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Software Note

Simple Web-based interactive key development software (WEBiKEY) and an example key for *Kuruna* (Poaceae: Bambusoideae)[1]

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- *Premise of the study:* Programs that are user-friendly and freely available for developing Web-based interactive keys are scarce and most of the well-structured applications are relatively expensive. WEBiKEY was developed to enable researchers to easily develop their own Web-based interactive keys with fewer resources.
- *Methods and Results:* A Web-based multiaccess identification tool (WEBiKEY) was developed that uses freely available Microsoft ASP.NET technologies and an SQL Server database for Windows-based hosting environments. WEBiKEY was tested for its usability with a sample data set, the temperate woody bamboo genus *Kuruna* (Poaceae).
- *Conclusions:* WEBiKEY is freely available to the public and can be used to develop Web-based interactive keys for any group of species. The interactive key we developed for *Kuruna* using WEBiKEY enables users to visually inspect characteristics of *Kuruna* and identify an unknown specimen as one of seven possible species in the genus.

Key words: bamboos; identification tools; interactive keys; *Kuruna*; Poaceae; WEBiKEY.

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 computer 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* Attigala, Kathriar. & L. G. Clark. This simple, easy-to-use interactive key enables users with plant material from an unknown species in *Kuruna* to visually inspect characteristics of the bamboo and identify it as one of seven possible species in the genus: *Kuruna debilis* (Thwaites) Attigala, Kathriar. & L. G. Clark, *K. densifolia* (Munro) Attigala, Kathriar. & L. G. Clark, *K. floribunda* (Thwaites) Attigala, Kathriar. & L. G. Clark, *K. scandens* (Soderstr. &

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R. P. Ellis) Attigala, Kathriar. & L. G. Clark, *K. serrulata* Attigala, Kathriar. & L. G. Clark, *K. walkeriana* (Munro) Attigala, Kathriar. & L. G. Clark, and *K. wightiana* (Nees) Attigala, Kathriar. & L. G. Clark (Attigala et al., 2014, 2016). The images used in the *Kuruna* interactive key ensure that the characters and unique character states are easy to understand.

