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Properties, users' assessment and applicability of nine types of taxonomic keys in diagnosing some Nigerian species of *Ocimum* L., *Hyptis* Jacq. and *Ficus* L.

Adepoju Tunde Joseph OGUNKUNLE

Environmental Biology Unit, Department of Pure and Applied Biology, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Oyo State, Nigeria.

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Nine types of taxonomic keys have been listed from the literature. These are the dichotomous, numerical, multi-access table of identification, punched-card, columnar-diagram, graphical, flow-chart, pictorial-diagram and circular-diagram keys. In this study, each type of key was observed at two levels namely, its format (which is its peculiarity, depicting the general plan, arrangement or organization of its elements) and style (which is one-to-several structural variants in which a key format may be presented in printable form). The format of each type of key along with its representative styles (which determines whether a key is single-access or multiple-access) is illustrated using anatomical features of six Nigerian species of *Ocimum* L., four of *Hyptis* Jacq., and 12 of *Ficus* L. The systematic mode of application and spectrum of usage of each key are discussed and the users' opinions on its usability, efficiency, prospects, users' familiarity and general acceptability are presented. The strengths and limitations of the key formats are also evaluated and discussed on the basis of which taxonomists are charged to consider research efforts towards improving upon the qualities, and devising new key formats with the prospect for better performance.

Key words: Artificial key, diagnostic key, *Ficus,* leaf epidermis, plant identification, taxonomic key, wood anatomy, *Hyptis, Ocimum*.

INTRODUCTION

There are at least 1.4 million species of plants, animals and microorganisms which share the planet earth with man (Asthana and Asthana, 2012). In other to retrieve, utilize, communicate and accumulate information about these organisms, it is necessary for man to identify, name, describe as well as place them into groups that reflect his current knowledge of their evolutionary relationships. These activities make up the discipline of taxonomy (Sivarajan, 2005; Judd et al., 2007). Identification is particularly important since the correct name of an organism is taken as the basic requirement towards having access to its literature. There are two approaches to identify and classify plants. These are the traditional approach and the scientific or formalized approach. The traditional approach (or folk taxonomy) applies the considerable unwritten knowledge of plants in particular localities for plant diagnosis. These unwritten facts have been unconsciously harmonized into a system of ordering plant life so that there is a system of naming them and of referencing particular plants (Olorode, 1984).

In the formalized approach, three options are available to the taxonomist to identify his plant(s) of interest: one,

E-mail: tjogunkunle@lautech.edu.ng.

by comparing the unknown plant specimen with already identified plants using herbarium specimens and botanical/horticultural gardens; two, by comparing the unknown plant with appropriate photographs, drawings, and/or paintings (Mbuya et al., 1994; Akobundu and Agyakwa, 1997; Nyanayo, 2006); and three, by the use of descriptions and 'keys', which are available in the floras, manuals or any other taxonomic publications relating to the plants of a particular region (Hutchinson and Dalziel, 1963-1972; Keay et al., 1964; Lowe and Stanfield, 1974; Keay, 1989). These devices are called 'artificial' or diagnostic keys because the choice of characters is limited to those that are found to be most reliable and convenient to use, and which are readily available for evaluation. Hence, the arrangement is solely for the convenience of identification (Pankhurst, 1991). These are at variance to the 'natural' or synoptic keys, each characterized by many features of the plants which may not be easily observable in the field such as chromosome features, chemical characters, etc., and whose main thrust is to reflect as close as possible, the scientific classification of the organisms (Pankhurst, 1991).

Every taxonomic key has an easily recognizable starting point that serves as the first notable step in its application. This starting point delimits the scope and coverage of a key, that is, it defines the extent to which it can be used for the purpose of identification. A key also carries a title, which should normally give the user enough information for him to easily select specimens or objects that fall within the scope of the key.

The literature is rich with much, but fragmented pieces of information on types and applicability of artificial keys. Some authors have also variously pointed out the merits and demerits of using some of the available key formats in plant identification, but information on objective comparative assessment of these tools is lacking. This study was therefore meant to collate information about the different types of taxonomic keys with two goals in mind, which were to generate practical tools and a readily available source of information with wider taxonomic and teaching implications from the existing but dispersed and highly essential materials; and to do a users' comparative assessment of the qualities and potentials of these tools for possible refinement towards enhancing the practice of plant identification.

MATERIALS AND METHODS

Literature search

A literature search was conducted on the basics or formats, the styles of presentation and modes of application of the commonly used artificial key systems (Clark, 1938a, b; Herms and Gray, 1944; Osborne, 1963; Keay et al., 1964; Hopkins and Stanfield, 1966; Lowe and Stanfield, 1974; Saldanha and Rao, 1975; Olorode, 1984; Keay, 1989; Jones et al., 1998). The format of a type of key is its general plan, arrangement or organization of its elements that distinguishes it from any other type, e.g. paired contrasting statements, tabulated statements, diagrammatic or numeric representations (Saupe, 2009). The style is one-to-several structural variants in which a known key format may be presented in printable form. The mode of application refers to the prescribed route(s) and means for navigating an artificial key arrangement for an effective identification of a plant specimen.

Attempts were made to trace the origin of diagnostic keys from available information in the literature. The formats, styles and modes of application of the artificial key types encountered in the literature were then described and illustrated using epidermal and wood anatomical features from some species of *Ocimum*, *Hyptis* and *Ficus* in Nigeria. Details of voucher information, data collection and character definition for this purpose are contained in Ogunkunle (1989, 2013) and Ogunkunle and Oladele (1997, 2000, 2008). Some properties common to all the keys were identified and used for their comparative assessment.

Assessment of types of taxonomic keys

A questionnaire was designed to seek the opinions of academic and research workers in systematic botany and related disciplines on the qualities and potentials of some artificial key arrangements. Details about the respondents in the Nigerian Universities and Research Institutes used for the study are contained in Ogunkunle (2006). There were three parts in the questionnaire. The first part gave some background information to the respondents. This included the names of the nine types of artificial keys for consideration, a short description of each format and a brief explanation of its mode of navigation. In addition, the respondents were introduced to six other general qualities of taxonomic keys namely, spectrum of usage (the range of target users), usability, efficiency, weaknesses (or demerits), strengths (or merits) and prospects (or potentials) to enable them respond adequately to the succeeding questions or statements.

The spectrum of usage of a key is here defined as the range of environments in which a key is meant to be effective for the purpose of identification, e.g. field, herbarium, laboratory, etc. Usability is the ease or difficulty with which a key can be navigated for identification by professionals and/or non-professionals. Usability is a function of two factors, namely, the prescribed mode of applying the key and the degree of prior knowledge that is expected in its navigation. Efficiency of key means the ability to accomplish or fulfill the act of identification within a reasonable time limit with the use of the key. The weaknesses or demerits, pertaining to a key, are those pertinent questions surrounding the determination of a plant's identity to which the answers provided by the key are not on the favourable side, e.g. can the key be used for quick confirmation of a suspected identity? is the usage restricted to only a class of workers? Is the format difficult or easy to construct? and so on. If on the other hand, the answers provided to such questions are on the favourable side, we speak of the strengths or merits of the key. The prospects refer to all other possible applications or potentialities of a taxonomic key in plant sciences apart from identification for which it is primarily meant, e.g. the possibility of recognizing relationships among individuals or groups from the key.

The second part of the questionnaire was devoted to seeking personal information about the respondents. This included their places of work, areas of specialization, years of experience, whether they consulted experts or personally handled identification, and how often they required a taxonomic key for the purpose of identification. The third and the final part of the questionnaire asked the respondents to assess the qualities of the nine artificial key formats under investigation. There were two sections in this part of the questionnaire. Section 'A' required the respondents to give their opinions on four qualities of the types of keys over a four-point scale in decreasing order of magnitude as follows: users' extent of

Table 1. Enumeration of the guided statements used to evaluate the properties of some artificial key formats*.

SN.	Guided statement
1	The key shows relationship or affinities among individuals or groups that are included in it (A).
2	It is simple and easy to construct even when the number of specimens involved are many (B).
3	It takes care of realities in the world of plants with provisions made for missing parts; seasonal variations, geographical variations *et cetera* (C).
4	Confirmation of suspected identity can be undertaken by the use of the key within a short time (D).
5	The key has a wide Spectrum of users that is, it is applicable in many environments (E).
6	It is easy to navigate with minimal error as the mode of use is not intricate (F).
7	There is the possibility of a quick retreat once an error is detected (G).
8	The key is concise and handy that is, less voluminous relative to the number of specimens involved; sometimes represented by a single chart (H).
9	Plant Specimen needs not be on ground for its identification to be effected (I).
10	The key can be electronically programmed and made interactive for greater efficiency (J).
11	User is free to choose any character in any order/sequence, thus avoiding the usual rigid (single-entry) format (K).
12	Number of characters applicable is not usually limited, thus embracing the principle of natural classification (L).
13	The key is not cumbersome for storage and handling as no loss of parts may render the key invalid (M).
14	Amount of prior knowledge or vocabulary required for navigating the key is not high such that it may be handled by professionals and non-professionals alike (N).
15	It is applicable for both situations in which there are small and large number of choices in characters and specimens (O).

