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Taxonomic Studies in Indian *Curcuma* L.

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2007

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Front cover: *Curcuma rubrobracteata*. Photographed at RBG Edinburgh.

Dedicated to all, who stayed by me during the Indian journey…

DECLARATION

I declare that I have written this thesis and that it has not been submitted for the award of a degree at any other University. All sources have been cited and clearly acknowledged.

ACKNOWLEDGEMENTS

It is a pleasure to use the first pages of this work to thank various people, who helped me along the way. Without them, the following pages could have hardly been written. No matter how long this list will be, it can never be complete. There were countless people who helped me in different ways during my *Curcuma* journey - in India, Czech Republic, UK or Singapore. I apologise to everyone, who is not explicitly named here.

I would not be able to start my thesis without support of my supervisors. Dr. J. Sádlo provided me the chance to pursue my passion for gingers. In 1999, he was the only 'brave man' willing to take me as a PhD student on Gingers, which had not been studied by any Czech before. I was glad that in 2004, Dr. Karol Marhold got on board as second supervisor. He took up the difficult task of convincing me that the most confusing book on Earth, the ICBN, indeed makes sense (in most cases) and guided me through thorny nomenclatural puzzles. My almost five years of study in India would not be possible without Dr. M. Sabu, who shared with me his staff room in Calicut University, advised on various aspects of survival in India and helped tremendously with providing space, a gardener and the logistics for cultivation of living collections.

I wish to thank the Departments of Botany of Charles University, Prague and Calicut University, Kerala for their continuous support and patience.

The Ministry of Education and Sports of the Czech Republic together with the Indian Council of Cultural Relationships provided the opportunity of a long-term stay at Calicut University (Kerala, India) and facilitated the necessary research visa. This study was financially supported by the Grant Agency of the Academy of Sciences of the Czech Republic (Grant No. B.6407401), the Department of Science and Technology, Government of India (Order No. SP/SO/A-20/99 dt. 09.11.2001) and the International Association of Plant Taxonomy (Grant award for the year 2004). The stay at BM, E, and K would not be possible without funding by the European Commission's Research Infrastructure Action via the SYNTHESYS Project (GB-TAF-606).

Ministry of Environment and Forests, Government of India, is acknowledged for granting permission to collect and Forestry Departments around the country in providing help during several field trips. The Botanical Survey of India is acknowledged for granting permission to access BSI herbaria. I would like to thank in particular to Dr. M. Sanjappa, Director of Botanical Survey in India for his great encouragement during the first years. I thank the director of Royal Botanic Garden, Dr. D.S.A. Wijesundara for his great help during my short trips to Sri Lanka.

The thanks are due to all helpful curators at AMH, ASSAM, BHAG, BLATT, BM, BO, BR, BSA, BSD, BSHC, BSI, C, CAL, CALI, CDRI, DD, E, G, GAT, K, KEP, KIEL, KLU, L, LD, LE, LINN, LIV, LWG, MH, PBL, PCM, PDA, PR, SAR, SING & WU for letting me examine specimens in their care, checking on availability of specimens and providing digital images. Many thanks to staff of libraries at BM, CAL, E, K and Liverpool Museum Record's Office for the help provided while accessing historical literature, manuscripts and letters.

Four Botanic Gardens, namely Calicut University Botanic Garden (CUBG), Royal Botanic Garden Edinburgh (RBGE), Prague Botanic Garden (PBG) and Singapore Botanic Gardens (SBG) let me access their collections. I am deeply indebted to the directors for providing all facilities during my repeated visits and their staff for taking perfect care of the plants. These thanks go namely to Vasudheva (CUBG), Helen & Kate (RBGE), Klara (PBG) and to Andrea & al. (SBG).

Many people from various institutions participated in fruitful discussions on nomenclature, taxonomy, history of botany, fieldwork methodology, morphology and developmental biology of floral structures and other topics. To name a few - Dr. J. Edmondson (LIV), Bruce Kirchoff (University of North Carolina, USA), Dr. David Middleton (E), Dr. Mark F. Newman (E), Dr. H.J. Noltie (E), Dr. Axel D. Poulsen (E) & Tanya M. Rehse (Duke University, USA). Special thanks to Dr. Jan F. Veldkamp (L) for supplying latin diagnoses, discussions about terminology and e-chats on nomenclature. Personal thanks goes to Dr. R. Kiew (SING, now FRIM) for her extensive support over the tough years in India.

I am thankful to all my *Curcuma* co-fighters, in particular to Ota Šída and Tomáš Fér, who are behind the 'white part' of the *Curcuma* story. They supported me in many different ways and frankly, without them I would have given up quite some time ago. Thanks also to Jan Suda for his help and humor, as well as Veronika Machalová, Vlasta Jarolímová & Pavel Trávníček for the technical help and patience in the labs.

Thanks are also due to the most generous people of India, who were always curiously looking over my shoulder, but at the same time ready to help me, accommodate me, feed me, bring cups of tea to the middle of the forest, share their seat in the always full Indian trains and buses, accompany me to the field and many more. I personally thank my "Indian families", who warmly adopted me and gave me homes in different parts of India. In particular Family Thomas in Calicut, Family Banik in Calcutta, Family Sahani in Ranchi, my "Indian siblings" Dipanwita, Sudhip, Sujith, Neesha and Pankaj. I would not have survived without their jokes, love, support and help. Special thanks to Pankaj, my "orchid brother", for accompanying me to remote parts of central India. I could have never explored these places without his help.

