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# REVIEW

# Research trends and perspectives on African orchids: a bibliometric overview

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**Tendances et perspectives de la recherche sur les orchidées africaines : Synthèse bibliométrique**

**Résumé** : Les publications scientifiques mondiales sur la famille très diversifiée des Orchidaceae sont assez nombreuses, mais l'engouement en Afrique pour ce taxon s'est fait sentir il y a seulement quelques décennies. Cette famille de plantes à fleurs très large et menacée est largement répandue dans les zones tropicales et est reconnue par plusieurs auteurs pour son importance environnementale, ornementale et médicinale. Cette revue de littérature vise à identifier les types de recherches scientifiques conduites sur les orchidées africaines en utilisant l'analyse de co-citations et la visualisation des informations bibliométriques. 386 publications concernant les orchidées africaines répertoriées dans la base de données Scopus de 1968 à Mai 2020 ont été analysées. La description de nouveaux taxons d'orchidées, l'adaptation des orchidées à divers pollinisateurs et la phylogénie ont émergé comme les aspects les plus discutés. Au total, 889 auteurs ont investi dans la recherche sur les orchidées en Afrique. Johnson Steven D. a été l'auteur le plus remarqué dans les discussions scientifiques sur les orchidées d'Afrique avec l'indice h-index (37) le plus élevé. Fait intéressant, plusieurs institutions ont été impliquées dans ces études avec une large prédominance de l'Université du KwaZulu-Natal, une université sud-africaine. Les recherches futures devraient s'appesantir sur l'identification de nouvelles espèces d'orchidées et mettre davantage l'accent sur la distribution, l'écologie et les menaces des orchidées. Elles devraient également se concentrer sur le développement de stratégies efficientes de gestion et de domestication des espèces d'orchidées afin de réduire les menaces pesant sur cette famille. La restauration et la planification de la conservation des habitats dégradés des orchidées sont des pistes supplémentaires à explorer par les recherches futures.

**Mots clés :** Orchidées, tendance de la recherche, thèmes de recherche prioritaires, Afrique.

**Abstract**: Worldwide scientific publications on the remarkably diverse Orchidaceae family are comprehensive, but Africa's craze for the taxon was only felt a few decades ago. This largest and threatened family of flowering plants is widely distributed in tropical areas and recognized by several authors for its environmental, ornamental, and medicinal importance. This review aims to identify research patterns on African orchids using co-citation analysis and bibliometric information visualization. 386 publications concerning African orchids listed in the Scopus database from 1968 to May 2020 were recorded and reviewed. The description of new orchid taxa, the adaptation of orchids to various pollinators and phylogeny emerged as the most discussed aspects. In total, 889 authors have invested in research on orchids in Africa. Johnson Steven D. was the most

impactful author with h-index 37. Interestingly, several institutions were involved in these studies with a large dominance of the University of KwaZulu-Natal, a South African University. Future research efforts should target the identification of new orchid species and emphasize on orchid distribution, ecology, and species' threats. They should also focus on developing efficient management and domestication strategies for orchid species to reduce threats to this family. The restoration and conservation planning of degraded orchid habitats are additional avenues to be explored by future research.

**Keywords:** Orchids, research trend, priority research topics, Africa.

# 1. Introduction

Africa is a continent of diverse vegetation systems, from tropical moist forests to deserts, that have undergone major changes over geological time periods. However, little is known of its orchid flora. Orchidaceae is one of the largest flowering plant families worldwide (Cozzolino & Widmer, 2005). It is an exceptionally diverse plant family comprising 25,000 to 30,000 species (almost 8% of the angiosperm species), distributed in approximately 1,000 genera, and in a large range of ecosystems around the world (Swarts & Dixon, 2009; Willis, 2017). However, the number of recognized orchid species is highly contentious, and taxonomists opinions may differ around the world (Vereecken et al., 2011).

In addition to the beauty of their flowers, orchids are recognized for several ecosystem services they provide. They are famous and used in several regions by local populations for their ornamental, cultural, environmental, nutritional, and medicinal properties (Subedi et al., 2013; Assèdé et al., 2017; Tsering et al., 2017). However, they are part of the most threatened taxonomic groups worldwide (Acharya & Rokaya, 2010; Wraith & Pickering, 2019). Indeed, because of their complex ecology based on interactions with other species (fungi, pollinators...), their disturbed habitats and overexploitation, more than 600 species of orchids are now listed as endangered on the global database of threatened species known as the International Union for the Conservation of Nature Red List (IUCN, 2017; Wraith et al., 2020).

In Africa, the interest in this taxon is recent, especially in the east and west of the continent. Orchids pollination, taxonomy, or ethnobotany have received most attention (Peter & Johnson, 2014; Van der Niet et al., 2015; Assèdé et al., 2017, 2018; Boukehili et al., 2018; Balducci et al., 2019). In South Africa and neighboring countries, botanical exploration, University research, and various orchid and wildflower societies, generated much interest in orchids and contributed to the development of accounts and illustrated guides to wild orchids of southern Africa, with the first accounts published in 1888 (Bolus, 1888) and 1912-1913 (Stewart et al., 1982). Research on orchids in Africa is therefore at its beginnings and a synthesis on the progress already made, the various aspects tackled and the contribution of African authors and institutions for the evolution of knowledge in this field will help in identifying important gaps and research priorities on the continent. In spite of extensive work on orchids worldwide, African orchids seem always subject to major conservation issues (Assèdé et al., 2018). Appropriate research questions for sustainable orchid conservation requires evaluation of the relevance of the current research on the continent.

Existing literature reviews on the subject specifically relate to the progress made in ethnobotany (Chinsamy et al., 2011; Bhattacharyya & van Staden, 2018), the pollination of orchid species (Jersakova & Johnson, 2006; Micheneau et al., 2009; Van der Niet et al., 2015), and their taxonomy (Sanford & Adanlawo, 1973; Vermeulen, 1987; Linder, 1995; Pillon & Chase, 2007; Droissart et al., 2014; Simo-Droissart et al., 2018; Phillips & Bytebier, 2020). Therefore, it is essential to adopt a more global approach on studies concerning orchids in Africa and to identify future directions for scientific research in this area.

This paper aims to review the available research on orchids in Africa through a bibliometric synthesis and identify research gaps for the sustainable conservation of African orchids. Specifically, it addresses the following questions: (1) What is the current trend in the number of publications over time on African orchid species? (2) What are the key research topics covered? (3) Who are the most influential authors and what are the specific contributions from African institutions? (4) In what direction is orchid research trending and what are the potential priorities for future research?