*The list emanated from the author's conception of expected properties of an ideal key format. The alphabets in parentheses are the codes assigned to the guided statements during the investigation.

familiarity (high, medium, low, nil); usability (very difficult, difficult, easy, unaware); efficiency (high, low, very low, unaware); and acceptability to the user (very high, high, low, very low). Section 'B' of the third part of the questionnaire presented the respondents with fifteen guided statements for evaluating the merit level of each of the key formats. The statements were all drawn out of the investigator's conception of an ideal tool for plant identification, each being a desirable comment on one definite task (Table 1).

The respondents were made to react to each statement over a two-point scale, 'agree' or 'disagree'. The questions and/or statements in both sections 'A' and 'B' were independent of one another. As such, a respondent who, for instance was not familiar with a type of key, going by his response in section 'A' might still assess its efficiency or usability from the knowledge of the background information given about the key in the introductory part of the questionnaire. Moreover, such a respondent could adequately assess the merit level of the key format by responding to the guided statements in section 'B'. A total of 56 questionnaires were administered and analyzed.

Data analysis

The four responses to each of the questions in Part IIIA were assigned weight values 4, 3, 2 and 1, respectively. The mean of all responses to a question was then computed and taken as the representative opinion of all the respondents in that question. With regards to the analysis of the data in Part IIIB, the percent number of respondents in agreement with each of the fifteen statements for all the key types was first computed and recorded. These percent values were then ranked into five class intervals, each with a size of 20 and assigned a weight value of points in increasing order of magnitude as follows: 1-20% = 1 point; 21-40% = 2 points; 41 -60% = 3 points; 61-80% = 4 points; and 81 – 100% = 5 points. Thereafter, for each type of key, the weighted mean of the percent affirmative responses was computed using the formula adapted from Spiegel (1992) as follows:

$$\text{Weighted mean} = \frac{\sum_{i=1}^{n} PiWi}{\sum_{i=1}^{n} Wi} \quad (1)$$

Where, P_i = percent affirmative response to a statement of merit assessment; W_i = weight value of points attached to each % response; n = number of guided statements adopted for assessment of a key.

The weighted mean of percent responses was taken as the index of merit for each type of key and the key format with the highest index was taken to have satisfied a substantial number of expectations in an ideal artificial key format.

RESULTS AND DISCUSSION

Origin and types of taxonomic keys

There are strong indications from the literature that taxonomic keys (albeit unpublished) have been in use for several hundreds of years, the two basic types being the single-access and the multiple- or multi-access keys (Pankhurst, 1991). These two basic types have however undergone some radical transformations in the hands of taxonomists, evolving into nine different kinds currently in use, that is, dichotomous (Osborne, 1963; Fahn, 1974; Olorode, 1984; Sharma,1993), numerical (Keay et al., 1964; Lowe and Stanfield, 1974; Olorode, 1984), multi-access table of identification (Jones et al., 1998), punched-card (Clarke, 1938a, b; Saldanha and Rao,

Table 2. Dichotomous (bracketed) key to some Nigerian species of *Ocimum* based on leaf and stem stomatal characteristics.

1a	Diacytic, anisocytic and amphidiacytic stomatal complex types found on the lamina; petiole and stem epidermises are also with various types of stomatal complexes…………………………………………………..2
1b	Only diacytic and amphidiacytic stomatal complex types are found on the lamina; petiole and stem epidermises lack stomata/ stomatal complexes……………………………………………………………*O. Suave*
2a	Staurocytic and anisocytic stomatal complex types are observable on the stem epidermis along with other types; anisocytic type also occurs on the petiole…………………………………………………………………3
2b	Diacytic, paracytic and paradiacytic stomatal complex types found on stem epidermis, never staurocytic nor anisocytic……………………………………………………………………………………………*O. lamiifolium*
3a	Paradiacytic stomatal complexes occur on the stem epidermis; and also on the petiole unless the leaf is sessile ………4
3b	Staurocytic, anisocytic and cyclocytic complexes are observable on the stem, never paradiacytic; if leaf is petiolate, only diacytic, anisocytic and staurocytic stomatal complex types are found…………*O. gratissimum*
4a	Stem epidermis, with paracytic stomatal complex; staurocytic stomatal complex, absent on the petiole……………………………………………………………………………………………………*O. basilicum*
4b	Stem epidermis, without paracytic stomatal complex; petiole if present, has staurocytic stomata…………….5
5a	Diacytic, anisocytic, paradiacytic and staurocytic stomatal complexes are observable on the petiole…………………………………..*O. canum*
5b	Leaves sessile (that is, without petiole)………………………………………………………………………*O. Irvinei*

Table 3. Dichotomous (bracketed) key to some Nigerian Species of *Hyptis* based on leaf and stem epidermal characters*.

1a.	Leaf adaxial epidermal cell walls are straight but those of abaxial surface are wavy……………………………2
1b.	Leaf adaxial epidermal cell walls are not straight; rather curved or wavy…………………………………………3
2a.	Surfaces of lamina bear only diacytic and amphidiacytic stomatal complexes; petioles bear diacytic, anisocytic and staurocytic stomatal omplexes……………………………………………….*H. lanceolata*
2b.	Surfaces of lamina bear anisocytic stomatal complexes along with diacytic and amphidiacytic types; petioles also bear paradiacytic complex in addition to diacytic, anisocytic and staurocytic types………………………………………………………………………………………..*H. spicigera*
3a (1).	Leaf adaxial epidermal cell walls are curved (not wavy); stems bear diacytic, anisocytic, staurocytic and paradiacytic complexes …………………………………………….*H. pectinata*
3b.	Leaf adaxial epidermal cell walls are wavy; paracytic stomatal complex type are found on stems along with diacytic, anisocytic, staurocytic and paradiacytic complexes……………. …………………………………………………………………………………*H. suaveolens*

*Number in parentheses immediately after couplet number indicates the couplet that sent user to the current couplet.

1975), columnar diagram (Herms and Gray, 1944), graphical (Dawkins, 1951; Hopkins and Stanfield, 1966), flow- chart (Jones et al., 1998; Monteith, 2000), pictorial diagram (Harris and Harris, 2001) and circular diagram (Herms and Gray, 1944) keys, which are illustrated in Tables 2 to 8 and Figures 1 to 7. Preceding these transformations and publications, identification tables were said to have been presented by Richard Waller in 1689 to his assembled colleagues at a meeting of the Royal Society in the form of image-based dichotomous keys for the herbs of Britain (Griffing, 2011).

The single-access key, also called sequential or analytical key is strictly speaking, a family of types of taxonomic keys, each characterized by the sequence and structure of identification steps that are fixed by the author of the key. If the entire key consists of exactly two choices at each branching point, the key is called dichotomous, and is polytomous if there are more than two choices, the former being the more commonly applied format. Some of the other key formats that have evolved from the single-access key arrangement include columnar diagram, graphical, flow-chart, pictorial-diagram and circular-diagram keys (Figures 3 to 7).

There is evidence to show that the origin of single-access keys, and perhaps, of any taxonomic key, could be in the age-long decision tree or tree diagram used in operations research to identify a strategy most likely to reach a goal; a decision support tool that uses a tree-like graph of decisions and their possible consequences including chance, event outcomes, resource costs and utility (Yuan and Shaw, 1995). The dichotomous key gained popularity in botanical (and zoological) works, a form in which single-access keys were first published in 1672 by Morison in his *Plantarum Umbelliferarum*

Table 4. Leaf epidermis-based dichotomous key to some Nigerian species of *Ficus* using an integral hierarchical format*.

1a.	Prickle-like hairs present on both adaxial and abaxial leaf surfaces ……………………………Subgenus *Ficus*	
1b.	Prickle-like hairs, absent on both adaxial and abaxial leaf surfaces……………………………………………….2	
2a.	Adaxial epidermal cells, variable in shape and intermixed, including isodiametric, tabular, square and irregular……………………………………………………………………………………………...Subgenus *Urostigma*	
2b.	Adaxial epidermal cells, isodiametric in shape…………………………………………..Subgenus *Sycomorus* (3)	
	3a(2).	Bulbous glands, unicellular and circular, found in-between and on the veins of abaxial leaf surface; polycytic stomatal complexes with 4 and with 5 subsidiary cells, found on abaxial surface………..4
	3b.	Bulbous glands absent; instead, flask-shaped glands are present in-between and on the veins of abaxial surface; polycytic stomatal complexes with 6, with 7, and with 8 subsidiary cells, found on abaxial surface; those with 3, 4 and with 5 subsidiary cells are absent……………….*F.vallis-chondae*
	4a (3).	Abaxial epidermal cells, isodiametric in shape, with curved anticlinal walls; stomata located in-between the veins only; stomatal complex types with 4 and with 5 subsidiary cells are found; mean stomatal density/unit of veins, less than 100……………………......................................*F. mucuso*
	4b.	Abaxial epidermal cells, irregular in shape, with wavy anticlinal walls; stomata located in-between and on the veins; anisocytic stomatal complexes (that is, with 3 subsidiary cells) are found along with those with 4 and with 5 cells; mean stomatal density/unit of veins, about 168…........................*F. Sur*

*Number in parentheses immediately after couplet number indicates the couplet that sent user to the current couplet, while that after the couplet statement indicates the next couplet to which the user is directed.

Table 5. Wood and leaf anatomy-based dichotomous key to some Nigerian species of *Ficus* using separate hierarchical (or multi-part) format.