Czech friends kept my head above the water. There are many but in particular: Family Valachovi and Ms. Kumarová from the Czech embassy in India, Czech students/lecturers scattered in different parts of India – M. Hříbek, H. Weisserová and H. Drahošová. In Czechia it was Ms. Marie Vobořilová from MŠMT, families Rázgovi, Votlučkovi including Jiří, Family Markova and my brother Roman and his wife Eva.

In Singapore I could not have made it without the 'gang' from Singapore Herbarium, especially Serena Lee, Paul Leong & Hassan Ibrahim and others, library staff, Christina Soh & Zakiah Agil, and friends from plant records unit Nura Abdul Karim & Sin Lan Koh. Special thanks to Hassan for 'suffering' through the raw manuscript and proof-reading whenever possible (i.e. he was not lost among blood-dripping pages) and to Lenka Holubová for keeping my spirits high.

I cannot thank my parents and grandfather enough, who had to (and still have to) cope with my ginger passion and the fact that I am not by their side.

My work could also not be completed without the understanding and cooperation from my mother-in-law, our sons Christopher and Matthew and especially the continuous support of my husband Michael - obviously my better half. It is he who fully supported my field trips and runs our family during my long stays abroad or when I am 'camping' in little underground room of Singapore Herbarium, nicknamed the 'ginger cave'.

Lastly, huge thanks to the marvellous, interesting and intricate plants – gingers, for giving me the pleasure, excitement, headaches and … the reason to be a botanist!

FOREWARD – The Indian journey

In early 2000 I was awarded a 10-month fellowship at Calicut University in Kerala, South India to study gingers. However, upon my arrival in New Delhi I was told that the scholarship is either for three or five years. From my previous Indian experiences, I already knew that termination is always easier than applying for extention, and so I decided on the spot the next five years of my life.

I became a part of a small group, working on the revision of Indian Zingiberaceae. I was asked to produce within three years the revision of Indian *Curcuma* and *Amomum* and help out with some smaller genera. I was not very happy about that, as I was very keen to work on *Hedychium* or *Globba*. However, left with no choice, I accepted. Dr. M. Sabu, my Indian supervisor, 'encouraged' me that by sorting out the problems in Indian *Curcuma* I will earn 'neverfading glory'. I sniffed trouble for the first time. Within my second year I had to drop the genus *Amomum* and everything else. I realized, that *Curcuma* alone was a big task. Yet, in the beginning I was still very optimistic and almost confident, that if I work hard I can produce within another four years a revision of the genus *Curcuma* for the Indian subcontinent. However, as the weeks and months passed by, I was more and more confused. The only thing, which appeared to be clear was, that taxonomy and nomenclature of this genus is so complicated and messed up, that my present work represents just several steps in the long journey towards the revision of Indian *Curcuma*. I learned, that there is no name without its own story, connected either to its obscure history, missing type specimens, weird ploidy level or morphological peculiarity. Many times during those five Indian years, I have realized that earning the fame is less important than staying sane. And many times during my stay I have packed my bags with only one desire – to run away. The first time such a thought entered my mind was just about 5 weeks after my arrival in India. During that time, my personal belongings and equipment sent as cargo from Czech Republic were destroyed, I was bitten by a rat in the middle of night in the University guesthouse and my 'closest friend' – my notebook - gave up and 'died'.

The crucial point of my Indian journey was my first two-month stay at Central National Herbarium in Calcutta, the biggest Indian herbarium. I have seen in front of me piles and piles of specimens, collected all over India during past two centuries. Even after staring at hundreds of 'flat & dead' *Curcuma* specimens again and again, they all looked more or less similar, superficially belonging to 5-7 groups. After searching for more detailed characters, the piles suddenly disintegrated into over 100 minigroups and it became clear that something was wrong. I was to sort them out into about 30 taxa, which seemed impossible. I did not know then, that number of *Curcuma* species are more variable than others due to the ability to set seeds. I reached the point of waking up in the middle of night out of frustration. I realized that either I have to give up these 'silly plants' or I have to start afresh. Those who knew me, knew that I have fought long for the opportunity to work on gingers in the tropics, which I unexplicably loved since childhood. And so, that first option – giving up - was at that particular moment the harder one. (I have to admit though, that I did regret hundreds of times that decision I made in February 2001). So I started from scratch. I went back to protologues and to type localities. I went on extensive field trips and documented as much as possible from living materials. I read everything written about *Curcuma*, yet stopped myself from believing anything without seeing it with my own eyes. I revised all herbarium sheets, which came into my hands (not less than 3500) and photographed most of them. I looked only at their collection details, rather than their determinations. Only by learning about the living plants and observing their metamorphoses as they underwent pressing, drying and becoming herbarium specimens, I was able to understand them enough to reveal their identity and resolve most of typification puzzles.

I believe that ultimately, this is the only way to go about uncovering identities of gingers described in the early history and pursuing the ginger revisions.

SUMMARY

This thesis is the culmination of my work over six years (2000–2006), carried out mainly in India between 2000–2005. The primary aim of the thesis was to shed some light on taxonomy and nomenclature of Indian representatives of the economically important genus *Curcuma*.