# 2. Material and methods

## 2.1. Data collection

Bibliometric data and publications on African orchids were collected using the Scopus search engine in

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May 2020. Scopus includes a large range of high-impact and international academic journals (Leydesdorff et al., 2010) covering various field from botany to engineering. Scopus represents also one of the largest databases on scientific literature (Djalante, 2018), with nearly 70 million of the world's leading publications. It provides wide-ranging access to bibliographic and citation information (Wraith et al., 2020) for high-quality articles. The most studied components of a bibliographic record are keywords, authors, authors affiliations (institutions and countries), year of publication, and journal in which a document is published (Noyons, 2001). Thus, the first step consists in the search for relevant articles using a combination of key search terms. We searched for publications having the words "orchidaceae, orchid or orchids" in their titles, abstracts, or keywords, without restriction to the publication period. The search results were subsequently restricted to publications concerning the 55 member's states of the African Union (http//au.int/fr), categorized as scientific papers, and written either in English or French. Hence, a total of 386 publications were identified, spanning from 1968 to May 2020. The results were downloaded in BibTeX and CSV formats for further processing and analysis.

## 2.2. Data analysis

Bibliometric data recorded (including references of the 386 identified publications), were analyzed to extract the potential knowledge contained in the scientific literature. The results were visually presented using the Bibliometrix package (Aria and Cuccurullo, 2017) and its web-interface "biblioshiny" (based on R version 3.6.1). Bibliometrix is one of the most suitable R packages for bibliometric analyses of Scopus data (Janik *et al*. 2020) and its use has been considerably simplified in recent years with the development of the biblioshiny app. Bibliometric analysis is a "meta-review" technique of the literature (Fetscherin et al., 2010) based on linkages between and among articles, and with the capabilities to derive the relative impact of theoretical frameworks, authors, or institutions in the reviewed research field.

Trends in the number of publications over time (1968 to 2020) on African orchids associated with the related global citation dynamics were plotted (Fig. 1), with x-axis representing the year of publication and y-axes 1 and 2 representing the number of publications and global citations respectively. A comprehensive overview coupled with a correspondence analysis of recorded literature were performed to identify the relevant research topics. Cluster view based on the occurrence of the most used keywords in the literature as well as the annual number of publications on major research topics were considered. We used "keywords plus" as units of analysis as they are believed to better represent the knowledge structure of each document and interlinking of different research topics (Tripathi et al., 2018). In contrast to author keywords, "keywords plus" are automatically generated by an algorithm from the titles of the references cited in the documents and are usually more informative than keywords from authors (Zhang et al., 2016).

The most prominent authors and the contributions from African institutions in the study field were evaluated based on the total number of publications to their credit, as well as the total global and total local citations of these publications (h-index). Global citations are the number of times a scientific paper was cited globally reflecting its overall impact on academic research, while local citations refer to the number of times an article has been cited by other articles within the same database (i.e. the 386 publications retrieved on the topic). Country production (number of publications) was determined using the country of the first author.

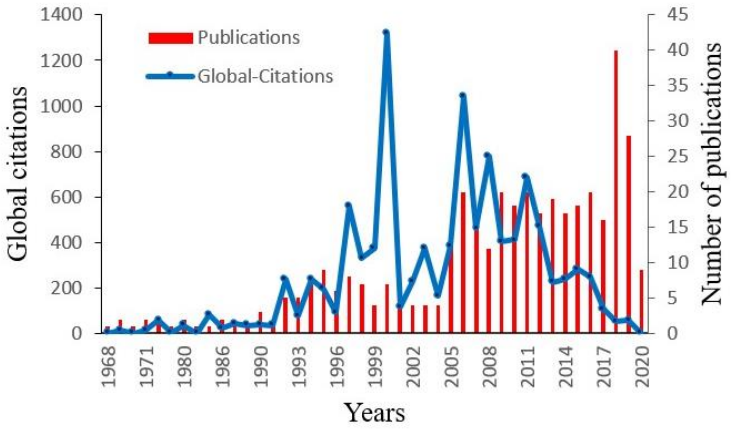


Fig. 1 Evolution of the number of scientific publications and total global citations on African orchids from 1968 to May 2020.

Fig. 1 Evolution du nombre de publications scientifiques et des citations mondiales totales sur les orchidées africaines de 1968 à Mai 2020.

We discussed emerging trends, interesting research directions and perspectives on African orchids from the comprehensive analysis of the information in the publications of the last 5 years (2016-2020).

## 3. Results

### 3.1. Evolution of the number of publications on African orchids

Dynamic trends of the studies on African orchid species on the continent exhibited a general increasing trend over the years (Fig. 1). It should be noted that data from the year 2020 were incomplete as the publications were retrieved only until May 2020. From a macro-overview, this dynamics in the field over time can be subdivided into three major periods. An initial development stage occurred from 1968 to 1991. The worldwide research on African orchids during this period was extremely limited with less than 5 publications and up to 84 total global citations. The second stage between 1991 and 2005 of slow development of the research on the topic exhibits an overall upward trend of the influence of articles on African orchids. However, scholars' publications were still low (under 10 publications per year). The last stage, characterized by a rapid development, extends from 2005 to present. There is a substantial increase in the number of publications by the international community on African orchids, as well as an increasing influence yearly. The number of new publications and citations each year reached 40 and 1040 respectively, with an average of 19 publications cited worldwide 391 times. However, in general, small to great fluctations were observed in some areas over time and new research areas emerged. The most relevant disciplines in which publications on African orchids are developed included agronomy and biological sciences (352 publications), biochemistry, genetics, and molecular biology (64 publications) and environmental sciences (44 publications).

The most cited authors on African orchids and their citation network are presented on Figure 2. Three groups of frequently co-cited authors were demarcated and the most cited authors were Johnson S.D., Linder H.P. and Dressler R.L.

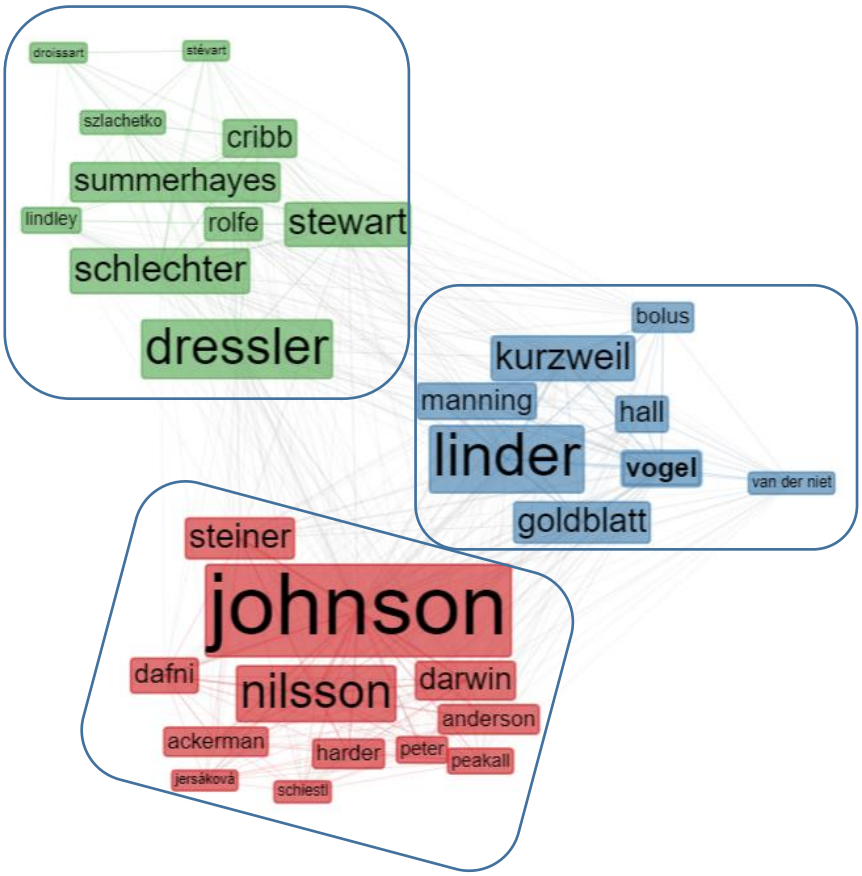


Fig. 2 Co-citation network of the 30 most cited authors on African orchids. The size of each rectangle is proportional to the number of citations of an author. The lines establish citation relations between the rectangles. The colors surrounded by a box indicate the three groups of authors frequently cited together.

