng* for the stem. Other common names were under-differentiated: fangji can be the root of three species (*Aristolochia fangchi* – *Aristolochiaceae*, *Stephania tetrandra* and *Cocculus orbiculatus* – *Menispermaceae*). In the Iberian Peninsula, the common name árnica may refer to one of 32 plant species in six plant families.

Without the use of the correct binomial (including author citation and current family designation) accurate identification is uncertain. Nesbitt et al. (2010) discuss the problem with respect to food plants. Fifty publications that they reviewed listed 502 plant species. More than one fourth of the plants names were obsolete or misspelled. The problem is not unique to plants. Janda and Abbott (2002) note that misidentification can produce "an inaccurate body of information in the medical literature concerning the clinical significance of many microbial species."

3. The importance of taxonomy and nomenclature in medicinal plant research

> "Unfortunately, all of us have to use taxonomy, so it is in all our best interests to have at least a working understanding of taxonomy." (Calisher and Mahy, 2003)

We are unsure about why it is unfortunate that taxonomy is a requisite, but Calisher and Mahy are correct in arguing that a working knowledge of taxonomy is important. For the past 260 years, biological nomenclature has been guided by the binomial system developed by Carolus Linnaeus. May 1, 1753, the publication date of *Species Plantarum*, is the starting date for botanical nomenclature. The first name validly and effectively published on or after that date has priority. Other names referring to the same taxon are synonyms. Scientist around the world employ the rules of the International Code of Nomenclature for Algae, Fungi, and Plants (known as the International Code of Botanical Nomenclature until 2011), including the rule that there can be one and only one correct name for a taxon in a system of classification.

The universal use of a common moniker allows unambiguous communication and documentation. All reputable scientific journals throughout the world use anglicized Latin names based on the system developed by Linnaeus. Yet, Drebot et al. (2002) accurately note that "Taxonomy is of little interest to most people and scientific journals do not seem eager to understand or employ modern taxonomy." Linnaeus's system of nomenclature and classification was innovative in solving the first bioinformatics crisis that resulted from global exploration and an explosion in the number of known species during his lifetime (Godfray, 2007). The system is not perfect, nor does it lack detractors. Nevertheless, it has been universally accepted as the means of ordering global biodiversity. While there is growing support for replacing the Linnaean-based International Code

of Nomenclature for Algae, Fungi, and Plants with the PhyloCode (e.g., de Queiroz, 2006; Rieppel, 2006), there is growing realization among PhyloCode proponents that binomials should be retained. The binomial system remains the only standard for unambiguous determinations.

4. The importance of taxonomy and nomenclature in other disciplines

> Ignoring proper taxonomy is ignoring not only history but the similarities and differences between living things, and to ignore the evolutionary aspects of classification and choose chaos over neatness. Virologists, bacteriologists, parasitologists, mycologists, mammalogists, ornithologists, ichthyologists, and just about everyone else sort their subjects of study and separate them into related categories. (Calisher, 2007)

Accurate taxonomy and nomenclature are vital to reproducibility, documentation, and prediction, not just with respect to medicinal plants identification but also with almost every discipline involved in medicinal plant research. Lack of concern for nomenclature can undermine science and, in medicine, it can lead to fatal mistakes.

4.1. Nomenclature in chemistry

Systematic nomenclature is essential for the accurate description of chemical compounds (Buntrock, 2001) and the interpretation of chemical names is obscured by inaccurate names in common usage (Brecher, 1999). Different naming conventions used for isoprostanoids has created ambiguity about the identity of some of these compounds (Mueller, 2010). In an analysis of 300^{+} systematic names of organic compounds found that 25% were unacceptable and thus of absolutely no value (Eller, 2006).

4.2. Nomenclature in genetics

Assigning names to mouse genes based on the presumed orthology to rat genes is not always appropriate and has created inaccuracies that are duplicated in frequently used databases (Nelson, 2005). Fundel and Zimmer (2006) contrast the "descriptive and free nomenclature" used for *Drosophila* that makes identification of gene names difficult with rigorous nomenclature to that used for yeast, which facilitates gene name identification. The nomenclatural problem of human genes has been recognized and addressed by the HUGO Gene Nomenclature Committee (Wain et al., 2002). Similarly, naming of the cytochrome p450 enzymes is well codified (Nelson, 2009).

4.3. Nomenclature in medicine

The importance of standardized nomenclature is well established in medicine, even if it does not always extend to botanical nomenclature. Singh and Ferguson (2009) recognize the necessity of standardized definitions for improving the quality of critical care clinical trials. Biological taxonomy is now ruled by the principle of monophyly (a group that includes its ancestor and all of its descendants). Failure to consider monophyly in defining groups is a problem not only for taxonomy but for medicine. For example, the American–European Consensus Conference definition of acute respiratory distress syndrome is a heterogeneous disease (Phua et al., 2008). In taxonomic terms, it is not monophyletic. They argue that the heterogeneous definition could negatively influence the outcome of clinical research as well as patient management.