Part A:	Subgenera of *Ficus*	
	1a.	The characteristic ray type observable in wood TLS is convex type II, occurring in two forms that is, the thicker and the thinner; in the thicker rays, the cells are round, relatively thin-walled, conspicuously tiny and numerous per ray, with few of the cells enlarged; in the thinner rays, the cells are variable in shape but usually angular or round and thin-walled with none being enlarged………..Subgenus *Ficus*
	1b.	The characteristic ray type combination of the convex type II in wood TLS as described in 1a is not applicable…………………………………………………………………………………………………2
	2a.	Convex type I ray, observable in wood TLS…………………………………………Subgenus *Sycomorus*
	2b.	Convex type I ray, absent in wood TLS………………………………………………Subgenus *Urostigma*
Part B:	Sections of the subgenus *Urostigma*	
	1a.	Wood substance, variable in colour but frequently whitish or yellowish- white; heartwood/sapwood boundary is distinct; mean density of epidermal cells on abaxial leaf surface, relatively low (between 300 and 400/mm^2), never up to 600/mm^2…………………………………Section *Galoglychia*
	1b.	Wood substance, pinkish-white; heartwood/sapwood boundary indistinct; mean density of epidermal cells on abaxial leaf surface, very high (up to 800/mm^2)………………………………Section *Urostigma*
Part C:	Subsections of the section *Galoglychia*	
	1a.	Glands, present on abaxial leaf surface…………………………………………………………………2
	1b.	Glands, absent on abaxial leaf surface…………………………………………………………………3
	2a.	Scales or other sessile glands on abaxial leaf surface are unicellular and circular; rarely oval and if oval, are also unicellular……………………. ……………………………………Subsection *Caulocarpae*
	2b.	Scales or other sessile glands on abaxial leaf surface are multicellular and oval; else, such glands are absent……………………………………………………………………………Subsection *Chlamydorae*
	3a.	Anisocytic stomatal complex type is observable along with the polycytic (4 or more subsidiary cells) types; mean stomatal density/mm^2 of leaf surface is very high (above 200)……………………………..4
	3b.	Anisocytic stomatal complex type, absent on leaf surface; mean stomatal density/mm^2 of leaf surface is low (less than 40)………………… ………………………………………Subsection *Crassicostae*
	4a.	Epidermal cell walls on abaxial leaf surface are curved; glands occur on adaxial epidermis; usually bulbous and circular…………………………………………………………………Subsection *Galoglychia*
	4b.	Epidermal cell walls on abaxial leaf surface are straight; glands are absent on adaxial epidermis………………………………………………………………………Subsection *Cyathistipulae*

Table 5. Contd.

Part D:		Species of the subsection *Caulocarpae*
	1a.	Dumb-bell shaped (or constricted) rays are found in wood TLS……………………………………………..2
	1b.	Dumb-bell shaped rays are absent in wood TLS..…………………………………………………………..3
	2a.	Vessels in wood TS occur as solitary units and in radial chains of up to 7; uniseriate rays and giant rays are found in TLS…………………………………………………………………………*F. umbellata*
	2b.	Vessels in wood TS occur as solitary units and in radial chains of maximum of 2; uniseriate and giant rays are absent in TLS……………………………………………………………………………….*F. ovata*
	3a.	Rays in wood TLS occur as heterocellular types only………………………………………....*F. ottonifolia*
	3b.	Rays in wood TLS occur as both homocellular and heterocellular types…………………………*F. polita*

Table 6. Leaf epidermis-based dichotomous (indented) key to some Nigeria species of subsection *Caulocarpae* (Section *Galoglychia*, subgenus *Urostigma*, genus *Ficus*).

1a.	Bulbous glands found on one or both of the adaxial and abaxial leaf surfaces………………………….…2	
	2a.	Bulbous glands observable on abaxial epidermis only; scales also present on adaxial surface only; number of radiating basal cells of glands on abaxial leaf surface 10-14; types of basal cells of the glands on adaxial surface consist of the unmodified and the radial type II………………………………*F. ottonifolia*
	2b.	Bulbous glands and scales, found on both leaf surfaces; number of radiating basal cells of glands on abaxial leaf surface 7 or 8; types of basal cells of the glands on adaxial surface consist of the unmodified and the radial type I…………………………………………………………………………………...*F. polita*
1b.	Bulbous glands, absent on both leaf surfaces…………………………………………………………………3	
	3a.	Epidermal cell walls on abaxial leaf surface are irregular in shape; scales and club-shaped glands, found on both adaxial and abaxial epidermises; mean stomatal density is high, being 200/mm^2 of leaf surface and 89/unit of the veins………………………………………………………………………………*F. ovata*
	3b.	Epidermal cell walls on abaxial leaf surface are tabular in shape; scales are found only on adaxial while club-shaped glands are found only on abaxial surface; mean stomatal density is low, being 87/mm^2 of leaf surface and 23/unit of the veins…………………………………………………………………*F. umbellata*

Distributio Nova (Stace, 1991), and in 1778 by Jean Baptiste-Larmark (Saupe, 2009; Griffing, 2011).

As much as possible, a single-access key is made to start with characters that are reliable, convenient and generally available throughout most of the year. But this is often impossible to achieve for all the taxa in a key. Polyclave, random-access or multiple-entry key is the identification key which overcomes this problem along with that which has to do with fixed sequence of identification steps in the single-access keys. The flexibility in multi-access key lets the user undertake character choices in the key according to the state of the specimen being identified and the prevailing circumstances such as seasonal variations, and field or laboratory situations. He is thus free to choose the set of characters that are convenient to evaluate for the plant to be identified. Some of the states or condition which may arise include occurrence of important characters that are difficult to observe, presence of some characters that may likely be misinterpreted, a situation when a single character may be unreliable in isolation, and when a part of a specimen is missing or seems abnormal. The printable forms of multi-access keys include numerical, tabular, matrix, formula styles, the pictorial diagram and the punched- cards (Virtual Field Herbarium, 2000; Key-to-Nature, 2010; Tables 7 to 8; Figures 1 to 2)

Structure and applicability of some types of taxonomic keys

A simplified dichotomous key is illustrated in Tables 2 and 3, both of which refer to the bracketed or linked variant of the key format.

As it is in all single-access keys, there is only one point of entry in each of the two keys in Tables 2 and 3. In order to identify a specimen, there is a step-wise perusal of the contrasting statements in the key, starting from the first pair (or couplet), resulting in the acceptance of one (a lead) and the rejection of the other with respect to the features of a plant specimen on hand. The acceptance of one of the first pair of statements leads to the second pair in the series and so on. This exercise will eventually terminate when, instead of an earlier accepted lead pointing to a further pair of couplet now points at a name. Such name is generally taken as the identity or correct name of the 'unknown' plant (Tables 2 and 3).

The bracketed or linked style in a key makes polytomous statements applicable since the leads within a couplet follow each other contiguously (Table 3). More-

Table 7. Wood anatomy-based numerical key to some Nigerian species of *Ficus.*

Diagnostic characters

1. Oval-shaped vessels in wood T.S
2. Tylose in the vessels
3. Broad rays in TS of wood
4. Convex rays of Type III in wood TLS
5. Occurrence of heterocellular rays of type A
6. Homocellular rays
7. Uniseriate rays
8. Biseriate rays
9. Maximum number of vessels in radial chains in TS is up to 6 or more

Codes and species

1	2	3	0	0	0	7	8	0	*F. lutea*
1	0	3	4	0	6	7	8	9	*F. exasperata*
1	0	3	4	0	6	7	8	0	*F. mucuso*
1	0	3	0	5	6	7	8	9	*F. umbellata*
1	0	3	0	5	6	7	8	0	*F. thonningii*
1	0	3	0	5	6	0	0	9	*F. populifolia*
1	0	3	0	0	6	7	8	0	*F. polita*
1	0	3	0	0	6	0	8	0	*F. ovata*
1	0	3	0	0	0	7	8	0	*F. ottonifolia*
1	0	0	0	0	6	7	8	0	*F. ingens*
1	0	0	0	0	0	7	8	0	*F. natalensis*
0	2	3	0	5	6	0	0	0	*F. sur*

Table 8. A wood anatomy-based multi-access table of identification for some Nigerian species of *Ficus*.