Fig. 2 Réseau de co-citations des 30 auteurs les plus cités sur les orchidées africaines. La taille de chaque rectangle est proportionnelle au nombre de citations d'un auteur. Les lignes établissent les relations de citation entre les auteurs. Les couleurs entourées d'un cadre indiquent les trois groupes d'auteurs fréquemment cités ensemble.

### 3.2. Analysis of key research topics

Key research terms related to the annual occurrence of the most frequent keywords in the publications about African orchids, included phylogeny and pollination (Fig. 3). Most of the advanced research on the topics were carried out in South Africa hence the presence of these research terms (phylogeny and pollination) as one of the most frequent keywords. Research around these different terms, in line with the research priorities in the field, increased between 1999 and 2010 (Fig. 3). Noteworthy is that research on taxonomy and species diversity of orchids are included in the term "Orchidaceae" which presented the highest occurrence (326) and have attracted the most scientific attention. The research also includes the taxonomic description of several orchid species mostly endemic to South Africa.

In general, the research interest on African orchids can be divided into two major groups (Fig. 4). The first and largest group is centered on taxonomy, biodiversity, and phylogeny of orchid species. Research on these themes provided the baseline for understanding orchid taxa. Efforts in this field were mostly focused on gathering knowledge on orchid diversity through systematic inventory and classification, phylogeny and genetics. This was an advanced research step on the conservation of African orchids through the study of their evolutionary history. The second group deals with the pollination processes of orchids, notably the diversity of pollinators and the mechanisms of orchid pollination. Research in this group aimed at understanding the reproduction processes of African orchids and the interconnections (or linkages) between the pollinators and their corresponding orchid plants. This category demonstrated that the complexity in orchid reproduction process has always been a concern, even on the African continent. It highlighted the different mechanisms of deception in orchids.

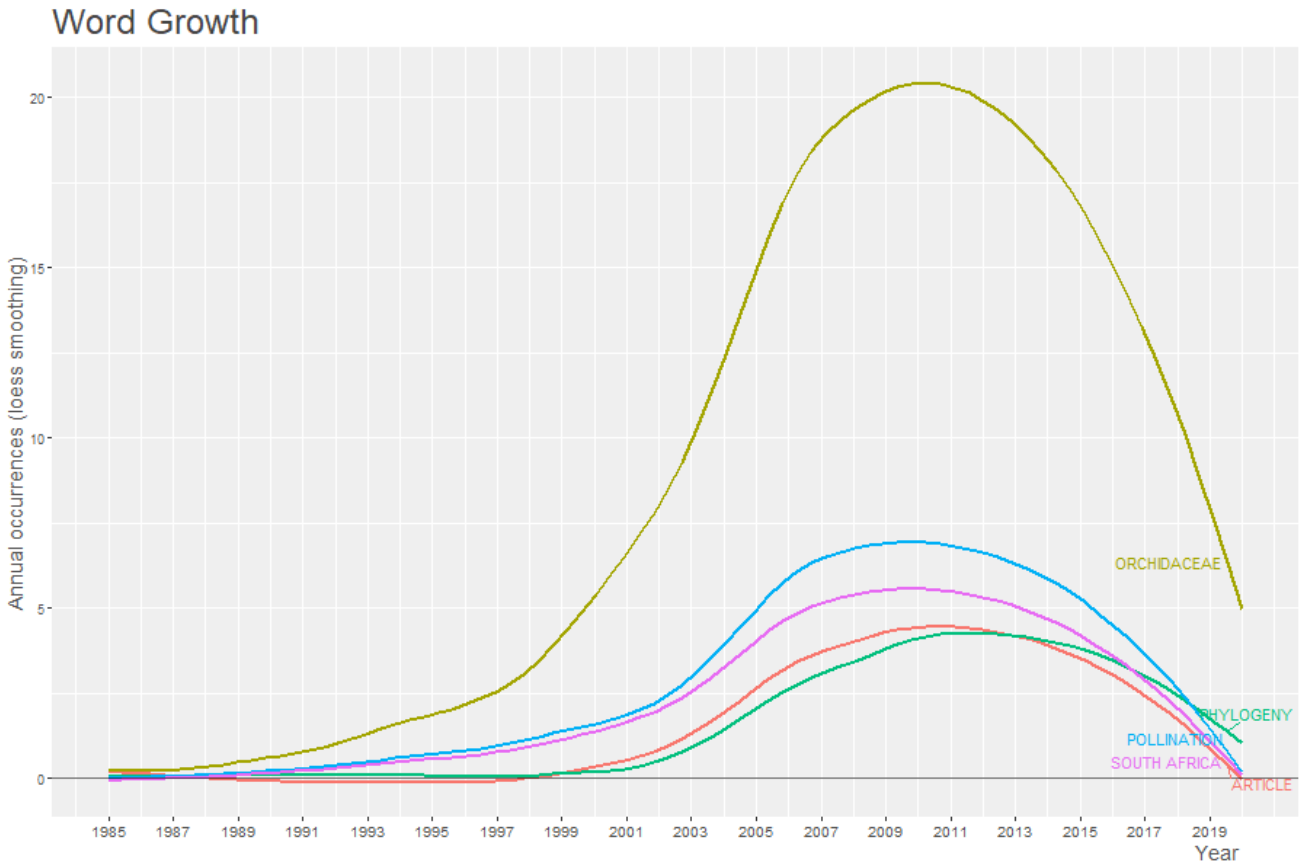


Fig. 3 Annual occurrence of the top 5 key terms (Scopus keywords plus) in the publications about African orchids.

Fig. 3 Occurrence annuelle des 5 principaux mots clés (mots clés autogénérés par Scopus) dans les publications sur les orchidées africaines.