The medical community commonly employs The International Statistical Classification of Diseases and Related Health Problems (ICD) to classify diseases (WHO, 2013). Administrative databases, which often are used for congenital cardiac disease research have little validation and therefore often misclassify ICD codes, thereby complicating research and treatment (Strickland et al., 2008).

Biological nomenclature in biomedical texts issues is especially confounding. The task of identifying species names in biomedical text presents several challenges. In addition to the problems associated with over-differentiation of common names and the uncertainty of species acronyms, Gerner et al. (2010) discuss three problems that have parallels in medicinal plant nomenclature: (1) Ambiguity of abbreviated species names. *C. elegans* is a valid abbreviation for 41 different species in the NCBI database, not merely the oft presumed *Caenorhabditis elegans*. (2) Lack of attention to synonomy. (3) Orthographic problems, in their words, "… while species dictionaries cover a large number of scientific names, synonyms and even some common misspellings, they cannot match human authors in variability of term usage. In some cases, authors use non-standard names when referring to species, spell names incorrectly or use incorrect case."

4.4. Nomenclature in microbiology

Like Radford's (1986) proclamation that taxonomy is the pedestal upon which all biology rests, Janda and Abbott (2002) assert that "The accurate and definitive identification of microorganisms, including bacteria, is one of the cornerstones forming the joint foundation of the fields of microbiology and infectious diseases." They aver that identification requires the application of the appropriate binomial. Virology is often guilty of taxonomic laxness (Calisher and Mahy, 2003) and taxonomic errors are frequent in the Archives of Virology (Drebot. et al., 2002).

4.5. Nomenclature in pharmacology and pharmacy

The importance of nomenclature is well-recognized in pharmacology. Pharmacological Reviews regularly publishes updates on receptor nomenclature (e.g., Ye et al., 2009). Nomenclatural problems are, unfortunately, too frequent in pharmacy. Confusion generated by drugs with similar name may account for up to 25% of medication errors (Filik et al., 2004). Substitutions of Clomiphene for Clomipramine, Hydralazine for Hydroxyzine, Prednisone for Prednisolone, or Serzone for Seroquel are common problems.

5. Reasons for the lack of concern for botanical nomenclature and taxonomy

The lack of attention to botanical binomials is widespread. The reason for this is uncertain but it may be related to one or more explanations. These explanations can be grouped into several categories: Apathy or Ignorance, Biases, and Phobias.

Scientific names are deemed to be cumbersome and difficult to spell and to pronounce. The general public attitude "I don't know and I don't care" is too often shared by the scientific community. Both groups are often unaware of the innate ambiguity of common names. Biases may play a role in the disdain for binomials. Anthropocentrism is widespread in many cultures creating a lack of concern for other organisms in the biosphere, including plants. For example, the negative perception of insects and arachnids in Western Cultures has led to little concern for their conservation (Kim, 1993).

Another form of bias is egocentrism, rampant in many academic and professional disciplines. It has been particularly well-documented in medicine (e.g., Hoffenberg, 2001; Berger, 2002;

Hughes, 2006; Lazarus, 2009). Its frequency, however, does not justify its existence. Zoocentrism, which dominates biology (Hallé, 2002) is another likely explanation for the indifference toward plants. Biology students from high school through graduate school learn little, if any, botany.

The irony of this isolation of disciplines is that medicine and botany, once were intimate disciplines and botany was a major subject of medical schools well into the 20th century (Youngken, 1956). Linnaeus, the father of taxonomy was trained in botany and in medicine. His dissertation title, *Hypothesis nova de febrium intermittentium causa*, (New hypothesis about the cause of intermittent fevers) is evidence of his interdisciplinary knowledge. In 1738, he established a medical practice in Stockholm and in 1741 was appointed professor of Medicine & Botany at the University of Uppsala. His medical contributions are numerous and included three books (Blunt, 1971; Frangsmyr, 1994): *Materia Medica* (1749), *Genera Morborum*, (a classification of disease, 1763), and *Clavis Medicinae Duplex* (Double Key to Medicine, 1766). Unfortunately, botany and medicine now are seen as having little in common.

Many of these explanations are symptoms of the malady called "plant blindness"—the inability to see or notice plants, which leads to, among other things, the inability to recognize the ecological and human importance of plants and the ranking of plants as inferior to animals (Wandersee and Schussler, 2001).