Diagnostic character	Species											
	LUT	NAT	MUC	OVA	ING	UMB	OTT	POL	THO	EXA	SUR	POP
OVV	2+	2+	5+	3+	3+	2+	2+	3+	5+	3+	-	5+
ROV	5+	3+	3+	5+	5+	3+	3+	5+	4+	4+	6+	4+
TYL	3+	-	-	-	-	-	-	-	-	-	4+	-
NAR	5+	6+	4+	4+	6+	5+	5+	3+	3+	3+	2+	5+
BRR	3+	-	4+	4+	-	3+	3+	5+	5+	5+	5+	2+
CRI	-	-	-	-	-	-	-	-	-	-	+	-
CII	+	6+	+	+	+	+	6+	6+	6+	+	+	+
CIII	-	-	+	-	-	-	-	-	-	+	-	-
DBR	3+	-	3+	2+	3+	3+	-	-	-	2+	2+	3+
HCR	-	-	3+	2+	3+	3+	-	3+	3+	3+	3+	3+
HRA	3+	-	-	-	-	3+	-	-	3+	-	5+	4+
HRB	5+	6+	5+	5+	5+	5+	6+	5+	5+	5+	3+	4+
USR	2+	3+	3+	-	3+	5+	3+	3+	2+	2+	-	-
BSR	3+	4+	3+	3+	3+	3+	3+	3+	3+	3+	-	-
MSR	5+	4+	5+	5+	5+	5+	3+	5+	5+	5+	6+	6+
GIR	+	-	-	+	+	-	-	-	-	-	+	+
PSV	73	86	61	78	63	69	68	72	69	53	34	38

LUT = *F. utea*, NAT = *F. natalensis*; MUC = *F. mucuso*; OVA = *F. ovata*; ING = *F. ingens*; UMB = *F. umbellata*; OTT = *F. ottonifolia*; POL = *F. polita*; THO; *F. thonningii*; EXA = *F. exasperata*; SUR = *F. sur*; POP = *F. popufolia*. OVV = oval-shaped vessel in wood TS; ROV = round- shaped vessels; TYL = presence of tyloses in vessels; NAR = rays narrow in wood TS; BRR = rays broad in wood TS; CRI = convex ray type I, CRII = convex rays of type II; CRIII = convex rays of type III; DBR = dumb-bell shaped rays; HCR = homocellular rays; HRB = heterocellular rays of type B; USR = uniseriatte rays; BSR = biseriate rays; MSR = multiseriate rays; GIR = giant rays; PSV = percent (frequency) of solitary vessels in wood TS; = absent/not applicable; + = observable but frequency is unknown; 2+ = 1-9% observation; 3+ = 10-39% observation; 4+ = 40-59% observation; 5+ = 60-99% observation; 6+ = 100% observation.

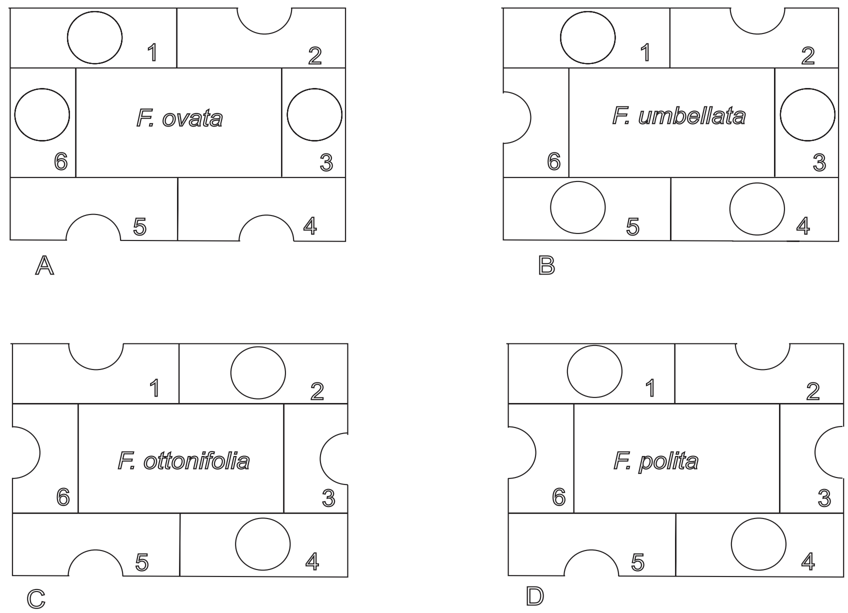

Figure 1. Diagrams of edge-punched cards for identification of some Nigerian species of *Ficus* (subgenus *Urostigma*, section *Galoglychia*, subsection *Caulocarpae*) based on wood anatomy. A, B, C, D represent the taxa; in taxon A (*F. ovata*), characters 1, 3, and 6 are applicable (intact holes) while characters 2, 4 and 5 are not applicable (holes are clipped off). List of the diagnostic characters:1, Homocellular rays found along with heterocellular rays in TLS; 2, Only heterocellular rays are found in wood TLS; 3, Dumb-bell (constricted) rays are present in wood TLS; 4, Uniseriate, biseriate and multiseriate rays are found in wood TLS; 5, Giant rays (more than 20 times taller than wide) are present in TLS; 6, Vessels in TS occur in solitary units and radial chains of maximum of 2.

over, linked dichotomous keys make it possible to have keys for different taxonomic levels possible (for example keys to genera and species) either within a single data matrix (integral hierarchical keys) (Table 4), thus allowing the user to change the level during iden-tification without losing information, or by linking a key to higher categories of taxa with other keys to allow iden-tification to proceed to lower taxonomic level (separate hierarchical keys) (Table 5) (Dallwitz et al., 2009). Another style of presenting dichotomous keys is in the indented (yoked or nested) form (Table 6), in which each successive couplet is indented with an equal distance from the left margin and the indentation increases with increasing couplets. Moreover, all the units in respect of one lead of a couplet are keyed out first before proceed-ing to the other half (Table 6).

Although, most dichotomous keys are simplified, that is, they follow the decision trees or binary search trees but to improve their usability and reliability, they may incur-porate reticulation, changing the tree structure randomly into a directed acyclic graph. Reticulation is a practice whereby different branches of the tree are connected to improve error tolerance and identification success (Osborn, 1963) in such a way that multiple paths lead to the same result. There are two forms of reticulation. The first is terminal reticulation in which a single taxon (or next-level key) is keyed out in several locations in the key after having scored the attributes of the taxa from different perspectives. The second is inner reticulation, in which a couplet with further leads can be reached through more than one path. Reticulations generally improve the usability of a key but may also diminish the overall probability of correct identification averaged over all taxa (Osborn, 1963; Payne, 1977; Payne and Preece, 1977).

Table 7 shows a variant of numerical key. For the purpose of identification, a nine-digit code is normally compiled for the 'unknown' specimen with regards to the nine-characters. The resulting code is then compared with the list of code in the key. The user is also free to evaluate and make use of one character at a time, and in the order he prefers for the process of taxa elimination. This arrangement is the simplest form of the numerical key format which assumes that no two characters used are mutually exclusive. In many cases however, a given pair of characters may be mutually exclusive. In that case, the figures representing the two characters can never occur together in a taxon. The figures in the code are usually separated from the neighbouring digits by a period. It is also possible to include more than nine characters. In such a case, those digits representing the first nine characters are separated from the second by a

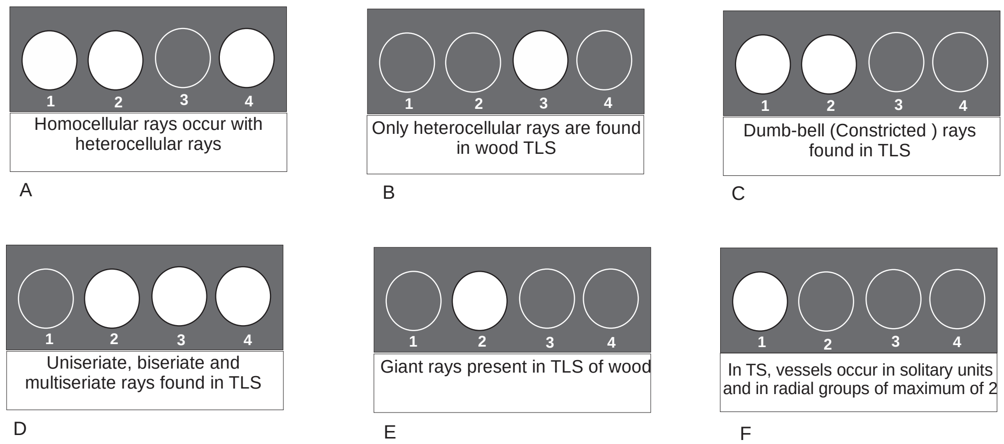

Figure 2. Diagrams of body-punched cards for identification of some Nigerian species of *Ficus* (Subgenus *Urostigma*; Section *Galoglychia*; Subsection *Caulocarpae*) based on wood anatomy. A, B, C, D, E, F = diagnostic characters; 1= *F. ovata*; 2 = *F. umbellata*; 3 = *F. ottonifolia*; 4 = *F. polita*. In Taxon 1 (F.ovata*)*, characters D and E are not applicable (represented by circles) while characters A, B, C and F are applicable (punched into holes).