The first part of the thesis consists of a broad general introduction to the subject to reflect current stage of knowledge and to formulate the major problems to be dealt with in the genus. It also presents several new findings, observations and preliminary results. **Chapter 1.** briefly introduces order Zingiberales, family Zingiberaceae, its importance in Indian flora and overview of cytological and molecular studies in the family. **Chapter 2.** focuses fully on the genus *Curcuma.* It covers introductory chapters regarding economic importance, distribution & species richness, ecology & conservation, followed by analyses of major problems hindering satisfactory treatment of the genus and summarizes current knowledge on cytology of gingers with special attention to *Curcuma*. I also incorporated preliminary results from the long-term observation of most of the taxa at their localities as well as in cultivation for several years that provided valuable data on the capability of producing single or two types of inflorescence and level of variability, which correlates with the mode of reproduction and rhizome architecture. **Chapter 3.** deals with *Curcuma* in India. Efforts have been made to understand the structure of the *Curcuma* plant and clarify some issues in morphological terminology. **Chapter 4.** sketches future perspectives and **Epilogue** and **References** closes the general part.

Papers presented as a second part of the thesis focused mainly on the identities of *Curcuma* species found in India and typifications, which were based on thorough field studies and revision of herbarium materials, in order to stabilize the nomenclature and application of the names. The results of cytology investigations (chromosome counts and genome size) provided useful insights about the genus and generally supported the observed level of variability, which correlated well with ploidy level and mode of reproduction.

The first three papers describe new *Curcuma* species. *Curcuma rubrobracteata* (in **paper I.**) is an interesting species. This is for the first time, that central inflorescence breaking out of a pseudostem through a lateral slit is observed in the genus. This is a feature so far known only in the genus *Plagiostachys* and few species of *Alpinia* within the family Zingiberaceae. **Paper II.** describes *C. codonantha*, a new species discovered in Andaman Islands. **Paper III.** deals with *C. mutabilis*, a seed-setting species endemic to South West India, an area of huge *Curcuma* diversity. Interestingly, this species displays huge intrapopulation variability.

Paper IV. deals with re-circumscription of the genus *Curcuma* to include the only member of the highly endemic monotypic genus of Western Ghats, *Paracautleya,* into *Curcuma*. The generic delimitation of *Curcuma* as drawn by botanists almost 200 years ago is no longer suitable as it was drawn mostly on sterile polyploidy taxa. Characters like single flower per fertile bract, reduction or even lack of the bracteole, fertile bracts not necessarily connate to each other at sides to name a few are also found among several seed-setting species of *Curcuma.* Thus such characters cannot be taken for delimitation of monotypic genus *Paracautleya*, which was consequently reduced to *Curcuma*. The tiny *C. bhatii* represents probably the smallest *Curcuma* in the world.

Unveiling the identity of imperfectly known species *Curcuma kurzii*, treated as doubtful species by Baker in *The Flora of British India* is the main topic of **paper V.** In 1984 Balakrishnan & Bhargava have identified this plant as the Burmese species *C. petiolata* and published tis finding as a new record for India, followed by other botanists. Only recent recollection from its type locality in Andaman Islands showed that *C. kurzii* represents in fact another Burmese species *C. roscoeana* - one of the most magnificent plants of the genus. As *C. kurzii* and *C. roscoeana* have not been previously typified, lectotypes were designated for both names.

Curcuma zanthorrhiza (in **paper VI.**) is one of the first historical species described by William Roxburgh from Amboina. It is widely used and also cultivated over the whole S and SE Asia. It is a fairly common species in South India and appears to be native there. Yet it was never reported from India, as the species was misidentified as *C. zedoaria* and *C. aromatica* over the years. These earlier identifications were based perhaps on descriptions, without verification and repeated over several generations. The identity of this taxon is clarified and postulated in the paper - *C. zanthorrhiza* is most likely to be of South Indian origin and have been spread through SE Asia during the early migrations long before Western domination. Investigation of this hypothesis by using molecular markers in the near future is anticipated.

The name *Curcuma zedoaria* is notoriously applied to many *Curcuma* species all over Asia. **Paper VII.** deals not only with unveiling the identity of the taxon named *C. zedoaria*, but also untangles complex taxonomic and nomenclatorical puzzles around the names *Amomum zerumbet*, *C. zerumbet* and *Erndlia subpersonata.* It also provides a new name *C. picta* for a plant left without a valid name after sorting out the 'historical mess'.

Curcuma longa, the source of turmeric, is a plant of immense economical importance. It is also important from a taxonomic point of view, as it is the type species of the genus. Yet, there is prolonged confusion over its identity. Although *Curcuma* is conserved, with *C. longa* L. as its conserved type, the type of *C. longa* is still uncertain. There were numerous discussions about the identity of *C. longa* as well as several attempts to settle the type. Unfortunately, none of the previous proposals can be upheld due to various reasons. This is discussed in **paper VIII.** A lectotype selected from original material and epitype collected near the type locality are accordingly proposed.

Only after four years of intensive field work focused on re-collection of species from type or near type localities, together with thorough studies of herbarium sheets from Indian, major European as well as Asian herbaria, it was possible to review the types for all Indian *Curcuma* names, and to designate lectotypes, neotypes and epitypes, wherever needed (**paper IX.,** in preparation).