6. Solutions

> "Taxonomy is one way in which you let the world know you know what you are doing." (Calisher, 2007)

Resolving the rampant taxonomic problems in biomedical literature is not difficult. It simply requires understanding of the importance of taxonomy and its rules (Bennett and Balick, 2008; Chan et al., 2012) and careful application and use of scientific names. Failure to do so casts doubts on the credibility and reproducibility of science. With respect to errors in chemical nomenclature, Eller (2006) concludes, "… it seems to be tedious and unacceptable for any reader to waste his time with futile or even misleading names; on the other, it casts doubt on the reliability and thoroughness of other data provided." The same is true of misconstrued botanical binomials.

Precision of scientific researcher can be improved following a few simple rules (Table 1). (1) Provide the currently accepted binomial (spelled correctly) along with the complete author citation. The author citation need be cited only the first time the binomial is used. This information is widely available in both print and electronic forms from global databases based on taxonomic revisions or monographs (Bennett and Balick, 2008; Chan et al., 2012). (2) Indicate the source of the binomial. Taxonomic authorities often disagree but medical researchers need not be concerned with the debate as long as they use an authoritative source. (3) Provide relevant synonyms for binomials. These are available from the same taxonomic sources that provide the accepted binomial. (4) Treat binomials and names of other taxonomic ranks appropriately. Names at the rank of genus and below are italicized. Names at the rank of genus and above are capitalized. (5) Provide the family name indicated by the Angiosperm Phylogeny Group III (Angiosperm Phylogeny Group, 2009), which also is available online. Older family designations also should be included, if they are relevant. (6) Provide the common name(s). Either common names or binomials can subsequently be used within a paper or proposal, as long as they are operationally defined (e.g., Here, salvia refers to *Salvia officinalis* L., Lamiaceae). (7) Cultivars present an especially vexing problem. The species name alone is insufficient. Subspecific or varietal names must be provided along with the cultivar name. Common bread wheat (*Triticum aestivum* L., Poaceae) for example, has 20,000^{+} varieties. (8) When in doubt, consult a plant taxonomist.

Table 1
Steps for avoiding taxonomic errors.

1	Provide currently accepted binomial and complete author citation
2	Indicate source of binomial
3	Provide relevant synonyms for binomials
4	Capitalize and italicize scientific names appropriately
5	Provide Angiosperm Phylogeny Group III family name
6	Provide the common name(s)
7	For cultivars, provide subspecific or varietal names and the cultivar names
8	When in doubt, consult a plant taxonomist

An example of good taxonomic practices is shown in Table 2. The accepted binomial (according to two sources is provided along with synonyms and author citations, the family and common names. The reality is a bit more complex. Taxonomic authorities have recognized as many as six distinct species with the *Zamia pumila* complex. Fig. 1 represent a simplified version of the taxonomic confusion. If populations within the *Zamia pumila* complex are deemed to be distinct species, then *Zamia pumila*, *Z. angustifolia*, and *Z. floridana* would be the accepted names, as they are the oldest, legitimate names. If these populations are considered to be conspecific, the accepted name is *Zamia pumila*, based on priority. This kind of problem is not uncommon and when confronted with such, medicinal plant researchers should consult the appropriate taxonomic experts. Nonetheless, researcher should supply both the accepted names and all relevant synonyms.

These guidelines could greatly improve the reliability of scientific publications and they echo concerns expressed when dealing with organisms besides plants. Drebot et al. (2002) offered similar recommendations with respect to virus taxonomy. Our guidelines also are congruent with the U.S. National Institutes of Health guidelines, which require proposals to provide the name the product, including species and strains, so that reviewers can effectively evaluate the scientific strength of the project (NCCAM, 2013). Documentation, including proper nomenclature is a required by all top-tier journals but errors too often evade the review process.

The Uppsala Monitoring Centre (UMC), is responsible for the WHO Adverse Drug Reaction (ADR) database. To effectively monitor pharmacovigilance, Farah et al. (2006) cite three nomenclatural

Table 2
What is Florida coontie?

Currently accepted binomial and complete author citation. ***Zamia pumila* L.**
Indicate source of binomial: **The Plant List, Atlas of the Flora of Florida**
Provide relevant synonyms for binomials. ***Zamia angustifolia* Jacquin, *Zamia floridana* A. DC., *Zamia humilis* Salisbury *Zamia integrifolia* L.f. ex Aiton, *Zamia umbrosa* Small**
Provide Angiosperm Phylogeny Group III family name: ***Zamiaceae*** (note database also includes gymnosperm family names)
Provide the common name(s): **coontie, Florida arrowroot**