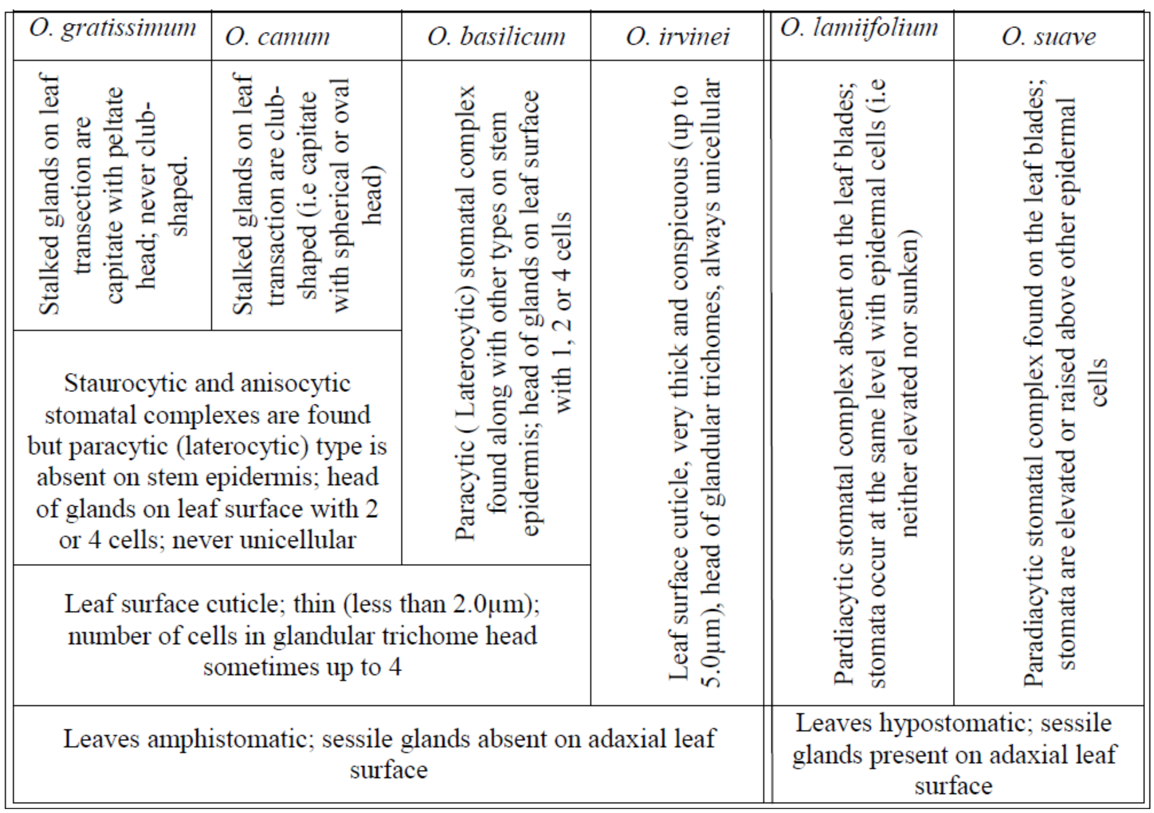

Figure 3. The columnar diagram key to some Nigerian species of *Ocimum* based on leaf and stem epidermal features. The point of entry into the key is the two boxes at the bottom of the columns.

colon, the second nine digits are also separated from the third by another colon, and so on.

Table 8 is a multi-access table of identification. In order to apply this key, the user first evaluates the 'unknown' specimen on the basis of those characters available to him from the list of all the characters in the table, one after the other and in accordance with the definitions attached thereto. Next, with the consideration of each

		Stellate hairs on the costal areas of leaf surface; sessile glands on TS of petiole if present, are normal (not sunken)		No stellate hairs on leaf surface; sessile glands on TS of petiole are sunken in pits	
		Type I stellate hairs on leaf surface	Type II stellate hairs on leaf surface	Stalked glands found on both leaf surface	Stalked glands absent on both leaf surfaces
Anticlinal walls of epidermal cells (Adaxial) are curved or wavy; Stomata on abaxial surface are normal (not raised)	Stomata on stem are scattered; not linearly arranged	*H. pectinata*			
	Stomata on stem are arranged linearly along the stem axis		*H. suaveolens*		
Anticlinal walls of epidermal cells (Adaxial) are straight; Stomata on abaxial surface are elevated (raised) above other epidermal cells	Anisocytic stomata absent on abaxial leaf surface				*H. lanceolata*
	Anisocytic stomatal complex found on abaxial leaf surface			*H. spicigera*	

Figure 4. A graphical key for diagnosing four Nigerian species of *Hyptis.* Type I stellate hair = simple uniseriate hairs occur in tufts; Type II stellate hairs = simple uniseriate hairs occur in tufts with stalked glandular trichomes; anisocytic stomatal complex = stomata with three subsidiary cells.

character in turn, some specimens in the table are eliminated or ignored while the others are selected. Each successive step narrows down the choices of specimens until only one specimen is left, its name being the identity of the ‘unknown’ plant.

Figures 1 and 2 are the two types of punched-card system commonly used in plant identification. These are named ‘species-per-card’ and ‘character-per-card’ types, respectively (Virtual Field Herbarium, 2000). The first step in the use of the edge-punched or ‘species-per-card’ key (Figure 1) is to align all the cards properly. Considering one character at a time, the user observes the ‘unknown’ specimen and for each character that is applicable to the specimen, a long needle is inserted through the hole representing that character. The cards are then gently shaken to allow those (cards) that are not applicable to the specimen to fall off the needle (those with clipped hole for the character). This process continues, with successive choice of characters in the desired sequence until only one card remains dangling on the needle. The name of the taxon on this card represents the identity of the plant.

The taxonomist applies the body-punched, that is, ‘character-per-card’ key (Figure 2) by first identifying and setting aside all the cards whose characters are observed by him on the ‘unknown’ plant specimen. From these, he selects a few cards at a time, says five, aligns them properly and holds them against a source of light. If more than one hole allows the light to pass through, he selects more of the remaining cards, aligns them with the earlier selected ones and repeats the exercise. At the time when only one of the holes allows the light to pass through, the

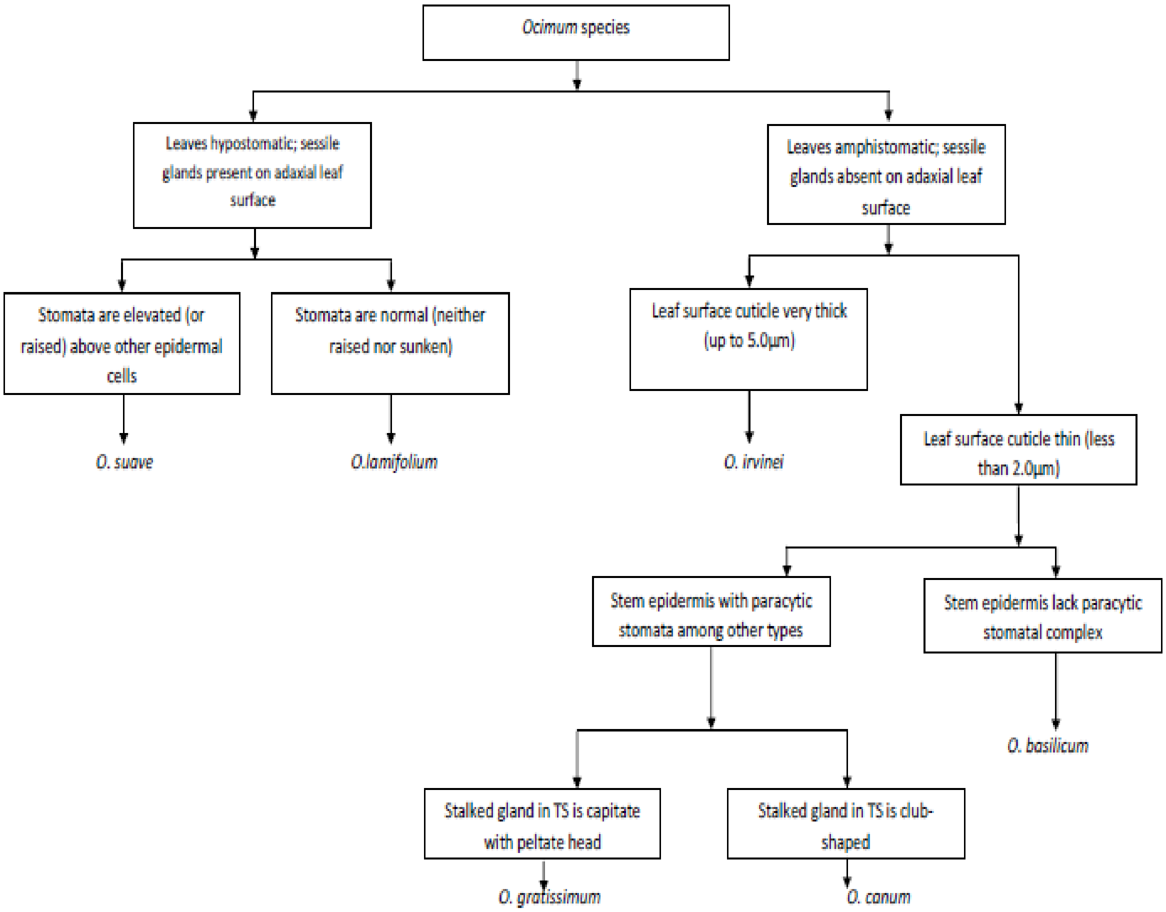

Figure 5. A flow chart key for diagnosing six Nigerian species of *Ocimum.*

identification process is completed. The name of the taxon whose hole allows the light to pass through represents the identity of the plant. The 'species-per-card' type has the advantage that species can be added as time goes on; and additional information in form of notes or images about species can be put on the card.

The punched-card system can be satisfying to use, like a game, especially with large sets of species. One problem however, is that each hole can only represent a 'yes' or a 'no'. So in multistate characters, each state has to be considered as a unit character and assigned a hole. This problem is better appreciated with the observation that only a limited amount of space can be available for characters on a card. Hence, 'species-per-card' packs are best when the number of characters is few. To a certain extent, this problem has been addressed with the use of only one card per character in the method developed by Sinnott (1982) provided there are ten or fewer character states (in a 78 taxa variation) or five or fewer states (in a 156 taxa variation). Another disadvantage is that the loss of a single card may render the pack almost useless, coupled with the requirement that the cards (particularly in the character-per-card arrangement) must be carefully ordered after each use to permit relocation. In order to prevent the pack becoming dispersed, The Virtual Field Herbarium (2000) has recommended some form of loose binding.