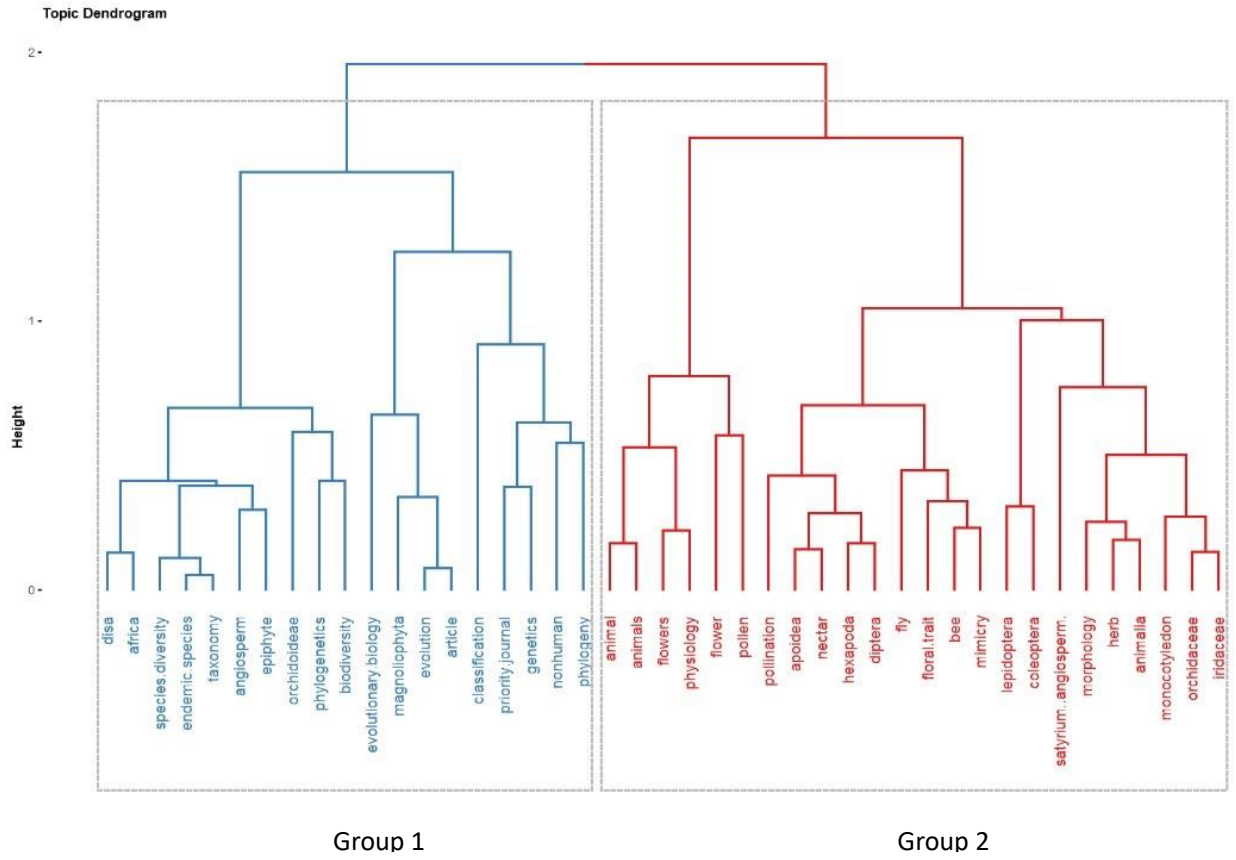


Fig. 4 Topic clustering dendrogram of publications on African orchids: Group 1= Taxonomy and phylogeny; Group 2= Reproduction processes of orchids.

Fig. 4 Dendrogramme montrant les groupes thématiques des publications sur les orchidées d'Afrique : Groupe 1 = Taxonomie et phylogénie ; Groupe 2= Processus de reproduction des orchidées.

### 3.3. Most influential authors and specific contributions from African countries and institutions

There is a great diversity of authors who collaborated to advance research on African orchids. In total, 889 authors and co-authors were invested in around 1400 research publications (including references from the downloaded publications) on African orchids in the last 50 years. Sixty-one (61) countries were represented, with the top ten (10) publishing 84% of the recorded documents (Tab. 1). South Africa produced most of the research output with 34.7% of the publications in the last 50 years, followed by France (9.8%), and Belgium (7.8%) (Tab. 1).

Table 1. Numbers of publications on African orchids from the top ten countries

Tableau 1. Nombres de publications sur les orchidées africaines des dix premiers pays

| Countries | Number of Publications | Percentage (%) |
|---|---|---|
| South Africa | 482 | 34.7 |
| France | 137 | 9.8 |
| Belgium | 109 | 7.8 |
| Cameroon | 102 | 7.3 |
| USA | 86 | 6.2 |
| China | 77 | 5.5 |
| UK | 64 | 4.6 |
| Germany | 43 | 3.1 |
| Madagascar | 35 | 2.5 |
| Sweden | 33 | 2.4 |
| Total (top 10) | 1168 | 84.1 |

The strongest collaborations were developped between South Africa, the United States (USA) and Switzerland on the one hand, and between Cameroon, Belgium and France (Fig. 5). Clearly, South Africa has more collaborations than any other country on research topics related to orchids.

Regarding the top authors, Johnson Steven D., who started working on African orchids in 1992, was the most impactful author with the highest h-index (37). He produced 6.3% of the total publications, and recorded 9% of the total citations (Tab. 2). He is followed by Stevart T. and Droissart V. H9owever, the publications of the latter two authors received less than 1% of the total citations (Tab. 2). Based on the search on Scopus database, the first paper on African orchids was published in 1968 by Hall A.V. who described the South African species of the genus *Eulophia*.