Paper X. presents results of cytological investigation of 161 plants belonging to 51 taxa. Six different chromosome counts including two representing new generic records were revealed. Three groups of taxa with significantly different homoploid sizes (Cx-values) and distinct geographical distribution were identified. Intraspecific variation in nuclear DNA-content was detected in five species. Chromosome counts and genome sizes of three *Curcuma*-like species (i.e. *Hitchenia caulina*, *Kaempferia scaposa* and *Paracautleya bhatii)* corresponds well with typical hexaploid ($2n=6x=42$) Curcumas and supported inclusion of these taxa in the genus *Curcuma*.

The huge potential of Curcumas as sources of medicine, spices, food, dyes, ornamentals and other uses is elaborated in chapter 14 'Other economically important *Curcuma* species' in the book 'Turmeric: the genus *Curcuma*' (**paper XI.**).

The stunning beauty of *Curcuma* species is brought to the layman in a short and pictorial way as an article for Gardenwise, the newsletter of the Singapore Botanic Garden (**paper XII.**). Another popular article about Curcumas appeared in 2003 in Živa, but is not included here as it was printed in Czech only.

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V. **Škorničková, J.** & Sabu, M. (2005b): *Curcuma roscoeana* Wall. in India. – *Gardens' Bulletin Singapore* 57: 187–198.

VI. **Škorničková, J.** & Sabu, M. (2005c): The identity and distribution of *Curcuma zanthorrhiza* Roxb. – *Gardens' Bulletin Singapore* 57: 199–210.

VII. **Leong-Škorničková, J.**, Šída, O., Sabu, M. & Marhold, K. (submitted): Taxonomic and nomenclatural puzzles in India *Curcuma*: the identity and nomenclatural history of *C. zedoaria* (Christm.) Roscoe and *C. zerumbet* Roxb. – *Taxon*

VIII. **Leong-Škorničková, J.**, Šída, O., Wijesundara, S. & Marhold, K. (submitted): On identity of turmeric: Typification of *C. longa* L. (Zingiberaceae). – *Botanical Journal of Linnean Society.*

IX. **Leong-Škorničková, J.,** Šída, O. & Marhold, K. (in preparation): Back to types! Towards stability of names in Indian *Curcuma* L. (Zingiberaceae). – *Botanical Journal of Linnean Society.*

X. **Leong-Škorničková, J.,** Šída, O., Jarolímová, V., Sabu, M. Fér, T., Trávníček, P. & Suda, J. (accepted): Chromosome numbers and Genome Size Variation in Indian Species of *Curcuma* (Zingiberaceae). – *Annals of Botany (Oxford).*

XI. **Škorničková, J.**, Rehse, T. & Sabu, M. (2007): Other Economically Important *Curcuma* Species. Chapter 14. In: Ravindran, P.N. (ed.) Turmeric: the genus *Curcuma*. CRC Press, Florida Pp. 451-467.

XII. **Škorničková, J.** 2006. *Curcuma* – Stunning Beauty, Hidden Treasure. *Gardenwise* 27: 2-5.

APPENDIX

A-i. *Curcuma* DESCRIPTOR
A-ii. HOW TO COLLECT & DESCRIBE *CURCUMA* PLANTS
A-iii. FLAT & DEAD, YET USEFUL - tips for preserving herbarium specimen
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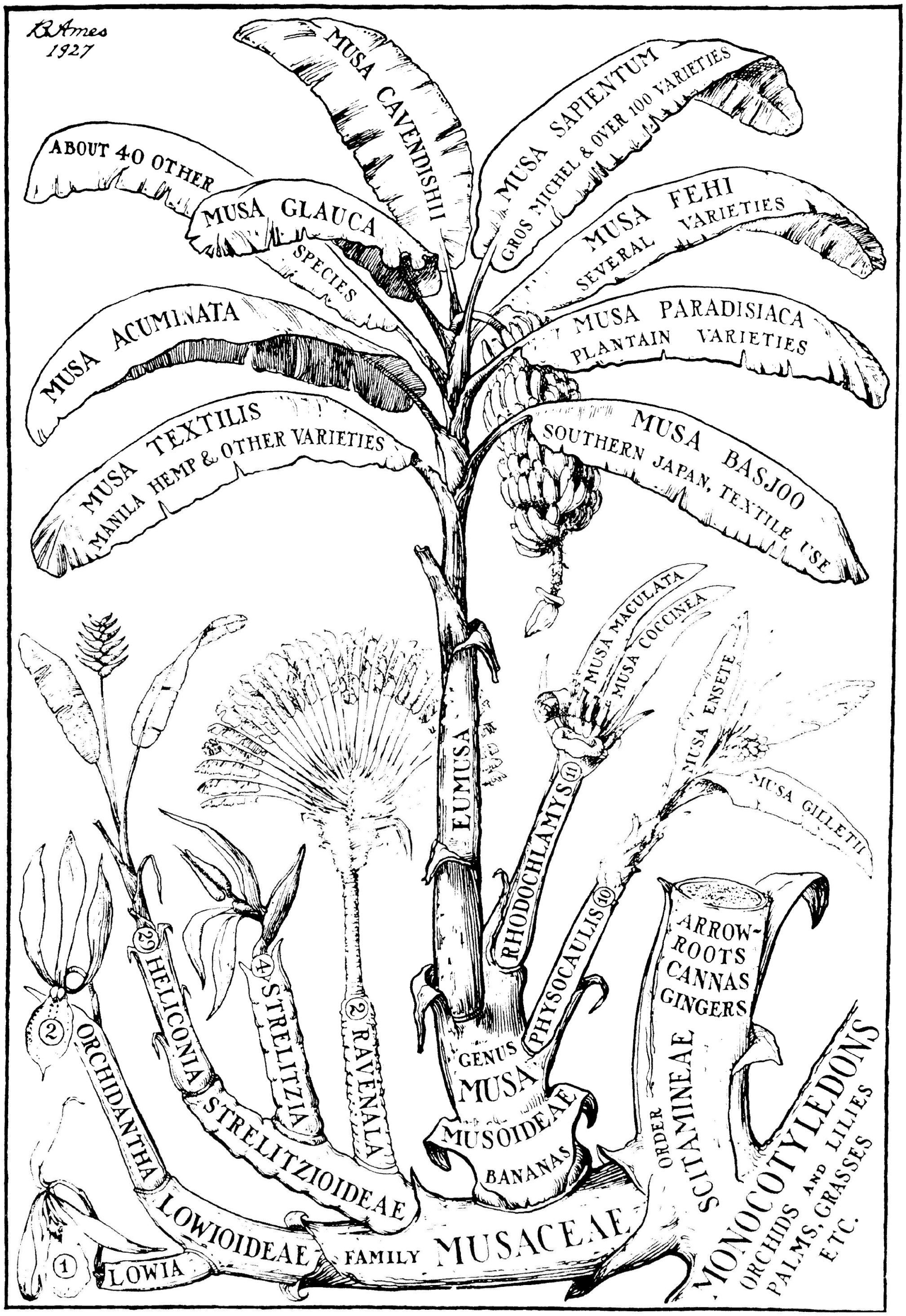
1. ZINGIBERALES & ZINGIBERACEAE