Figure 3 shows a columnar diagram key. In order to apply this key format, the user starts by considering first, the statements in the point of entry, that is, the two contiguous bars at the bottom. The acceptance of the statement in one box immediately restricts the user to one of the blocks as the possible provider of the plant's identity. Next, he proceeds to consider the two opposing statements in the two bars on top of the former. Again, this step makes him to drop one and accept the other statement, whose bar serves as a lead to other bars or columns above it with opposing statements. This process continues until only one column is eventually selected. The name at the top of this column gives the identity of the unknown plant.

The graphical key is illustrated in Figure 4. In identifying a plant specimen, one may choose to start with the horizontal or top statement bars, which enable the user to systematically ignore some columns and select others in line with the features of the specimen to be identified.

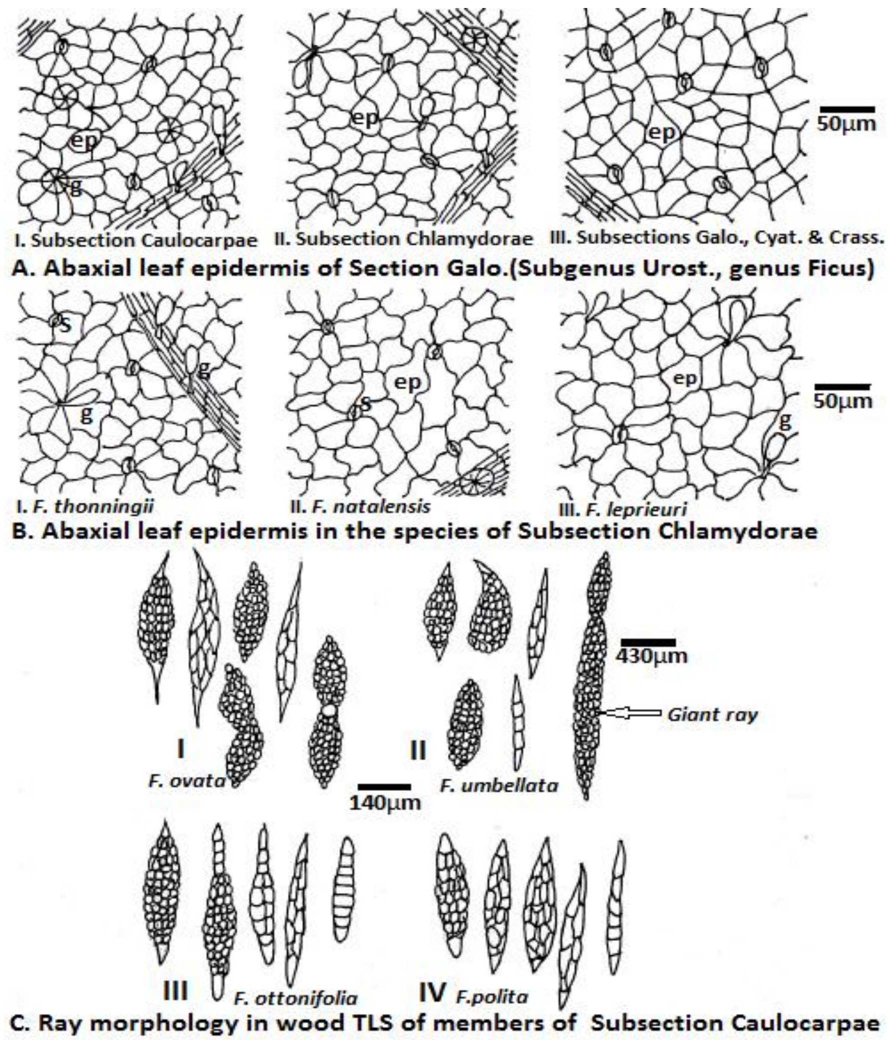

Figure 6. A pictorial diagram key for identification of some Nigerian species of *Ficus*. The key component 'A' distinguishes between the subsections in the section *Galoglychia* [I and II, stomatal complexes (STC) are predominantly with 5, 6, and 7 subsidiary cells (SUC); in I, scales are all in-between the veins; in II, scales, if present, are found on the veins, but other types of glands may occur; III, stomata are predominantly with 3 or 4 subsidiary cells, and glands and scales are absent in-between and on the veins]; Component 'B' separates three species of subsection *Chlamydorae* [I, STC are with 4, 5 and 6 SUC; abaxial epidermal cell walls (ABE) are slightly curved; II, STC also include those with 7 SUC; ABE are wavy; III, STC with 4 SUC are absent; ABE are curved]; and component 'C' diagnoses four species of subsection *Caulocarpae* , in each case the frequency of types of rays shown decreases from left to right.

This procedure eventually leads to a single column of boxes (the possible identities of the specimen). The next task is to pinpoint one out of the selected boxes in which the specimen is located. In order to accomplish this task, the vertical statement bars on the left hand side are followed in a similar way until a single row of boxes is selected. Now the box, which is located at the meeting point of the two axes, should contain the name of the specimen. The graphical key format derives its name from the characteristic vertical and horizontal axes approach for identification.

Figure 5 shows a flow chart key which follows the strict system of two or multiple choices of characters. The choices are laid down in the form of a flow chart, that is, a tree-like scheme of rectangular statement boxes and arrowed branches, which allows easy cross-checking of options. The arrows should be followed strictly after making a choice from the guiding statements. This step normally leads to two or more other statement boxes that require yet another round of choices and so on until

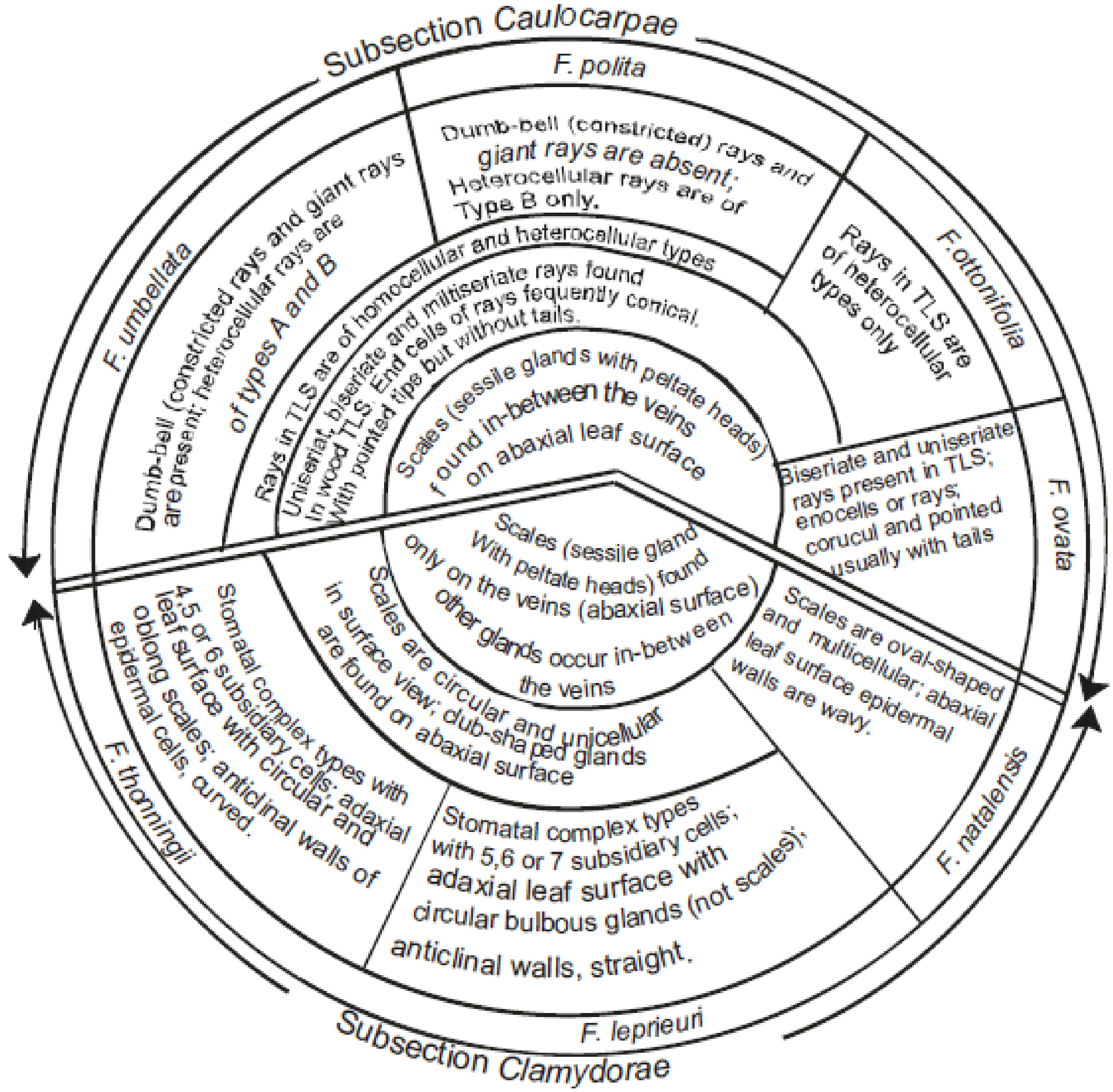

Figure 7. A Circular-diagram key for separating two subsections (*Caulocarpae* and *Chlamydorae*) of the Section *Galoglychia* (Subgenus *Urostigma* of *Ficus*) and for diagnosing some Nigerian species of the two subsections. Types of rays in TLS: heterocellular type A = rays that are pointed at one end; type B = rays that are pointed at both ends; giant ray = ray which is more than twenty times taller than wide.

eventually the arrow points at a name with which the specimen is identified.