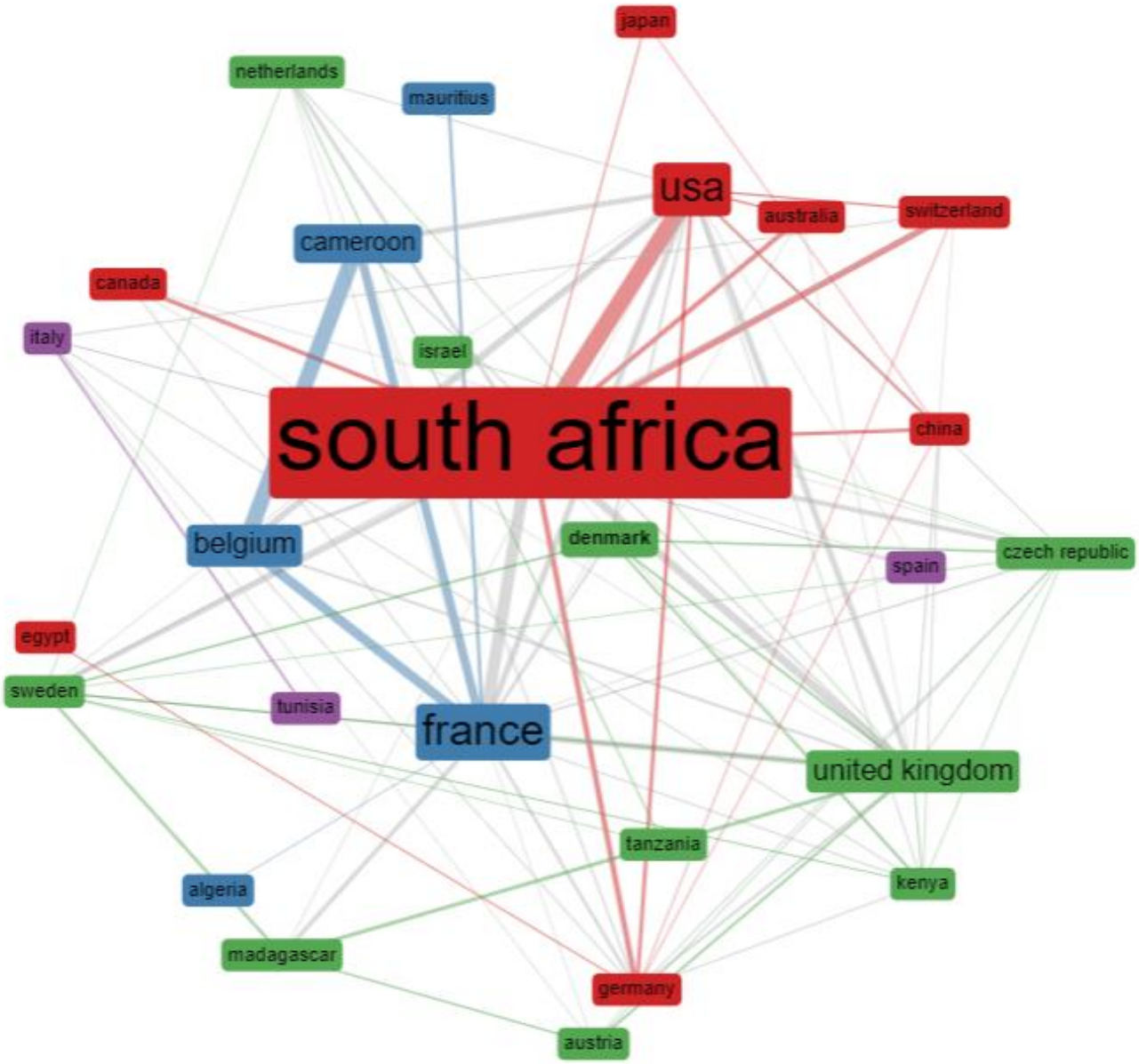


Fig. 5 Country collaboration network on African orchids. The size of each rectangle is proportional to the number of collaborations in which a country is involved. The size of the lines connecting the countries denotes the strength of their collaboration. The colors indicate the groups of countries involved in the same collaboration networks.

Fig. 5 Réseau de collaboration des pays sur les orchidées africaines. La taille de chaque rectangle est proportionnelle au nombre de collaborations dans lesquelles un pays est impliqué. La taille des lignes reliant les pays dénote la force de leur collaboration. Les couleurs indiquent les groupes de pays impliqués dans les mêmes réseaux de collaboration.

Table 2. Total number of publications and total number of citations of the top 10 authors on African orchids

Tableau 2. Nombre total de publications et nombre total de citations des 10 principaux auteurs sur les orchidées africaines

| Author | h index | Total Citations | Percent total citations | Number of Publications* | Percent number of publications | Year of the author's first publication |
|---|---|---|---|---|---|---|
| Johnson S.D. | 37 | 4098 | 9 | 101 | 6.3 | 1992 |
| Stevart T. | 8 | 152 | 0.3 | 32 | 2 | 2004 |
| Droissart V. | 8 | 140 | 0.3 | 30 | 1.8 | 2006 |
| Bytebier B. | 11 | 500 | 1.1 | 29 | 1.8 | 2005 |
| Linder H.P. | 14 | 980 | 2.2 | 25 | 1.5 | 1990 |
| Sonke B. | 8 | 131 | 0.3 | 23 | 1.4 | 2001 |
| Simo-Droissart M. | 4 | 45 | 0.1 | 18 | 1.1 | 2013 |
| Kurzweil H. | 9 | 396 | 0.9 | 17 | 1.1 | 1990 |
| Peter C.I. | 12 | 678 | 1.5 | 16 | 1 | 2003 |
| Van Staden J. | 10 | 211 | 0.4 | 16 | 1 | 1987 |
| Total | | 7331 | 16.2 | 307 | 19.1 | - |

* The table is ordered by decreasing number of publications of the authors / Le tableau est classé par ordre décroissant du nombre de publications des auteurs.

Concerning the institutions, a total of 332 institutions around the world were involved in research on African orchids and developed various aspects. These include orchids pollination, mycorrhization, taxonomy, ethnobotany, and phylogeny. They also addressed conservation measures. Clearly, research on African orchids was dominated by South African institutions (i.e., University of Cape Town, Stellenbosch University, Rhodes University and the University of KwaZulu-Natal, which is part of the University of Natal; Tab. 3). The two most productive institutions in Africa were the South African University of KwaZulu-Natal, and the Cameroon University of Yaoundé I, with 15% and 4.3% of the total publications respectively.

Table 3. Top 10 institutions and their recorded scientific publications on African orchids

Tableau 3. Top 10 des institutions et leurs nombres de publications scientifiques sur les orchidées Africaines

| Affiliations | Number of publications | Percentage (%) |
|---|---|---|
| University of Kwazulu-Natal, South Africa | 199 | 15.2 |
| University of Yaounde I, Cameroon | 56 | 4.3 |
| University of Cape Town, South Africa | 45 | 3.4 |
| Université Libre de Bruxelles, Belgium | 37 | 2.8 |
| Stellenbosch University, South Africa | 33 | 2.5 |
| Université de la Réunion, France (African island) | 31 | 2.3 |
| National Botanical Institute, South Africa | 23 | 1.7 |
| Rhodes University, South Africa | 19 | 1.4 |
| University of Natal, South Africa | 17 | 1.3 |
| University of Zurich, Switzerland | 16 | 1.2 |
| Total | 476 | 36.5 |

## 3.4. Research perspectives on African orchids

The selection of most recent publications from 2016 to 2020 resulted in 97 studies, representing more than 30% of the total scientific research on African orchids. These studies discuss many priorities for future orchid research, including three major flagship topics. In the first-place, future research should investigate the diversity and distribution of orchids, with continued efforts on botanical inventories for a better understanding of the diversity of orchid species, and studies on the factors that govern the variation in the frequency of natural hybridization between orchid species.

The second priority research topic concerns the need for research to investigate on the ethno-pharmacology of medicinal orchid species, with a focus on raising awareness about the uses of medicinal orchids and their economical incidence. Indeed, very little information is available on the use of orchid species in traditional medicine in Africa despite the great number of orchid species endemic to Africa (Grobler, 2005; Linder et al., 2005; Droissart et al., 2006), and the dependance of African people on natural resources for their livelihood (Ansoms & Marysse, 2011; Assèdé et al., 2017). Moreover, valuable phenolic compounds and the natural antioxidant potential of some orchid species should be better considered for medical advancements.