1.1. ZINGIBERALES Griesbach.

The Scitamenta of the ancients were savoury & well-spiced viands; the elegant delicacies of the tables of those times. Linnaeus applied a kindred word – Scitamineae – to denominate a group of plants, the products of which yield condiments, e.g. ginger, cardamoms.

H. Stansfield, 1955

Eight families, over 90 genera and more than 2,200 species form the order Zingiberales. This order includes many plants of economic importance, such as bananas (Musaceae), spices (several members of Zingiberaceae) and countless number of ornamental plants (Heliconiaceae, Strelitziaceae, Cannaceae, Costaceae, Zingiberaceae, Marantaceae) as well as medicinal plants (e.g. many members of Zingiberaceae and several Costaceae).

For a long time botanists have perceived that members of this order form natural and distinctive group of plants (Fig. 1), and this perception survived until today (Fig. 2), even though the group was going through several name changes during past 200 years as the classification kept changing. Commonly used older name refering to this group is Scitamineae.

FIGURE 2. Rhizogram of the Zingiberales. (Reproduced from Kress, 1990)

FIGURE 1. (Chapter cover page.) Rhizogram of the Zingiberales. (Reproduced from Reynolds, 1927)

The fact that Zingiberales form a very distinct group was supported over the years by morphological studies (e.g. Tomlinson, 1962; Panchaksharappa, 1962a;

Thorne, 1976; Cronquist, 1981; Dahlgren & al., 1985) as well as recently confirmed by molecular studies (Kress, 1990; APG II, 2006).

Within the order Zingberales, there always have been eight taxa, now commonly recognized as families. These are, and historically were, informally treated in two groups (e.g. Bentham & Hooker, 1883; Petersen, 1889; Loesener, 1930; Winkler, 1930; Hutchinson, 1934, 1959; Nakai, 1941; Tomlinson, 1962). The 'banana' group now comprises four families that have six or five fertile stamens (Musaceae, Heliconiaceae, Strelitziaceae, Lowiaceae) while the families, where the fertile anthers were reduced to one stamen (Zingiberaceae, Costaceae) or half stamen (Marantaceae, Cannaceae - only one of the two thecae is functional), form the ginger group. Staminodes, the sterile stamens that have lost their primary function of pollen production, are represented by small rudiments in the banana group, while the staminodes in 'ginger group' were modified into large, elaborate organs - petaloid staminodes (Walker-Larsen & Harder, 2000). Floral diagrams of the eight families as well as history of the classification of the Zingiberales was given e.g. by Kress (1990) or Pedersen (2003).

In earlier classifications, Costaceae was often included within the family Zingiberaceae (Petersen, 1889; Schumann, 1904), but Nakai (1941) proposed that Costaceae should be treated at familiar rank, which received support from anatomical evidence by Tomlison (1969), embryology by Panchaksharappa (1970), chemotaxonomy by Williams & Harborne (1977), and stomatal morphology by Olatunji (1980). Having a number of distinctive characters e.g. lack of aromatic oils, branched aerial stems and spiral monostichous phyllotaxy (Specht & al., 2001), Costaceae is unambiguously accepted as a separate family and sister clade to the gingers (Takhtajan, 1980; Dahlgren & al., 1985; Kress, 1990, 1995; Kress & al. 2001, Specht, 2006; Specht & Stevenson, 2006).

1.2. ZINGIBERACEAE Martynov

This family of plants had a strange fascination for Roscoe; the flowers are more quaint than beautiful; they have a certain 'stiffness' yet dignity, and all conform to set a pattern or design. He became interested in them, almost to the exclusion of any others. He studied them all as they came into flower, and dwelled in to the literature about them, as set forth by the earlier botanists. His botanical studies for the rest of his life were devoted to these plants "every man has his own pleasures."