METHODS AND RESULTS

***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 toolsets 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.

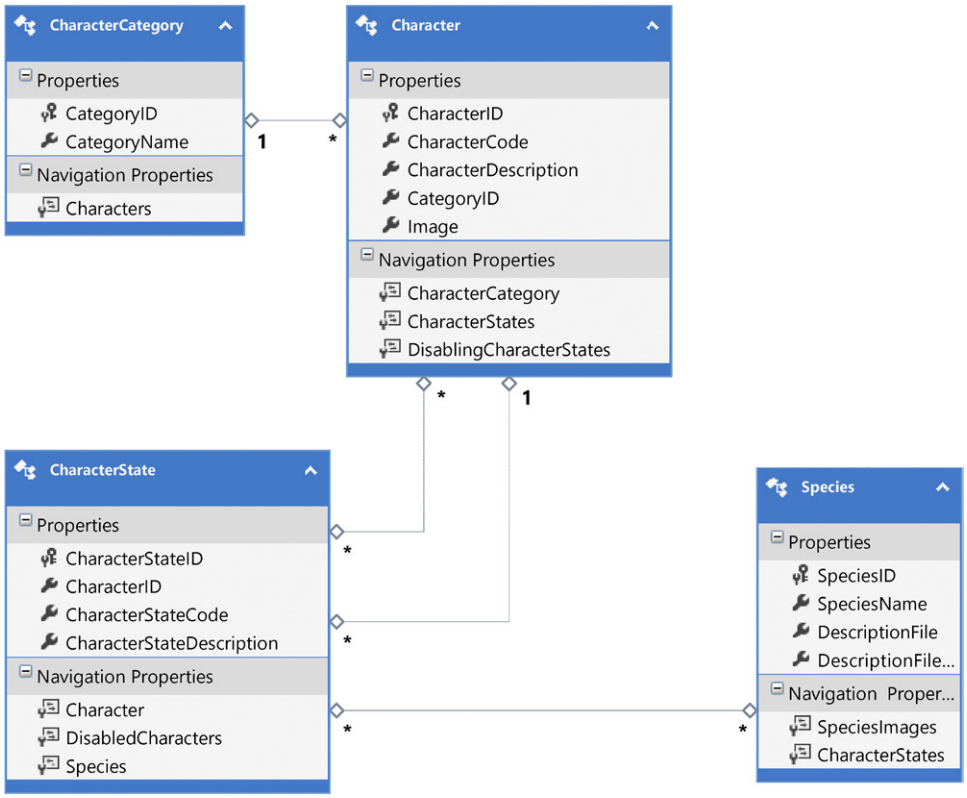

Fig. 1. Entity relation diagram (ERD) of the database design. Rectangles represent entities with their attributes, and the lines connecting these rectangles represent relationships between the entities. The number 1 and the "*" indicate the relationship type. For example, the relationship between *CharacterCategory* and *Character* is a one-to-many, i.e., one character category can have multiple characters, while each character must have one and only one character category.

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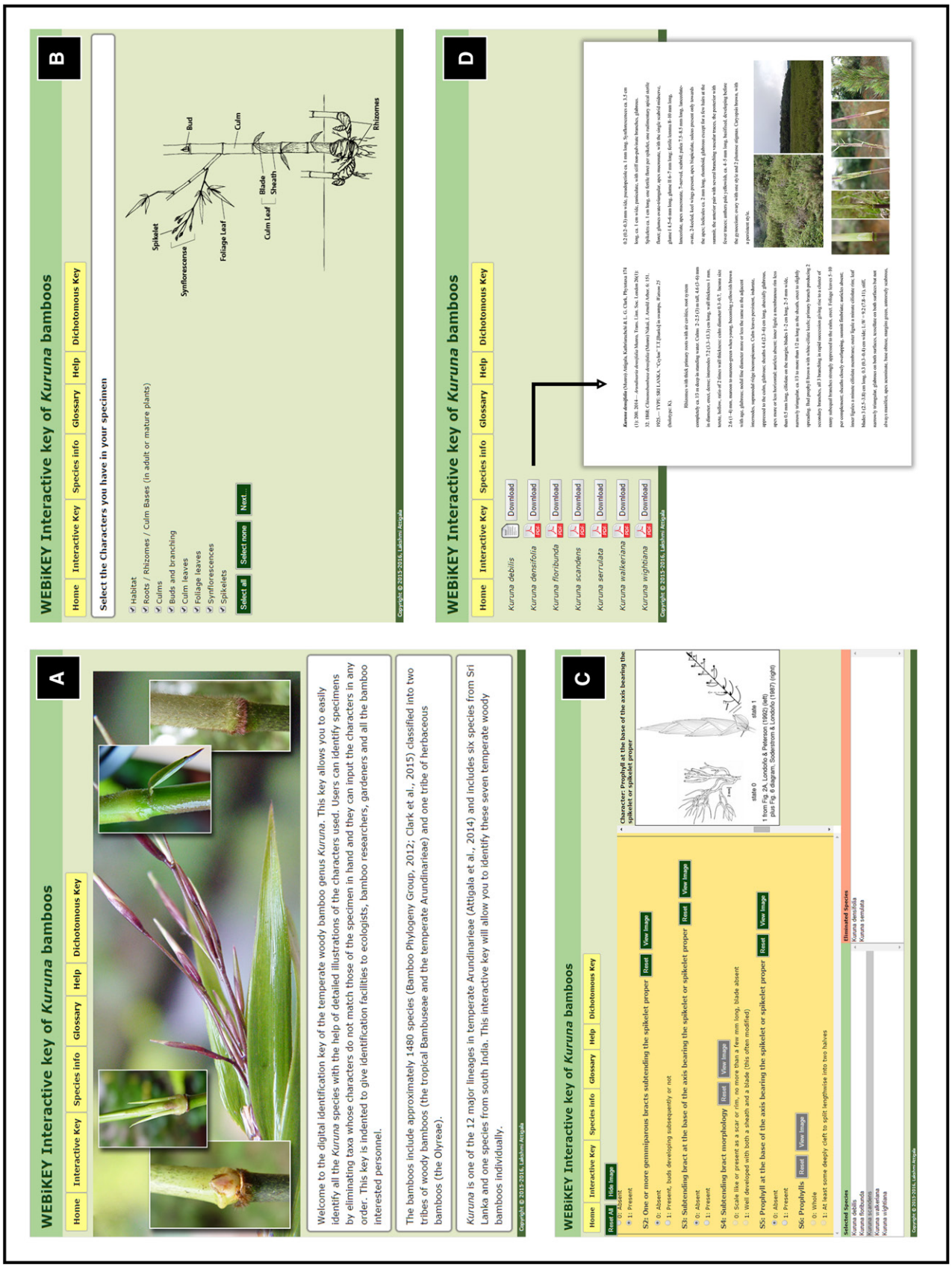