The third topic that requires more attention is the conservation of orchids, including advancing research on vegetative propagation, artificial regeneration protocols, and micro-propagation for conservation purposes. The benefit of using the in vitro collection method in integrated action plans for orchid conservation should also be further examined. Also, the redefinition of the protective management strategies for orchids and their inclusion in large numbers on the World Red List of the International Union for Conservation of Nature (IUCN) will help improving orchid conservation in Africa. Regarding the floral morphology of certain orchid species, an in-depth analysis should be carried out about the pollination of orchids by stony butterflies.

The upsurge scientific interest in orchids these last five years also denotes the existence of numerous priority areas for future research. For instance, the increasing number of publications concerning the description of new orchid species suggests the need to reinforce botanical inventories, especially in unprotected areas, habitats for several African orchids (Assèdé et al., 2018). Efforts should also be directed on west and eastern part of Africa as most of the research output analyzed was conducted in the southern part of the continent.

An astonishing aspect of the research conducted so far on African orchids is the scarcity of publications on their ecology. Orchid conservation requires detailed research on their ecology and specific interactions with their environment as local needs cause agricultural land expansion and deforestation, and climatic hazards continue to endanger biological diversity, in and around protected areas. The mitigation of the actual threats to the whole family (CITES, 2020) could be expected only through the development of appropriate conservation plans based on an improved understanding of the relation between orchids and a vast array of environmental factors.

## 4. Discussion

Studies on orchids in Africa have grown rapidly over the past 10 years with the enthusiasm of many authors from various horizons for this specific group of plant species. This enthusiasm is indeed well justified because research all over the world presents orchids as one of the most evolved flowering plant families now endangered (Fay, 2018; Wraith et al., 2020), and yet possessing multiple ecological, medicinal and economic benefits (Kasulo et al., 2009; Pant, 2013). Thus, several disciplines have been impacted as much on the continent as worldwide. A dozen of scientific papers referred to orchid reproduction process (Castro & Singer, 2019), threat and emergency in conservation (Liu & Gao, 2020; Wraith et al., 2020) and the genetic and molecular traits that justify their medicinal and pharmacological properties (Gutiérrez, 2010). So far, very few studies emphasized the specific ecology of African orchids, domestication processes and management plan for habitat restauration. Recent research pointed out major factors contributing to orchids decline, including wildfire and habitat degradation (IUCN, 2017; Wraith & Pickering, 2018; Wraith et al., 2020). This is partly true but also a moot point because of various perceptions. The main question is: How do we know orchid populations are declining if we do not exactly know what drives orchids occurence in different African environnements? Some orchid species suddenly appear and become known after major disturbances, such as a severe fire after a prolonged dry period. The reality is that disturbance-recovery processes, and sometimes quite severe disturbance changes, are part of the natural processes of all vegetation systems (Franklin et al., 2007). It would be interesting to assess how different orchid species have become adapted to different parts of the disturbance-recovery gradient that underlies on the dynamics of different vegetation systems in which orchids are present. It would also be interesting to identify what type of orchid species are specific to different vegetation systems, such as epiphytic *versus* terrestrial orchids, and different types of terrestrial orchids, and how such information would guide conservation management efforts taking account of specific adaptations patterns of various species. Maybe different orchid species and growth forms could be indicators of good or poor management strategies in a global vegetation system.

Overall, the research on African orchids is developed in three main areas, namely taxonomy, reproductive processes and medicinal or pharmacological uses of orchids (Zeng et al., 2016; Possobom & Machado, 2017; Fay, 2018). However, the analysis on the orientation of future research on African orchids suggested that more effort is needed to find yet undescribed species and estimate orchids' species richness in different African natural habitats (Jecmenica et al., 2017; Chimi et al., 2020). The ethnopharmacology of African orchids and the use of medicinal orchids is another priority that has not been the subject of major research (Assèdé et al., 2017; Bhattacharyya & van Staden, 2018; Fonge et al., 2019). The protocols for artificial regeneration, micropropagation, a more complete understanding of mycorrhizal relationship with orchids, pollination mechanisms and orchids inscription on the IUCN red list represent other important research topics to be addressed in the field of orchids' conservation (Dearnaley et al., 2012; Kendon et al., 2017).

The results of the bibliometric synthesis showed that South Africa is one of the most productive and prolific country with the most advanced research on pollination, taxonomy, and phylogeny of African orchids. Interestingly, this part of the continent is described as an exceptionally diverse area, a hot spot and part of a major center of endemism in plant species, including orchids because of its habitat diversity (Travers et al., 2014). An overview of the geological history of the southern part of Africa suggested that the presence of great rifts and swells over geological time periods (Assédé et al., 2020) could explain its high diversity in habitats and thereby in plant species and plant endemism. Nevertheless, other parts of the continent have contributed to the discovery and knowledge of African orchids (Assèdé et al., 2017; Boukehili et al., 2018). A great collaboration was developed between African institutions, and with those from Europe and Asia. A North-South collaboration is much needed because Africa remains the primary focus for field work for several research topics,

while the technology for advanced research is yet to be developed to address the above mentioned issues.

This review exclusively focused on the literature available from the Scopus search engine. Although Scopus is one of the largest scientific databases, with nearly 70 million of the world's largest publications, the completeness of this database cannot be guaranteed because the indexed literature does not take into account the years before 1968 when significant research has been conducted on the topic. For example, several of the publications from South Africa are older than 1968 and described the first orchids species of Southern Africa (see Stewart et al., 1982). Stewart et al. (1982), in their book preface, indicated the publication of Harry Bolus published in 1888 on the account of the Orchids of the Cape Peninsula with 117 species. Also, the first complete accounts of orchids of South Africa were published in 1912 and 1913, and these two publications formed the bulk of Volume V, section 3, of the Flora Capensis, an important set of volumes on the flora of South Africa. Finally, the Scopus database does not cover all available research on African orchids, particularly the grey literature. Despite the difference in the codification of published document databases, efforts to combine multiple databases and library documents will certainly strengthen the results of this study in the future.

## 5. Conclusion

Until now, research on African orchids focused on their taxonomy, species diversity, and the different modes of pollination. Most of the publications were authored by scientists from South Africa and a few countries from the northern hemisphere. This study suggested trending research areas for the advancement of science on African orchids to achieve a better conservation of these threatened species. In particular, future research should continue botanical inventories for the identification of yet to be discovered orchid species, and increasingly focus on the ecology, artificial regeneration and micro-propagation of orchids to guide restauration and conservation planning. Furthermore, efforts should be directed towards the development of domestication processes to reduce threats. It is expected that this study will help to gear scientists towards the important lines of research on African orchids.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## REFERENCES

Acharya K. P. and Rokaya M. B. 2010. Medicinal orchids of Nepal: are they well protected?, *Our Nature*, 8 (1), pp. 82–91. doi:10.3126/on.v8i1.4315

Ansoms A. and Marysse S. 2011. *Natural Resources and Local Livelihoods in the Great Lakes Region of Africa*. Springer. doi:10.1057/9780230304994

Aria, M. and Cuccurullo, C. (2017) bibliometrix: An R-tool for comprehensive science mapping analysis, Journal of Informetrics, 11(4), pp 959-975. https://www.bibliometrix.org

Assédé E. S. P., Azihou A. F., Geldenhuys C. J., Chirwa P. W. and Biaou S. S. H. 2020. Sudanian versus Zambezian woodlands of Africa: Composition, ecology, biogeography and use, *Acta Oecologica*, 107, pp. 103599. doi:10.1016/j.actao.2020.103599

Assèdé E. S. P., Djagoun C. A. M. S., Azihou A. F., Kouton M. D., Gogan Y. S. C., Geldenhuys C. J., Chirwa P. W. and Sinsin B. A. 2017. Folk perceptions and patterns of use of orchid species in Benin, West Africa, *Flora et Vegetation Sudano-Sambesica*, 20, pp. 26–36.