In the pictorial diagram type of key (Figure 6), a set of annotated diagrams or photographs of some observable features of plants are displayed in such a way as to allow two or more choices at a point in time. The choices are laid down in a tree-like form for easy comparison with the specimen on hand. The acceptance of one of these illustrations along with its annotation leads the user, with an arrow to one or more other illustrations for yet another round of cross-checking and a choice. As these processes continue, the arrow eventually leads to a diagram or photograph attached with a name (Fishel and Kendig, 2003). This name is usually taken as the identity of the unknown plant specimen. This type of key can be viewed and applied more or less in the same way as the flow chart key, in which the rectangular boxes of statements are replaced by the illustrations (Fishel and Kendig, 2003) (Figures 5 and 6).

A circular diagram key is shown in Figure 7. For the purpose of identification, the user first considers the characters in the two contiguous compartments at the

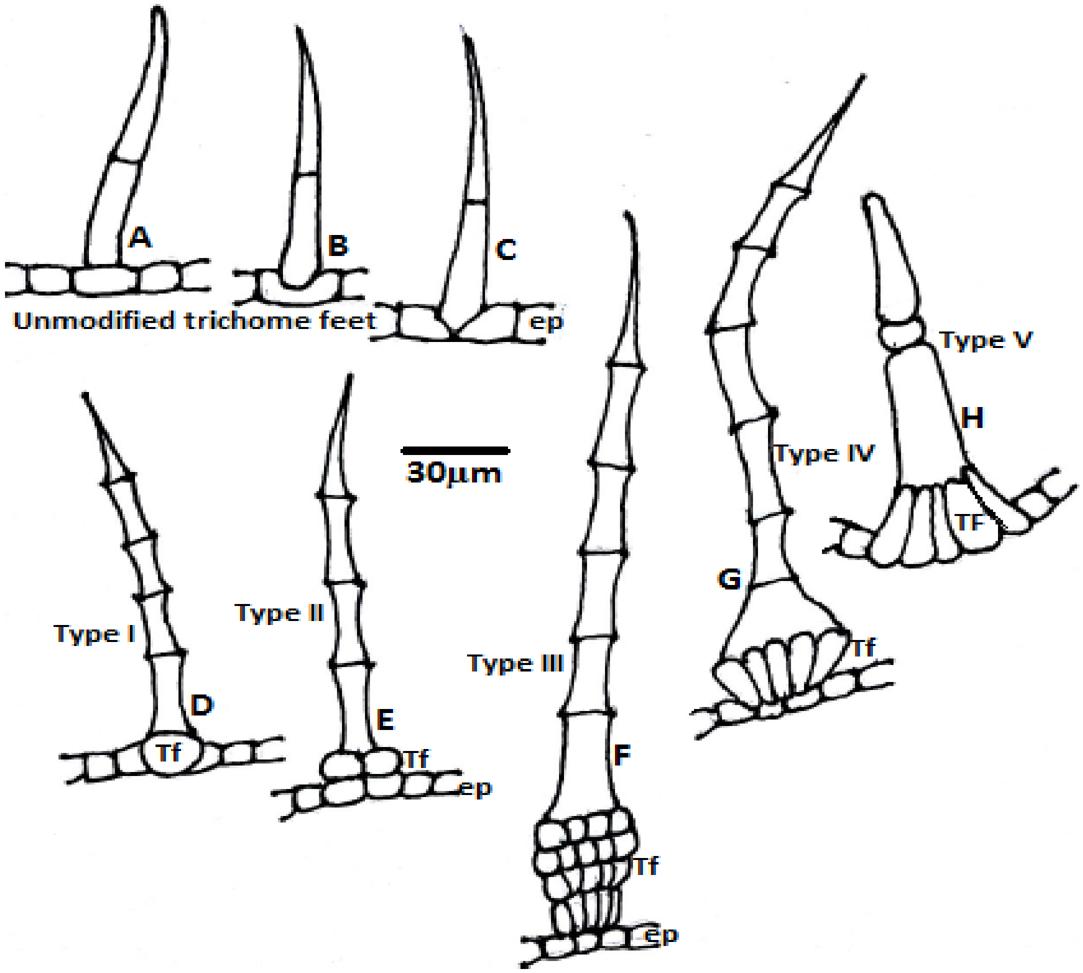

Figure 8. Simple uniseriate trichomes and their feet observed in some Nigerian species of *Ocimum* and *Hyptis*. A-C = unmodified feet in the leaf blades of *O. gratissimum*, *O. basilicum* and *O. canum* respectively; D = Type I foot (leaf blade of *H. suaveolens*), E = Type II foot (leaf blade and petiole of *H. suaveolens*), F = Type III foot (stem of *H. suaveolens*), G = Type IV foot (leaf blade of *H. suaveolens*), and H = Type V foot (leaf blade of *O. lamiifolium*); Tf = trichome foot; ep = epidermal cell.

centre of the circle, proceeding outwards, and following the alternative choices.

The adoption of one of the first two statements or compartments restricts the user to a few of the taxa as the possible identities of the unknown plant. Subsequent steps reduce the number of possibilities until only one name is achieved, referring to the identity of the specimen. Moreover, by proceeding inward from the circumference, the distinctive characters of any taxon in the key may by compiled and this makes it possible for one to confirm the identity of a specimen for which a name has been suspected (Figure 7).

Enhancement of artificial keys

Taxonomists have devised two common means of introducing additional pieces of information to artificial keys to provide further diagnosis of their specimens. These are by the use of panels and by reference to *tabula.* A panel is a short but diagnostic description of each of a number of plant taxa that have been found to share some common characteristics up to certain level through the use of a key. On the other hand, *tabula* refers to botanical illustrations or representations in the form of drawings, photographs or herbarium/live specimens or even video clips. Although such additional information frequently demand some extra efforts on the part of the key user, they nonetheless assist the taxonomist to identify his specimens with little or no reservation. Moreover the use of these facilities to enhance artificial keys, is an attempt to introduce a visual dimension to the practice of plant identification.

Practically, all the types of key formats earlier enume-

Table 9. An artificial key to diagnose the types of uniseriate trichome feet in some Nigerian species of *Ocimum* and *Hyptis.*

1a.	Trichome foot (i.e mode of attachment of a simple trichome to the surface of a plant organ as viewed in transection of the organ) is developed on one or two epidermal cells which are not distinguishable in size, shape or position from the other epidermal cells…………. ……………………..Unmodified foot (Figure 8 A-C)		
1b.	Trichome foot (i.e mode of attachment of a simple trichome to the surface of a plant organ as viewed in transection of the organ) is developed on one or more epidermal cells that have been transformed in a way and distinguished in size, shape and/or position from neighbouring epidermal ells…………….Modified foot (2)		
	2a.	Tichome is seated on a single epidermal cell that is enlarged more than the other epidermal cells…………………………………………………………………………….Modified Type I foot (Figure 8D)	
	2b.	Trichome is seated on two or more cells that are raised (or elevated) above the level of the other epidermal cells……………………………………………………………………………………………………3	
		3a.	Foot consists of two contiguous cells positioned on top of other epidermal cells………Modified Type II foot (Figure 8E)
		3b.	Foot consists of some tiers of many contiguous cells positioned on top of other epidermal cells…..Modified Type III foot (Figure 8F)
	2c.	Trichome is seated on a few cells that are radially elongated…………………………………………………4	
		4a.	Foot consists of elongated cells radiating away from other epidermal cells to the direction of the bottom of the trichome……………………………………………..Modified Type IV foot (Figure 8 G).
		4b.	Foot consists of elongated cells radiating away from the bottom of the trichome to the direction of the other epidermal cells….. …………………………………………Modified Type V foot (Figure 8 H).

Table 10. The users' representative opinions about some qualities of nine taxonomic key formats.

S/N	Key format	Users' familiarity	Usability	Efficiency	Users' acceptability
1	Dichotomous	High	Difficult	Low	Low
2	Numerical	Medium	Difficult	Low	High
3	Graphical	Nil	Easy	High	High
4	Circular-diagram	Nil	Easy	Low	Low
5	Columnar-diagram	Medium	Easy	High	High
6	Punched-card	Medium	Easy	Low	Low
7	Multi-access table	Low	Very difficult	Low	Low
8	Flow-chart	Low	Easy	High	High
9	Pictorial-diagram	nil	Easy	High	Low

rated can be enhanced with panels and/or illustrations. The pictorial diagram key format as it were, can be considered as an enhanced form of the flow chart key (Figures 5 and 6). So also, in the numerical key, additional pieces of information are necessary where more than one related taxa e.g. a genus of some species share the same code. The information, usually enclosed in parentheses, could be in the form of a lead or a pointer to one panel. In the panels, names of the related taxa hitherto sharing the same numerical code are listed in alphabetical order. Their features are also described, sometimes along with illustrations, through which the process of elimination arrives at the name of an individual taxon. This is the numerical-to-panel key (Lowe and Stanfield, 1974).

