Simple Web-Based Interactive Key Development Software (WEBiKEY) and an Example Key for *Kuruna* (Poaceae: Bambusoideae)

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Plant and animal identification keys are used by many biologists to assign a scientific name to a biological specimen (Dallwitz, 1980; Jarvie and Stevens, 1998; Dallwitz et al., 2000 onwards; Heidorn, 2001). The most common form of identification key used in printed publications is the dichotomous key, which presents a series of choices or couplets that must be followed in order (e.g., the Kuruna dichotomous key in Attigala et al., 2016). In a dichotomous key, if the diagnostic features of the couplet are ambiguous for the specimen or are not part of the specimen (e.g., the couplet focuses on fruits, but the specimen is in flower), it can be difficult to correctly identify the plant species using the key. In contrast, an interactive key supports multiple access points where users are allowed to choose the characters in any order and use only the characters available on the specimen.

DELTA-format (Description Language for Taxonomy; Dallwitz et al., 1993 onwards) interactive keys are available for many species (http://www.delta-intkey.com/); however, these require installation of the DELTA Intkey application on the user’s personal computer. There are commercially available interactive key development programs available, such as LucID (http://www.lucidcentral.com), but they are relatively expensive (ca. US$600). While programs like MEKA (http://ucjeps.berkeley.edu/meacham/meka/) and NaviKey (http://www.navikey.net/) are freely available, these often require helper applications, plug-ins, or Java applets, resulting in a lengthy download time from the server to the client computer. SLIKS (http://www.stingersplace.com/SLIKS/) is another freely available JavaScript program that enables the development of interactive keys. However, it requires some knowledge of JavaScript to develop the interactive key and its data are weakly protected as anyone with minimal computer skills can access or change the actual data file. In addition, some of these free interactive key programs are complex to run and difficult to use.

We designed a Web-based multiaccess identification tool (WEBiKEY) that uses Microsoft ASP.NET technologies and an SQL Server database (Microsoft, Redmond, Washington, USA), both of which are currently available online as free downloads for Windows platforms. The information related to the study group can be imported to WEBiKEY using Microsoft Excel spreadsheets (.xlsx). While the end-users of WEBiKEY can use any software platform that supports a Web browser, the interactive key developer (or administrator) must use a Windows-based computer to host WEBiKEY. Although WEBiKEY can be used to develop Web-based interactive keys for any group of species, we tested it for usability with a sample data set, the temperate woody bamboo genus Kuruna (Poaceae), and identify an unknown specimen as one of seven possible species in the genus.

Key words: bamboo; identification tools; interactive keys; Kuruna; Poaceae; WEBiKEY.
Development of WEBiKEY—Our current approach uses Microsoft ASP.NET technologies and an SQL Server database that are freely available online for Windows users. ASP.NET contains Microsoft’s latest framework and tool-sets for building Web-based applications. SQL Server is a robust, fast, and secure relational database, which is also available as a free download in its Express Edition. We developed a set of entity relations and an entity relation diagram (ERD) for the database (Fig. 1). The database consists of four main tables: CharacterCategory, Character, CharacterState, and Species. The characters are classified into a few major groups based on vegetative and reproductive morphology. Each group is then represented by a row in the CharacterCategory table. The Character, CharacterState, and Species tables contain information about the characters, variable character states, and the species, respectively. Because a character category can contain one or more characters, there is a “one-to-many” relationship between these two tables. However, the relationship between the CharacterState and Species tables is “many-to-many” because a species can have many character states and a character state can be shared by many species. The ERD (Fig. 1) illustrates the database structure and its tables with relationships that ensure data integrity and can handle dynamic data changes such as insertions, deletions, and updates.

The WEBiKEY application is intended for two types of users: end-users and users with administrative privileges (Admins). Admins can set up the application by uploading all of the species information, character information, and character state details with images. The characters, character states, and species can be imported from spreadsheets (.xlsx). Setting up the application for the Admin’s desired plant or animal group is explained in the README documentation (https://github.com/WEBiKEY/InteractiveKey/blob/master/README.pdf). The Admin is also responsible for hosting the application on a Windows-based server, where end-users can access it via the Internet to identify their unknown species. This program is capable of handling large amounts of species and character data. Even though there are no theoretical limitations on the number of species in a key, there may be practical limitations due to the hosting system’s resources (e.g., hard disk space, memory, processing power).

Testing WEBiKEY for the bamboo genus Kuruna—We chose Kuruna to trial our identification key because (1) it is a small group of species that often need to be identified by Sri Lankan biologists, (2) there is no interactive key currently available for the genus, and (3) identifying bamboos requires the use of many unique characters that may not be familiar to biologists. Although there is a Web-based identification key for the flowering plants of Sri Lanka that includes 438 species, it uses a different interactive key format (KeyBase: http://keybase.rbg.vic.gov.au/projects/show/8) that provides an environment where dichotomous keys, traditionally developed for print, can be more easily and effectively deployed and used. However, KeyBase is not a true multiaccess interactive key and it includes no keys for the grass family (Poaceae) or for the seven Kuruna species found in Sri Lanka.