Fig. 2. Online pages of the multiaccess Web-based interactive identification key (WEBiKEY) of *Kuruna*. (A) Home page. (B) Major character group selection page. (C) Detailed Web-based interactive key of *Kuruna*. (D) "Species info" page with a PDF opened for *Kuruna densifolia*.

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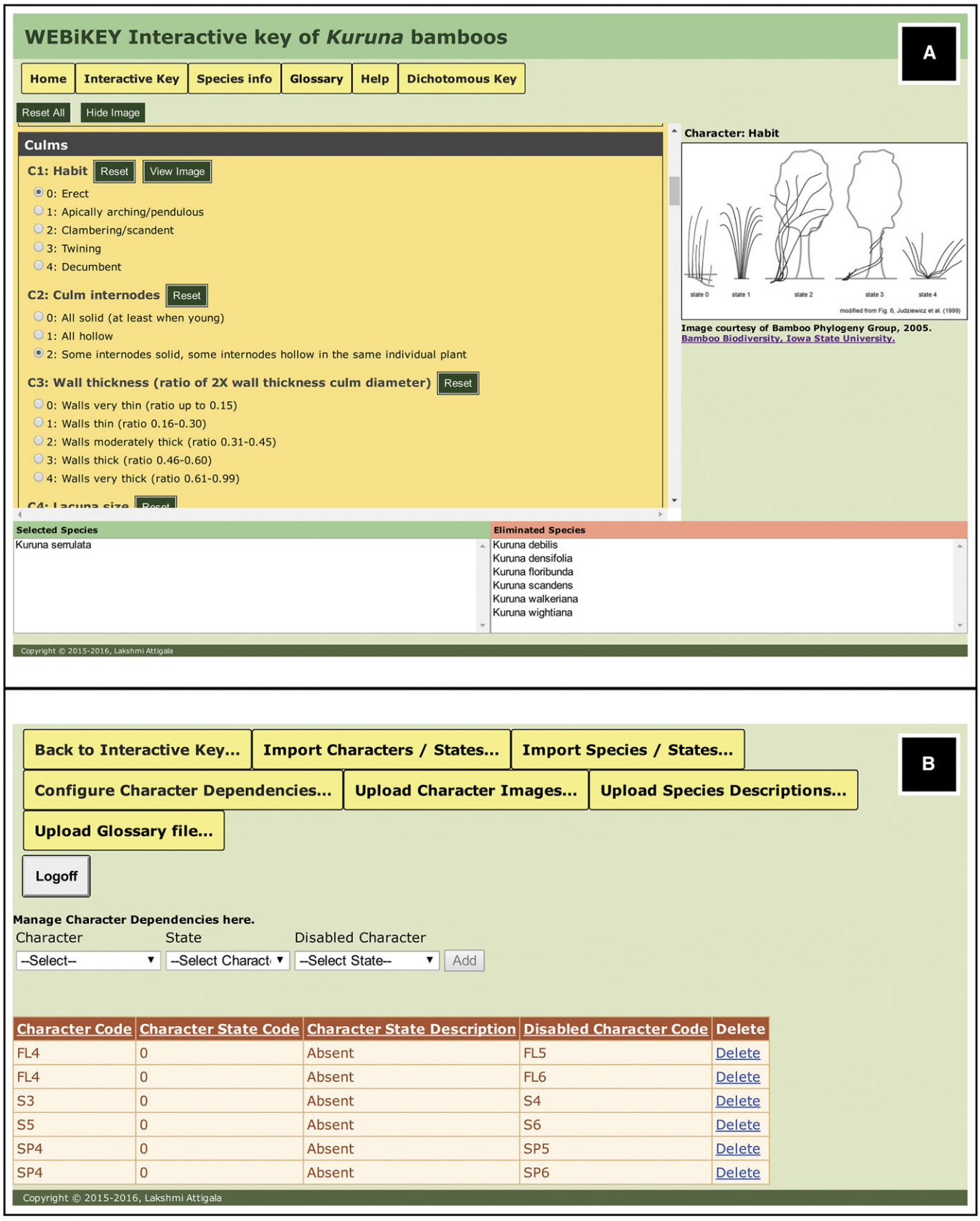