The chart-to-panel key of Hopkins and Stanfield (1966) represents an enhanced form of graphical key. In this case, instead of the pair of selected axes of a graphical key meeting to point at a species name for instance, they may point at a box containing an alphabet or a number which serves as a lead to one panel or the other. Moreover, Table 9 and Figure 8, illustrate how a dichotomous or polytomous key can be enhanced with relevant drawings or images (El-Gazzar and Watson, 1970).

Enhancement of taxonomic keys has been epitomized through computerization and development of expert systems for identification of living organisms as recorded by scientists such as Bell (2002), Abdulrahaman et al. (2010) and Gueguim-Kana et al. (2012). These efforts have yielded various forms of computer-aided interactive keys with notable merits over the paper-based keys (Dallwitz et al., 2009). At the moment, there are many computer-based internet-enabled interactive keys with

Table 11. Outcome of the users' merit assessment of nine types of artificial key formats.

S/N	Key format	Percent affirmative responses to the statements of assessment															Index of merit*
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
1	Dichotomous	98	4	41	0	61	82	0	0	0	4	0	94	79	1	65	68.3
2	Numerical	0	89	0	72	59	66	0	4	45	58	0	2	66	20	29	59.1
3	Multi-access Table	0	6	48	1	0	0	0	0	0	0	0	84	71	11	44	55.4
4	Punched-card	0	55	0	60	0	41	0	0	56	44	70	62	0	16	52	54.4
5	Columnar diagram	11	0	0	33	0	20	0	72	0	0	0	50	62	22	31	46.8
6	Graphical	0	2	0	2	0	16	6	58	0	0	0	40	54	18	18	29.9
7	Flow-chart	51	15	0	0	0	65	40	52	0	0	0	31	84	10	12	55.4
8	Pictorial diagram	43	19	0	21	0	42	32	60	0	0	0	4	60	10	6	38.0
9	Circular diagram	15	0	1	19	0	4	0	88	0	0	0	38	66	31	22	48.7

*Index of merit = weighted mean of % of responses. The alphabets A, B, C to O are the codes assigned to the guided statements of assessment of taxonomic key formats as listed in Table 1.

hyperlinks for identification of various groups of plants, animals, microbes and pollen (LPP Foundation, 1999; Monteith, 2000; UNL Nematology Laboratory, 2002; Richter and Dallwitz, 2009; Botany.com, 2010).

Other uses of taxonomic keys

Diagnostic keys are commonly used for identification of plants, animals, microbial organisms, fossils, soils and other biological entities (Marshall, 2000; Soil Survey Staff, 2010). If looked from a general point of view, taxonomic key refers to a way in which classified information is presented (Bauholz, 2013). Going by this definition, a taxonomic key should be found useful in all human endeavors where information is utilized. It can therefore be used to characterize both biological and non-biological entities, or situations alike. It is being adopted, albeit subtly, as a viable tool in organizational decision making process (Gelder, 2010) and in other forms of diagnoses and rational decision making such as in pest control and forensics (Marshall, 2000). Moreover, there is ample evidence that the decision making skills of health diagnosticians (medical doctors, dentists, pathologists e.t.c.) are used to match the facts (or information) of particular case to a diagnostic category (Foucar, 2001; Croskerry and Nimmo, 2011).

The mark of an expert is to seek for precision in each class of things, that is to make better decision and reduce diagnostic error. His ability to make use of diagnostic keys will therefore enhance his thinking skills and ensure rational decision making. In the face of current technological development, training in the construction and use of diagnostic keys can be a good starting point for all professionals for the development of computer-based expert systems to enhance their productivity.

In alpha taxonomy (El-Gazzar and Watson, 1970) descriptive ecology and biodiversity studies, diagnostic keys have been employed for vivid and unambiguous description of observed structures or phenomena; and any type of key format can be used for this purpose. As an illustration, Table 9 and Figure 8 gives a lucid description of the types of uniseriate trichome feet as observed by Ogunkunle and Oladele (2000) in the petiole, leaf blade and stem transections of some Nigerian species of *Ocimum* and *Hyptis*.

Users' assessment of some taxonomic key formats

Table 10 gives the representative opinions of all the respondents about some properties of the nine key formats investigated. The most familiar of the nine was the dichotomous key format while the respondents had no familiarity at all with the graphical, circular diagram, columnar diagram and the pictorial diagram formats (Table 10). According to the respondents, most of these key formats were easy to apply with the exception of the dichotomous, numerical and the multi-access table. Efficiency was acknowledged by the users to be high in the graphical, columnar diagram, flow chart and the pictorial diagram keys but low for the others.

The results of the merit assessment of the nine artificial key formats by the users are shown in Table 11. The key formats can be listed in decreasing order of index of merit as dichotomous (68.3%), numerical (59.1%), multi-access table (55.4%), punched-card (54.4%), circular-diagram (48.7%), columnar-diagram (46.8%), pictorial-diagram (38.0%) and graphical key (29.9%).

This study has revealed that the dichotomous key format is the most frequently applied and the type to which users of taxonomic keys are most familiar (Table 10). More often than not, a systematist in describing what a taxonomic key is, simply defines a dichotomous key. Sharma (1993), while introducing the topic "Identification with Keys" implicitly described the dichotomous type of key when he defined "a key as an artificial arrangement or analytical device whereby a choice is provided between two contrasting statements resulting in the acceptance of one and the rejection of the other". He further described a single pair of contrasting statements in a key as a couplet and referred to each statement in a couplet as a lead.

Similarly, Olorode (1984) defines a key as a device in which a few characteristics of the plants are so arranged that the features of a known and an unknown plant could be compared in a systematic manner. These submissions are true for the dichotomous key format than for any of the other eight examined in this study. Furthermore, most of those taxonomic publications with keys for the identification of selected groups actually, are catalogues of data presented in the form of dichotomous keys (Hutchinson and Dalziel, 1963-1972; Keay, 1989*).* The foregoing point to the fact that the taxonomic key as hitherto used in botanical literature and circles is synonymous with dichotomous key. This study has however established that other forms of artificial keys also do occur which might equally be usable or more usable than the familiar dichotomous type. It has thus exposed the practicing taxonomist to those available tools from which he can choose to achieve the desired goal.

Of the nine artificial types of keys examined, the widely recognized dichotomous key was among the three that were of low efficiency and tedious to navigate, the other two being the numerical key and multi-access table of identification. In spite of these flaws, the respondents' assessment gave a 68.3% index of merit to the dichotomous key format, putting it over and above all the other eight. This may appear strange, but is understandable; the respondents were not familiar at all with most of the key formats and could expectedly be as critical as possible, only in the assessment of that format to which they have been exposed right from their elementary bio-logy classes (WAEC, 1998-2000). There is little wonder therefore that the dichotomous key arrangement was also the generally acceptable among the supposed users of keys (Table 10).

The results of assessment of the keys have two implications. Firstly, that no single key format is superior to the others; the choice is a function of the availability of the device to the user, the condition of the specimen for identification, the working situation or environment and the exposure level or experience of the user with regards to the key formats. Secondly, the results have brought into limelight those areas of strengths and weaknesses of the taxonomic key types, which are important for consideration in the choice of a format, and which in addition might be helpful towards improving their qualities for better performance. The study therefore affords the taxonomist that opportunity of choosing from a list of instruments for identifying his plants.

Going by these results, the widely accepted dichotomous type of key surpassed the other formats in merit, but then, it is still far from the ideal tool for identification with respect to the expectations in this investigation. The difficulty often encountered in the construction and usage of this key format, especially with the involvement of a large group, is one notable area of its weaknesses. Perhaps this is incidental to the situation that makes people dread the use of keys as indicated by the results of this study. Generally, very few (6.0%) of the respondents frequently used keys while 66% sometimes did. Majority of the latter group often visited herbaria and research institutes where other professionals assisted them in identification.

Another point for noting is that the dichotomous key format is difficult, if not impossible to automate in such a way as for the computer to capture and manipulate generalized information on plant specimens (Okeyinka and Ogunkunle, 2002). If this were readily possible, systematists would be free from laborious process of key construction and tedious character-matching and perusal of volumes that characterize the use of dichotomous keys. On the other hand, multi-access keys, especially in the form of computer-aided interactive devices have advantages over the single-access keys, some of which have been enumerated. With paper-based dichotomous keys, the discovery of a new species renders the key incomplete, while computerized keys are easily updated by adding information for newly discovered species and/or additional diagnostic features, and reposting computer files as appropriate.

CONCLUSIONS AND RECOMMENDATION

This study has collated the hitherto fragmentary pieces of information on nine types of paper-based taxonomic keys usable for plant identification. It has thus generated a handy tool for teaching and research in plant science. The paper has also presented diagnostic data from epidermal and wood anatomical sources on some Nigerian species of *Ocimum*, *Hyptis* and *Ficus* that may be helpful in identifying these potentially useful plants in medicinal, chemical and wood-based industries. Lastly, the paper has reported the outcome of an assessment of the qualities and potentials of the types of keys from the users perspective; and has established that the widely accepted dichotomous key format is still far from an ideal tool for plant identification. Taxonomists should therefore avail themselves of the other available key formats apart from the dichotomous type, and venture into designing new formats that might be more usable. In this direction, those key formats that can readily be electronically programmed and developed into computer-based interactive applications should be given due priority.

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