Assèdé E. S. P., Djagoun C. A. M. S., Azihou F. A., Gogan Y. S. C., Kouton M. D., Adomou A. C., Geldenhuys C. J., Chirwa P. W. and Sinsin B. 2018. Efficiency of conservation areas to protect orchid species in Benin, West Africa, *South African Journal of Botany*, 116, pp. 230–237. doi:10.1016/j.sajb.2018.02.405

Balducci M. G., Van der Niet T. and Johnson S. D. 2019. Butterfly pollination of Bonatea cassidea (Orchidaceae): Solving a puzzle from the Darwin era, *South African Journal of Botany*, 123, pp. 308–316. doi:10.1016/j.sajb.2019.03.030

Bhattacharyya P. and van Staden J. 2018. Molecular insights into genetic diversity and population dynamics of five medicinal Eulophia species: a threatened orchid taxa of Africa, *Physiology and Molecular Biology of Plants*, 24 (4), pp. 631–641. doi:10.1007/s12298-018-0523-6

Bolus H. F. L. S. 1888. *The orchids of the Cape Peninsula. South African Philosophical Society*. V. Cape Town: The Society.

Boukehili K., Boutabia L., Telailia S., Menaa M., Tlidjane A., Maazi M. C., Chefrour A., Saheb M. and Véla E. 2018. Les orchidées de la région de Souk-Ahras (Nord-est algérien): inventaire, écologie, répartition et enjeux de conservation, *Revue d'écologie*.

Castro J. B. and Singer R. B. 2019. A literature review of the pollination strategies and breeding systems in Oncidiinae orchids, *Acta Botanica Brasilica*, 33 (4), pp. 618–643. doi:10.1590/0102-33062019abb0111

Chimi D. C., Nfornkah B. N., Kabelong, B. L. P. R., Noudem J. C., Misse A. C., Tabue M. R. B., *et al.* 2020. Orchids diversity and biomass on a native host tree species in a semi-deciduous rain forest of Cameroon, *Journal of Sustainable Forestry*, pp. 1–12. doi:10.1080/10549811.2020.1746350

Chinsamy M., Finnie J. F. and Van Staden J. 2011. The ethnobotany of South African medicinal orchids, *South African Journal of Botany*, 77 (1), pp. 2–9. doi:10.1016/j.sajb.2010.09.015

CITES 2020. *Appendices I, II and III*. Available from: https://cites.org/sites/default/files/eng/app/2020/E-Appendices-2020-08-28.pdf

Cozzolino S. and Widmer A. 2005. Orchid diversity: an evolutionary consequence of deception?, *Trends in Ecology & Evolution*, 20 (9), pp. 487–494. doi:10.1016/j.tree.2005.06.004

Dearnaley J. D., Martos F. and Selosse M.-A. 2012. 12 orchid mycorrhizas: molecular ecology, physiology, evolution and conservation aspects, in: *Fungal associations*. Springer, pp. 207–230.

Djalante R. 2018. A systematic literature review of research trends and authorships on natural hazards, disasters, risk reduction and climate change in Indonesia., *Natural Hazards & Earth System Sciences*, 18 (6). doi:10.5194/nhess-18-1785-2018

Droissart V., Cribb P. J., Simo-Droissart M. and Stévart T. 2014. Taxonomy of Atlantic Central African orchids 2. A second species of the rare genus Distylodon (Orchidaceae, Angraecinae) collected in Cameroon, *PhytoKeys*, (36), pp. 27. doi:10.3897/phytokeys.36.7225

Droissart V., Sonké B. and Stévart T. 2006. The Orchidaceae endemic to Atlantic Central Africa occurring in Cameroon, *Systematics and Geography of Plants*, 76 (1), pp. 3–84.

Fay M. F. 2018. Orchid conservation: how can we meet the challenges in the twenty-first century?, *Botanical Studies*, 59 (1), pp. 16. doi:10.1186/s40529-018-0232-z

Fetscherin M., Voss H. and Gugler P. 2010. 30 Years of foreign direct investment to China: An interdisciplinary literature review, *International Business Review*, 19 (3), pp. 235–246. doi:10.1016/j.ibusrev.2009.12.002

Fonge B. A., Essomo S. E., Bechem T. E., Tabot P. T., Arrey B. D., Afanga Y. and Assoua E. M. 2019. Market trends and ethnobotany of orchids of Mount Cameroon, *Journal of Ethnobiology and Ethnomedicine*, 15 (1), pp. 29. doi:10.1186/s13002-019-0308-1

Franklin J. F., Mitchell R. J. and Palik B. J. 2007. Natural disturbance and stand development principles for ecological forestry, *Gen. Tech. Rep. NRS-19. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. 44 p.*, 19. doi:10.2737/NRS-GTR-19

Grobler L. 2005. Conservation in South Africa: An Orchidist's Perspective, *Selbyana*, pp. 81–84.

Gutiérrez R. M. P. 2010. Orchids: A review of uses in traditional medicine, its phytochemistry and pharmacology, *Journal of Medicinal Plants Research*, 4 (8), pp. 592–638. doi:10.5897/JMPR

IUCN 2017. The IUCN Red List of Threatened Species, Version 2019-2.

Jecmenica V., Droissart V., Akouangou E., Nyangala C., Bakita B., Biteau J. P. and Stévart T. 2017. Taxonomy of Atlantic Central African orchids, 6: Three new species of Angraecum sect. Afrangraecum (Orchidaceae, Angraecinae) from Gabon and Sao Tomé, *Phytotaxa*, 323 (2), pp. 143–158.