H. Stansfield, 1955

Gingers (family Zingiberaceae) are perennial herbs, which play an important role in tropical forests as ground cover. A few are epiphytic. They are found from lowlands to mountain range. Many of them are common in habitats destroyed by human activities. In moist evergreen forests and in ever-humid patches of seasonal forests the Zingiberaceae keep their leaves all year round. In the dry parts of seasonally dry forests they die down and survive as an underground rhizome.

Their centre of diversity is in Asia, few genera are represented in Africa and only one genus is native to S. America. Zingiberaceae represents moderately sized family of monocots. More than 50 genera with c. 1,300 species are known worldwide. However the total number of genera and species is uncertain. The progress in our understanding of its biodiversity, various opinions on generic delimitation, verification of synonymies and consequent nomenclatural changes keep the numbers constantly moving. Many new species and, more amazingly, number of new genera e.g. *Distichochlamys*

(Newman, 1995), *Siamanthus* (Larsen & Mood, 1998), *Tamijia* (Sakai & Nagamasu, 2000), *Laosanthus* (Larsen & Jenjittikul, 2001), *Smithatris* (Kress & Larsen, 2001), have been discovered in Asia during the last two decades. There are certainly many more gingers yet to be discovered in the jungles of Papua New Guinea, Burma, Laos, Cambodia, Vietnam and other less explored corners of Asia.

The ginger family contains some of the important global resources for spices, vegetables, food, dyes, pharmaceuticals and ornamental plants. Most of the economically important gingers are in the genera *Alpinia, Amomum, Curcuma*, and *Zingiber*, and to lesser extent, *Boesenbergia, Kaempferia, Elettaria, Elettariopsis, Etlingera* and *Hedychium*. Three species provide crop of major commercial importance: ginger (*Zingiber officinale* Roscoe), turmeric (*Curcuma longa* L.) and cardamom (*Elettaria cardamomum* (L.) Maton). Tribals all over Asia use a few hundred gingers. In many cases, the identities as well as biological compounds of these gingers are yet unknown. Likewise, many species in various genera with ornamental potential have yet to be employed.

The study of gingers is one of the more difficult among herbaceous groups, as they have to be studied from living flowering material. The delicate flowers open for just one day (several exceptions last two to few days among the mountain gingers and only a few species with nocturnal anthesis are known). In some genera, underground parts contain important diagnostic characters. It is difficult to preserve such parts in dried specimens. Spirit specimens lose colour and detailed field notes are necessary, thus making collecting good specimens tedious and time consuming. Burtt (1972a) pointed out, that studies made by Holttum and Valeton stand in a class apart, for the very reason that they were based largely on the living plants (or on adequate material preserved in alcohol). They showed up the enormous deficiencies that are inevitable in a herbarium investigation, such as that which was the basis for K. Schumann's account written for *Das Pflanzenreich* (1904).

A big problem resulting from difficulties in preserving plant's important characters is that we still do not know the identities of many names described in early history. Burtt & Smith (1972a) published a classic paper on key species in the taxonomic history of Zingiberaceae. The objective of that paper was to clear up the taxonomic and nomenclatural confusion surrounding many genera of this family described between the time of Linnaeus (1753) and of Roxburgh (1820). However, they pointed out that the identification of some obscure species, the correction of innumerable misuse of generic names and the misidentifications of species, must await a monographer, if one ever thinks the labour of such work is profitable. Indeed, the number of names with scanty protologues, the deteriorated specimens (if any!) and common application of one name to many taxa and vice versa, make revision of several genera (e.g. *Alpinia, Amomum, Curcuma*) a real nightmare.

First attempts for infrafamiliar classification were made by Petersen (1889). He recognized three tribes (*Hedychieae, Globbeae, Zingibereae*) and was followed by Schumann (1904) and Loesener (1930). Under their treatment, the genus *Zingiber* was in the same tribe with the genera *Alpinia, Amomum etc*. Holttum (1950) recognized also three tribes (*Globbeae, Hedychieae, Alpinieae*), but with different delimitation. He considered *Zingiber* as being more closely related to the members of tribe *Hedychieae* due to presence of well-developed staminodes, appearing as lobes at the base in *Zingiber*. He therefore removed *Zingiber* from the group and re-named the former tribe to Alpinieae. Holttum hesitated to rename the well-established tribe *Hedychieae*.

However this was not nomenclatorically correct, as the tribe including the type genus of the family must be called *Zingibereae* (Vienna Code, Art No. 19.4, McNeil & al., 2006). Burtt & Smith (1964) tentatively suggested that the *Zingiber* should be recognized as a separate tribe and examined this possibility in subsequent years. Further work of Burtt & Olatunji (1972) focused on the traditional morphological approach and their findings led into division of the family into four tribes, namely *Alpinieae*, *Globbaeae*, *Hedychieae* (included *Curcuma*) and *Zingibereae* which was followed since then until recently (Olatunji, 1970; Burtt & Olatunji, 1972; Burtt, 1972a; Burtt & Smith, 1972b; Smith, 1981; Larsen & al., 1998).