Fig. 3. Handling polymorphic characters and character dependencies. (A) An example of a polymorphic character: "Culm internodes" (C2). Character state 2 represents both hollow and solid culm internodes. (B) Page that allows character dependency configurations.

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The home page of the *Kuruna* key gives a brief description of bamboos in general and about the genus *Kuruna*. The choice of morphological characters for this study was based on the characters used in the Bamboo Biodiversity website (Bamboo Phylogeny Group, 2005). Bamboos have unique characters that require special botanical terms. Thus, illustrations and images are significant components of this interactive key and were reproduced from the Bamboo Biodiversity website (Bamboo Phylogeny Group, 2005) with permission. In the current interactive key, 55 different characters were used to distinguish the seven *Kuruna* species in Sri Lanka and southern India.

The end-user can first click on the "Interactive Key" link from the menu, which directs the user to a webpage that lists the eight major types of characters for temperate woody bamboos (Fig. 2B). The user must select which major character groups are present in the specimen that needs to be identified. The program will use this selection to display only the characters and their character states for each selected major group (e.g., if the specimen does not have flowers and flowering character groups are not selected, then only the vegetative characters will be displayed). This page also contains a diagrammatic drawing of a typical bamboo plant with most of the major character categories labeled. By clicking the "Next" button on this page, the user will be directed to the interactive key of *Kuruna* (Fig. 2C). The characters and character states corresponding to the major character groups that the user selected are in the top left panel, while images of the character states are displayed in the top right panel. The bottom left and right panels display in real-time the matching and eliminated species based on the user's selection of character states. Comparing the character states with the images further enhances the user-friendliness of this application. Under the "Species Info" menu item, users can download descriptions of species that have recently been published in Attigala et al. (2016), as well as images and illustrations, if they are available (Fig. 2D). By clicking "Glossary," users can see written descriptions of the scientific terminology used in the interactive key of *Kuruna*. Users may also click "Dichotomous Key" to see a traditional dichotomous key for the genus.

***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" along with all the other species with hollow culm internodes. Here the Admin simply needs to add character states 1 and 2 in the data matrix for *K. serrulata* as two separate rows (see https://github.com/WEBiKEY/InteractiveKey/blob/master/README.pdf).

Even though the *Kuruna* data set does not show an example of a polymorphic character type 2, WEBiKEY will handle these types of polymorphism comparable to the above example. If a species has some individuals with character state 1 and some with character state 2, then WEBiKEY will display this particular species in the "Selected Species" section, if the user selected either of the character states. For the users who happen to see some individuals with character state 1 and some with character state 2 in the same species, the Admin can introduce a third character state as "Both character state 1 and 2 present in different individuals." To handle this type of polymorphism, the Admin simply needs to add character states 0, 1, and 2 in the data matrix for that particular species as three separate rows.