Jersakova J. and Johnson S. D. 2006. Lack of floral nectar reduces self-pollination in a fly-pollinated orchid, *Oecologia*, 147 (1), pp. 60–68. doi:10.1007/s00442-005-0254-6

Kasulo V., Mwabumba L. and Cry M. 2009. A review of edible orchids in Malawi, *Journal of Horticulture and Forestry*, 1 (7), pp. 133–139. doi:10.5897/JHF.9000003

Kendon J. P., Rajaovelona L., Sandford H., Fang R., Bell J. and Sarasan V. 2017. Collecting near mature and immature orchid seeds for ex situ conservation:'in vitro collecting'as a case study, *Botanical Studies*, 58 (1), pp. 34. doi:10.1186/s40529-017-0187-5

Leydesdorff L., de Moya-Anegón F. and Guerrero-Bote V. P. 2010. Journal maps on the basis of Scopus data: A comparison with the Journal Citation Reports of the ISI, *Journal of the American Society for Information Science and Technology*, 61 (2), pp. 352–369. doi:10.1002/asi.21250

Linder H. P. 1995. Setting conservation priorities: the importance of endemism and phylogeny in the southern African orchid genus Herschelia, *Conservation Biology*, 9 (3), pp. 585–595. doi:10.1046/j.1523-1739.1995.09030585. x

Linder H. P., Kurzweil H. and Johnson S. D. 2005. The Southern African orchid flora: composition, sources and endemism, *Journal of Biogeography*, 32 (1), pp. 29–47. doi:10.1111/j.1365-2699.2004.01202. x

Liu H. and Gao J. 2020. Orchid Conservation Translocation Efforts in China, in: *Conservation and Reintroduction of Rare and Endangered Plants in China*. Springer, pp. 205–224. doi:10.1007/978-981-15-5301-1_19

Micheneau C., Johnson S. D. and Fay M. F. 2009. Orchid pollination: from Darwin to the present day, *Botanical Journal of the Linnean Society*, 161 (1), pp. 1–19. doi:10.1111/j.1095-8339.2009.00995. x

Noyons E. 2001. Bibliometric mapping of science in a policy context, *Scientometrics*, 50 (1), pp. 83–98. doi:10.1023/a:1005694202977

Pant B. 2013. Medicinal orchids and their uses: tissue culture a potential alternative for conservation, *African Journal of Plant Science*, 7 (10), pp. 448–467. doi:10.5897/AJPS2013.1031

Peter C. I. and Johnson S. D. 2014. A pollinator shift explains floral divergence in an orchid species complex in South Africa, *Annals of Botany*, 113 (2), pp. 277–288. doi:10.193/aob/mct216

Phillips D. P. and Bytebier B. 2020. A morphometric and molecular phylogenetic analysis of the African orchid genus Stenoglottis (Orchidaceae: Orchidoideae), *Botanical Journal of the Linnean Society*, 193 (3), pp. 340–362.

Pillon Y. and Chase M. W. 2007. Taxonomic exaggeration and its effects on orchid conservation, *Conservation Biology*, 21 (1), pp. 263–265. doi:10.1111/j.1523-1739.2006.00573.x

Possobom C. C. F. and Machado S. R. 2017. Elaiophores: their taxonomic distribution, morphology and functions, *Acta Botanica Brasilica*, 31 (3), pp. 503–524. doi:10.1590/0102-33062017abb0088 ISSN1677-941X

Sanford W. W. and Adanlawo I. 1973. Velamen and exodermis characters of West African epiphytic orchids in relation to taxonomic grouping and habitat tolerance, *Botanical Journal of the Linnean Society*, 66 (4), pp. 307–321. doi:10.1111/j.1095-8339.1973.tb02178.x

Simo-Droissart M., Stévart T., Sonké B., Mayogo S., Kamdem N. and Droissart V. 2018. New taxonomic and conservation status of Ossiculum (Vandeae, Orchidaceae), a highly threatened and narrow-endemic angraecoid orchid from Central Africa, *PhytoKeys*, (98), pp. 85. doi:10.3897/phytokeys.98.23511

Stewart J., Linder H. P., Schelpe E. A. and Hall A. V. 1982. *Wild orchids of Southern Africa*. Macmillan. Johannesburg.

Subedi A., Hunwar B., Choi Y., Dai Y., Tinde van A., Chaudhary R. P., de Boe H. J. r and Gravendeel B. 2013. Collection and trade of wild-harvested orchids in Nepal | Journal of Ethnobiology and Ethnomedicine | Full Text, *Journal of Ethnobiology and Ethnomedicine*, 9 (64). doi:10.1186/1746-4269-9-64.

Swarts N. D. and Dixon K. W. 2009. Terrestrial orchid conservation in the age of extinction, *Annals of Botany*, 104 (3), pp. 543–556. doi:10.1093/aob/mcp025

Travers S. L., Jackman T. R. and Bauer A. M. 2014. A molecular phylogeny of Afromontane dwarf geckos (Lygodactylus) reveals a single radiation and increased species diversity in a South African montane center of endemism, *Molecular Phylogenetics and Evolution*, 80, pp. 31–42. doi:10.1016/j.ympev.2014.07.017

Tripathi M., Kumar S., Sonker S. K. and Babbar P. 2018. Occurrence of author keywords and keywords plus in social sciences and humanities research: A preliminary study, *COLLNET Journal of Scientometrics and Information Management*, 12 (2), pp. 215–232. doi:10.1080/09737766.2018.1436951

Tsering J., Tam N., Tag H., Gogoi B. J. and Apang O. 2017. Medicinal orchids of Arunachal Pradesh: A review, *Bulletin of Arunachal Forest Research*, 32 (1 & 2), pp. 1–16.

Van der Niet T., Cozien R. J. and Johnson S. D. 2015. Experimental evidence for specialized bird pollination in the endangered South African orchid Satyrium rhodanthum and analysis of associated floral traits, *Botanical Journal of the Linnean Society*, 177 (1), pp. 141–150. doi:10.1111/boj.12229

Vereecken N. J., Streinzer M., Ayasse M., Spaethe J., Paulus H. F., Stoekl J., Cortis P. and Schiestl F. P. 2011. Integrating past and present studies on Ophrys pollination–a comment on Bradshaw et al., *Botanical Journal of the Linnean Society*, 165 (4), pp. 329–335. doi:10.1111/j.1095-8339.2011.01112.x

Vermeulen J. J. 1987. *Orchid Monographs: A Taxonomic Revision of the Continental African Bulbophyllinae*. Vol. 2. Brill Archive.

Willis K. J. 2017. *State of the world's plants report-2017*. Royal Botanic Gardens.

Wraith J., Norman P. and Pickering C. 2020. Orchid conservation and research: An analysis of gaps and priorities for globally Red Listed species, *Ambio*, pp. 1–11. doi:10.1007/s13280-019-01306-7

Wraith J. and Pickering C. 2018. Quantifying anthropogenic threats to orchids using the IUCN Red List, *Ambio*, 47 (3), pp. 307–317. doi:10.1007/s13280-017-0964-0

Wraith J. and Pickering C. 2019. A continental scale analysis of threats to orchids, *Biological Conservation*, 234, pp. 7–17. doi:1016/j.biocon.2019.03.015

Zeng S., Huang W., Wu K., Zhang J., Teixeira da Silva J. A. and Duan J. 2016. In vitro propagation of Paphiopedilum orchids, *Critical Reviews in Biotechnology*, 36 (3), pp. 521–534. doi:10.3109/07388551.2014.993585

Zhang J., Yu Q., Zheng F., Long C., Lu Z. and Duan Z. 2016. Comparing keywords plus of WOS and author keywords: A case study of patient adherence research, *Journal of the Association for Information Science and Technology*, 67 (4), pp. 967–972. doi:10.1002/asi.23437.