Kress & al. (2002) analysed 104 representatives of 41 genera covering all four former tribes and proposed new classification, which divides the family into four subfamilies and six tribes, *Curcuma* falling into tribe *Zingibereae*:

ZINGIBERACEAE
  Siphonochiloideae
    Siphonochileae
  Tamijioideae
    Tamijieae
  Alpinioideae
    Alpinieae
    Riedelieae
  Zingiberoideae
    Zingibereae* → *Curcuma
    Globbeae

1.3. ZINGIBERACEAE OF INDIA

> *Koenig was the first botanist of the Linnean School, that had resided long enough in India, to acquire any tolerable knowledge of the scitaminean plants of this country; for it is only the living, or recent state, that their flowers can be well understood; particularly the nice structure of the anther, which is here of more importance in determinig the genera; than in any other order.*
>
> W. Roxburgh, 1810

Zingiberaceae is among ten largest monocotyledonous families in India. If cultivated species are excluded, the northwestern, the central gangetic plains and the plateau regions of India are comparatively poor in their representation (Jain & Prakash, 1995). The Zingiberaceae in India are represented by 18 genera with over 180 species (Table 1). These are distributed mainly in SW India (especially Western Ghats area) and NE India. The largest genera are *Hedychium* with about 40 taxa, *Curcuma* with about 30 taxa (after revision the number is likely to be 40-45 species), *Globba* and *Zingiber* both with 18 taxa and *Amomum* c. 17 taxa. Several botanists have attempted to study several ginger genera in India e.g. *Hedychium* (Srivastava, 1984), *Alpinia* (Mangaly & Sabu, 1992), *Curcuma* (Kumar, 1991; Mangaly & Sabu, 1993; Velayudhan & al. 1996, 1999), *Cautleya* (Kumar, 1994), *Roscoea* (Kumar, 1993), *Amomum*, (Kumar & Raju, 1989), *Zingiber* (Kumar & Raju, 1991; Sabu, 2003) or gingers of some particular geographical area (Rao & Verma 1969a,b,c, 1971, 1972; Bhat, 1988,1993; Kumar, 1996, 2001; Tripathi & Prakash 1998, 1999a,b,c,d, 2000; Sabu, 2006). However, none of the works covered any genus for the whole of India and none of the genera underwent proper taxonomic revision, which would settle types, tackle nomenclatoric questions and shed light onto identities of many of the historical taxa. The above-mentioned numbers of species are thus approximated from Jain & Prakash (1995) & Karthikeyan & al. (1989). Number of genera and species has been adjusted to reflect current knowledge (e.g. two monotypic genera *Curcumorpha* and *Paracautleya* are now treated as members of *Boesenbergia* and *Curcuma* respectively, *Mantisia* was equated with *Globba*). The number of species after a revision of the major genera is likely to be over 200.

Genus	India [end.]	World	Notes
Alpinia	12 [2]	c. 250	
Amomum	16 [6]	c. 150	
Boesenbergia	6 [2]	c. 60	
Caulokaempferia	2	10	
Cautleya	5	5	
Curcuma	c. 45-50 [c. 20]	c. 120	Estimated number after revision
Curcumorpha	1	1	→ ***Boesenbergia,*** Das & Sikdar, 1982
Elettaria	1	c. 20	
Etlingera	3	c. 100	
Globba	21 [6]	c. 100	
Hedychium	39 + 4 var. [17]	c. 80	
Hemiorchis	2	3	
Hitchenia	*1 [1]*	2	*H. caulina* → *Curcuma caulina*
Hornstedtia	1 [1]	c. 60	*H. fenzlii -> Etlingera fenzlii*
Kaempferia	7 [3]	c. 70	
Mantisia	3	3	→ ***Globba,*** Williams & al., 2004
Paracautleya	1 [1]	1	→ ***Curcuma,*** Škorničk. & Sabu, 2005a
Parakaempferia	1	1	
Rhynchanthus	1	6	
Roscoea	5 [3]	c. 17	
Stahlianthus	1	6	
Zingiber	18 [7]	c. 90	

TABLE 1. Overview of Indian Zingiberaceae genera with the number of species in India, number of endemic species (in square brackets), approximate number worldwide. Genera printed in grey are not recognized or the only member known in India has been transferred to another genus.

1.4. MOLECULAR & CYTOLOGICAL STUDIES

Use of various cytological and molecular markers are becoming more popular in the past two decades due to their accuracy and the fact that unlike morphological markers, they are not prone to environmental influences (e.g. Benett 1987, Bennet & Smith, 1991).

Use of molecular markers in Zingiberaceae & *Curcuma*

During the last six years, several genera and tribes were investigated with the use of molecular markers (usually combination of ITS with another marker e.g. *trn*L-For *mat*K was employed). This helped to understand the phytogeographical disjunction (*Roscoea*, Ngamriabsakul & al., 2000), origin and relationships of some economically important species within their respective genus (e.g. *Alpinia galanga*, Rangsiruji & al., 2000a), recent rapid radiation within the studied groups (*Aframomum*, Harris & al., 2000), to shed light on the phylogenetic relationships within tribes (*Hedychieae*, Searle & Hedderson, 2000; *Zingibereae*, Ngamriabsakul & al., 2004; *Globbeae*, Williams & al., 2004) or large genera (e.g. *Hedychium*, Wood & al., 2000; *Alpinia*, Rangsiruji & al., 2000b, Kress & al., 2005; *Amomum*, Xia & al., 2004, *Etlingera*, Pedersen, 2004) and reveal phylogenetic position of genera with unclear affinities (*Leptosolena*, Funakoshi & al., 2005).