Another significant feature of the interactive key is that if the user selects a character state that determines the availability of another character, the user may or may not be able to select the dependent character states depending on the first character state selection. For example, if the user selects "S3: Subtending bract at the base of the axis bearing the spikelet or spikelet proper: absent," then they will not be able to select the other character states related to subtending bracts, such as "S4: Subtending bract morphology" (Fig. 2C). This allows the users to make fewer mistakes and makes the key easier to use. However, to work the interactive key in this manner, the Admin needs to set up these character dependencies. Figure 3B shows how these dependencies are configured during the development phase. The first step during the character dependency configuration is selecting the character and its character state that decides the availability of another character from the "Character" and "State" drop-down menus. Then the Admin needs to select the character(s) that should be set to "off" or be "disabled" from the "Disabled Character" drop-down menu, so that the end-user cannot select that dependent character state. The Admin would repeat this process for each character that needs to be "disabled" or turned "off." According to the *Kuruna* data set, there are six character dependencies (Table 1). If the end-user selects "Absent" for "FL4: Auricle (blade-derived appendage) development," "S3: Subtending bract at the base of the axis bearing the spikelet or spikelet proper," "S5: Prophyll at the base of the axis bearing the spikelet or spikelet proper," or "SP4: Rachis extension (internode only, with or without rudimentary floret)," then all the other characters that depend on these characters (FL5, FL6, S4, S6, SP5, and SP6) will be disabled or grayed out and the end-user will not be able to select them (Fig. 3B) (see https://github.com/WEBiKEY/InteractiveKey/blob/master/README.pdf [section on Configuring Character Dependencies]).

***Minimum system requirements and known issues*—**Readers can download the WEBiKEY source code and its database from GitHub (https://github.com/WEBiKEY/InteractiveKey) and use it to develop their own Web-based interactive keys. The minimum requirements for end-users who want to use the WEBiKEY of *Kuruna* are access to a computer with any operating system, a Web browser, and an Internet connection. Developers and administrators who wish to host their own interactive key need to have a system running Windows 7 or a newer operating system (OS), .NET Framework 4.5 or a newer version installed (freely available at: http://www.microsoft.com/en-us/download/details.aspx?id=42642), IIS Express 7 or a newer version (component of Windows OS), or SQL Server Express 2008 R2 or a newer version (freely available at: http://www.microsoft.com/en-us/server-cloud/Products/sql-server-editions/sql-server-express.aspx). Also, Visual Studio Express for Web 2013 (freely available at: https://www.visualstudio.com/en-us/products/visual-studio-express-vs.aspx) or a newer version is recommended if users are planning to modify the source code. Microsoft Excel 2010 or a newer version is required to create and edit worksheets that are uploaded to the application containing characters, character states, and species information.

Because .NET Framework 4.5 and Microsoft SQL Server are currently available only on Windows platforms, this version of WEBiKEY can only be hosted on Windows. However, the authors intend to upgrade the application so that it can be hosted on Mac- or Linux-based hosting environments when the ASP.NET Core 1.0 is released (https://get.asp.net). In addition, WEBiKEY

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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Features	WEBiKEY	Intkey	MEKA	NaviKey	SLIKS
Able to retain taxa for which a character is not recorded when that character is used	√	√	√	√	√
No restrictions on order of character use**	√	√	√	√	√
Able to remove or change characters used*	√	√	√	√	√
Can handle character dependencies*	√	√	—	√	—
Detailed explanations are conveniently available within the system to aid interpretation of characters*	√	√	—	—	—
A detailed glossary is available*	√	—	—	—	—
Illustrations of character states are provided*	√	√	—	—	√
Able to scale illustrations of any size*	√	√	—	—	—
Can directly import data sets via spreadsheets (.xlsx)*	√	—	?	—	—
Able to handle unlimited numbers of taxa, characters, and states*	√	√	?	?	?
Able to handle unlimited lengths of fields (e.g., taxon names, text of characters, character notes)*	√	√	—	√	√
Categorizes characters into major groups, allowing users to select only the major parts in an unknown (e.g., flowers, fruits, etc.)	√	—	—	—	—
Can run without illustrations (a package normally containing illustrations can run well without them)	√	√	—	—	—
Can attach text files to taxa	√	√	—	—	—
Complete, built-in help included	√	√	—	√	√
No special memory requirements for end-users	√	√	√	√	√
Available mainly as a Web-based application	√	√	—	√	√
Can access conventional dichotomous keys	√	—	—	—	—

Fig. 4. A comparison between WEBiKEY and a few other freely available interactive key development programs. Features in boldface denote essential features for identification. ** and * denote very important and important features for identification, respectively. Features not in boldface nor marked with an * are useful for identification, but not necessary. √ = feature is implemented in the program; — = feature is not implemented in the program; ? = feature is unknown.

will be modified to accommodate a mobile-friendly version in the near future.

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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