The WEBiKEY interactive key for Kuruna is available at http://webikey.agron.iastate.edu/. This interactive key has three main webpages: the home page (Fig. 2A), the major character group selection page (Fig. 2B), and a detailed interactive key page (Fig. 2C), along with three menus that allow users to download each Kuruna species description (Fig. 2D), and a glossary in PDF format. The “Help” link provides details on how to use the interactive key. A dichotomous key also is available as an additional resource.
Fig. 2. Online pages of the multiaccess Web-based interactive identification key (WEBiKEY) of Kuruna. (A) Home page. (B) Major character group selection page. (C) Detailed Web-based interactive key of Kuruna. (D) “Species info” page with a PDF opened for Kuruna densifolia.
Fig. 3. Handling polymorphic characters and character dependencies. (A) An example of a polymorphic character: “Culm internodes” (C2). Character state 2 represents both hollow and solid culm internodes. (B) Page that allows character dependency configurations.
Handling polymorphic characters and character dependencies—WEBiKEY can also handle polymorphic characters. Polymorphic characters can be of two types. If two or more character states exist in the same individual of a species, it is recognized as “polymorphic character type 1.” If there are some individuals with one character state and some with a different character state for the same character of a same species, it is recognized as “polymorphic character type 2.” Fig. 3A shows an example of a polymorphic character type 1. “Culm internodes” (C2) is a polymorphic character where character state 2 (“Some internodes solid, some internodes hollow in the same individual plant”) includes both solid and hollow internodes in the same individual. In Kuruna, if a user selects character state 2 for C2, WEBiKEY will show K. serrulata in the “Selected Species” section, as K. serrulata is the only Kuruna species that possess both solid and hollow internodes in the same culm. Furthermore, there are some individuals in K. serrulata that have only hollow culm internodes (Fig. 3A). Thus, if the user selects culm internodes as “All hollow” (character state 1), WEBiKEY will show K. serrulata in the “Selected Species” section instead. If the end-user selects “All solid” (character state 0), WEBiKEY will show K. serrulata in the “Selected Species” section as well. If a user selects character state 2 for C2, WEBiKEY will show K. serrulata in the “Selected Species” section, as this character state determines the availability of another character, the user cannot select that dependent character state. The end-user cannot select that dependent character state. The Admin would simply need to add character states 0, 1, and 2 in the data matrix for that particular species.

Table 1. Character dependencies of the Kuruna sample data set. The codes FL4, FL5, FL6, S3, S4, S5, S6, SP4, SP5, and SP6 are character codes used in the WEBiKEY interactive key of Kuruna.

| Character | Dependent character state | Disabled characters |
|-----------|---------------------------|---------------------|
| Auricle (blade-derived appendage) development (FL4) | Absent | Auricle size (FL5) |
| Auricle (blade-derived appendage) development (FL4) | Absent | Auricle indument (FL6) |
| Subtending bract at the base of the axis bearing the spikelet or spikelet proper (S3) | Absent | Subtending bract morphology (S4) |
| Prophyll at the base of the axis bearing the spikelet or spikelet proper (S5) | Absent | Prophyll apex (S6) |
| Rachis extension (internode only, with or without rudimentary floret) (SP4) | Absent | Relative length of the rachis extension (internode only, with or without rudimentary floret) when present (SP5) |
| Rachis extension (internode only, with or without rudimentary floret) (SP4) | Absent | Rachis extension (internode only) (SP6) |

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The current program was compared with some freely available interactive key development applications (Intkey, MEKA, NaviKey, and SLIKS) (Fig. 4). Many of the comparison features listed in Fig. 4 were adopted from Dallwitz (2000 onwards) along with additional features. The commercially available programs are not included in the comparison, as the current program is not intended to compete with more feature-rich applications such as LucID; obviously they are better than the freely available, simple interactive key development programs such as WEBiKEY.

CONCLUSIONS

The simple Web-based multiaccess interactive identification software we developed is freely available to the public and can be used to develop Web-based interactive keys for any group of species. Compared to other free interactive key development software, WEBiKEY is easier to use for both administrators and users. Some of the important user-friendly features of the application are that spreadsheets can be uploaded to the database, character state illustrations can be uploaded and displayed, illustrations of any size can be scaled to fit the contents, a glossary is available to help with unfamiliar terms, character dependencies are addressed, and an extensive amount of text can be incorporated to aid interpretation of the characters. In addition, there are a few other features that, while not necessary, provide a better user experience, such as categorization of the characters into major groups, accessibility of conventional dichotomous keys, ability to attach documents to species, and the convenience of running the program without illustrations.

Our WEBiKEY application was successfully used to create a Web-based interactive key for all the species of the bamboo genus *Kuruna* to test its effectiveness. Despite the availability of KeyBase, none of the Sri Lankan high schools or universities use any form of electronic identification keys frequently to identify flora or fauna. However, some universities and a very few high schools teach about interactive keys (L. Attigala, personal communication). In addition, there are only three studies that discuss native Sri Lankan bamboos (Soderstrom and Ellis, 1988; Attigala et al., 2014, 2016), and there is only one pictorial guide to identify some of the economically important bamboos in Sri Lanka (De Zoysa and Vivekanandan, 1994). Thus, we believe that providing an online interactive key to *Kuruna* will be important to scientists, students, gardeners, conservationists, etc. in Sri Lanka. The interactive nature of the *Kuruna* key, the ability to easily view images of the characters, and the large amount of information available (characters and character states) for each species also make it easier to teach students about bamboo morphology.

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