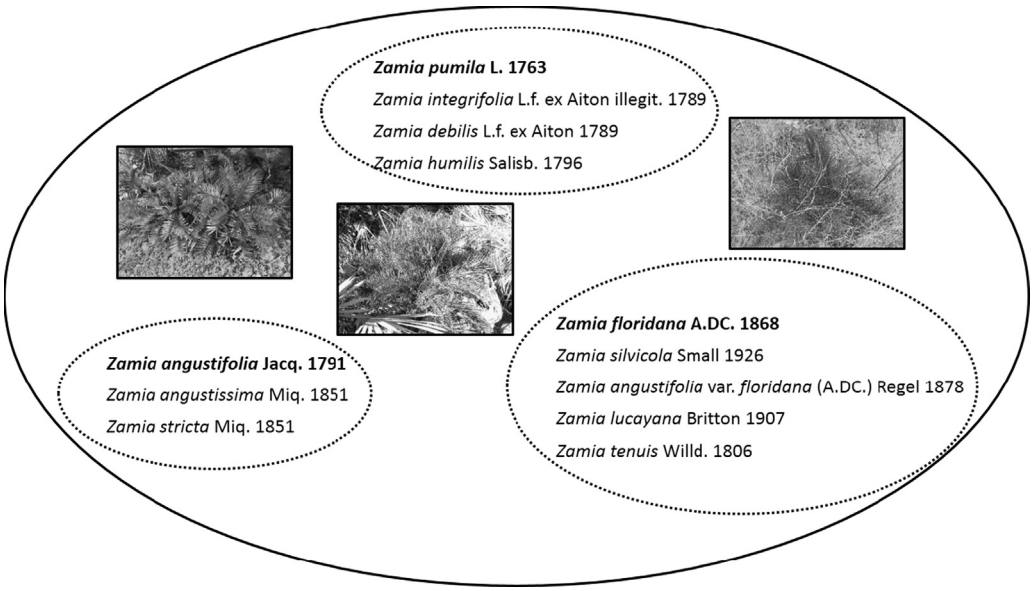

Fig. 1. A simplified schematic of the *Zamia pumila* complex. The date of publication follows each binomial. If populations are considered to be distinct species, the names in boldface type would apply. If they are considered to be a single species, *Zamia pumila* is the correct name. Binomials in regular type are synonyms.

criteria: (1) The name should indicate only one species of plant; (2) The source for this name must be authoritative; (3) The name should indicate which part of the plant is used. After evaluating four nomenclatural options, UMC selected scientific binomials and the nomenclature defined by the International Code of Botanical Nomenclature (now called the International Code of Nomenclature for Algae, Fungi, and Plants). They conclude, "We strongly recommend the adoption of scientific names to denote plant ingredients in medicine."

Despite the substantial advances molecular systematic have provided in understanding evolutionary relationships among plants, species-level nomenclature is still largely based on taxonomic decisions guided, in part or in whole, by morphological and anatomical data. With the advent of DNA bar-coding, is there still a need for classical taxonomy and nomenclature? Scotland et al. (2003) argue that with the exception of microbes, it is highly unlikely that DNA data can more efficiently identify organisms than traditional identification methods. These methods require a unique designator—the scientific binomial.

7. Conclusions

> "… from the beginning of medicine a knowledge of plant distribution, morphology, and taxonomy, has played a supportive role in the procurement of plants for medical purposes. As long as plant drugs are tools in medical diagnosis and treatment of diseases, specializations in botany must be consulted." (Youngken, 1956)

Let us consider the notion of ignoring errors in botanical taxonomy when faced with otherwise "good science" in a paper or proposal. Logic dictates that if one part of the science is suspect, especially when it forms the foundation for all subsequent research, how can the remaining science be "good"? Proper use of binomials and other taxonomic ranks is essential for unambiguous communication of results and for their reproducibility. Yet, a scientific name provides more than just a precise label. Taxonomic names provide judgments on species boundaries and on the phylogenetic relationships of taxa (Godfray, 2007). Closely related taxa are more likely to share characteristics, including chemical constituents, than distantly related ones. Therefore, they are more likely to produce similar physiological effects in vitro or in vivo.

The physicist Enrico Fermi quipped that if he could remember the names of the subatomic particles he would have been a botanist (Lloyd and Mitchinson, 2007). There are indeed many plant names. The Plant List, an online database created by the Royal Botanic Gardens, Kew and the Missouri Botanical Garden, includes 1,244,871 scientific names of vascular plants and byrophytes in its first iteration. Of these, 298,900 are accepted species names (The Plant List, 2013). Unlike Fermi, today's researcher has ready access to these names in online databases. There is no legitimate excuse for using incorrect name or misspelled names. If researchers and reviewers follow a few simple rules, they would avoid ambiguity associated with erroneous taxonomy. It is time for botany and medicine to reunite.

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