The results based on analysis of DNA sequences of the nuclear internal transcribed spacer (ITS) and plastid *mat*K (Kress & al. 2002) regions suggest that the genus *Curcuma* as accepted nowadays is paraphyletic with *Hitchenia*, *Stahlianthus* and *Smithiatris*, which also share cone-like inflorescences of few flowered, congested bracts. Since the analysis was done with limited number of samples (six *Curcuma* species), the authors themselves recommended that more species of such a large genera should be added in future molecular analysis to bring more light into the difficult questions of generic boundaries and their allied genera.

Ngamriabsakul & al. (2004) studied the phylogeny of the tribe *Zingibereae* using the same nuclear gene as Kress & al. (2002) but a different chloroplast gene, *trn*L-F. Their combined phylogenetic analysis showed that *Curcuma*-like genera (*Hitchenia*, *Paracautleya*, *Smithatris* and *Stahlianthus*) are actually well-nested within the *Curcuma* complex and may be regarded as a single genus. Though there are some morphological characters supporting the separation of each taxon (genus), these characters are, as the authors suggest, autapomorphic.

A number of works used molecular markers to investigate various questions in *Curcuma*. Apavatjrut & al. (1999) confirmed efficacy of isozymes as a tool or species identification of seven highly similar *Curcuma* taxa of the early flowering group, while Paisooksantivatana & al. (2001b) used isozymes as a tool to estimate the genetic diversity in *C. alismatifolia.* Chen & al. (1999) used RAPD analysis to investigate the relationship between two Chinese *Curcuma* species i.e. *C. wenyujin* and *C. sichuanensis* and suggested that these two species are not genetically distinct making the latter a synonym of *C. wenyujin*. Islam & al. (2005, 2007) employed RAPD analyses to investigate the level of genetic diversity within and between natural populations of *Curcuma zedoaria* (Christm.) Roscoe in Bangladesh. Nayak & al. (2006) combined the RAPD and genome size estimation to evaluate genetic variation in 17 cultivars of turmeric (*C. longa*). Nucleotid sequencing of 18S r RNA and *trn*K was proposed by Cao

& al. (2001) and Cao & Komatsu (2003) as a potential molecular identification tool to recognize six medicinally important *Curcuma* species from Szechuan, China.

So far, there are no major published works focusing on phylogeny of *Curcuma*. However apart from our work in India, works in other regions are in progress (M. Ardiyani, Java; C. Maknoi, Thailand; T. Rehse, Burma & Thailand).

Polyploidy in Zingiberaceae & *Curcuma*

Determination of ploidy level, chromosome numbers and karyomorphological data can provide useful insights into taxonomic relationships and evolutionary patterns within the genus. The first chromosome number counts in Zingiberaceae were in the 1920s (Suguira, 1928). Since then, counts for at least 300 species are known. The lowest somatic number in Zingiberaceae is 2n=20, which occurs in *Mantisia* (Datta & Sarkar, 1980; Newman & Jong, 1986) and *Boesenbergia* (Beltran & Kiew, 1984). The highest number so far encountered prior to this study was in *Globba marantina* 2n=96 (Ramachandran, 1969), but is topped now by *C. raktakanta* 2n=105 (paper X.).

Within Zingiberaceae, polyploid complexes are not rare. They have been detected mostly in the subfamily Zingiberoideae (sensu Kress & al., 2002) e.g. in the genera *Globba* with 2n = 24, 32, 48, c. 64, 80, 96 (Ramachandran, 1969; Lim, 1972a,b; Larsen, 1972; Takano, 2001; Takano & Okada, 2002), *Curcuma* with 2n = 20, 24, 28, 32, 34, 36, 40, 42, 56, 62, 63, 64, 84 and 86 (full overview in Table 1. in paper X.), *Hedychium* with 2n=24, 34, 68, 52, 56, 66 (Raghavan & Venkattasuban, 1943; Sharma & Bhattacharya, 1959; Mukherjee, 1970; Chen & Chen, 1984), *Kaempferia* with 2n= 22, 24, 33, 44, 48, 54 (Raghavan & Venkattasuban, 1943; Sharma & Bhattacharya, 1959; Ramachandran, 1969; Mahanty, 1970), *Boesenbergia* with 2n=24, 36 (Poulsen, 1993) and *Zingiber* with 2n=22, 55, 66 (Bisson & al., 1968; Sato, 1960; Ramachandran, 1969). The subfamily Alpinioideae seems to be very uniform, as almost all of the members exhibit 2n=44, 48. Goldblatt (1980) assumes that the families of the Zingiberales, which all have high haploid numbers, may be derived from polyploid ancestors.

Producing unreduced gamete and consequent arisal of autopolyploids have been observed in monocots before (e.g. Refoufi & al., 2001; Brandizzi & Caiola, 1998) as well as for *Globba* (Takano & Okada, 2002). Even though triploids are usually quite rare in most of the polyploid complexes, within Zingiberaceae, they were reported in *Globba* (2n=48, Takano & Okada, 2002) and *Curcuma* (2n=63, e.g. Ajpavarut & al., 1996; Joseph & al., 1999; Sirisawad & al., 2003). However, there is a dispute as the triploidy for *Globba* was suggested based on x=16 (e.g. Takano & Okada, 2002) while Lim (1972 a,b) previously suggested x=8 (which would correspond to hexaploidy). A similar situation in *Curcuma*, where the ploidy levels (commonly diploid 2n=42, triploid 2n=63and rarely tetraploid 2n=84) were assumed with basic chromosome number being x=21 (e.g. Ramachandran, 1961, Prana, 1977; Prana & al., 1978; Islam, 2004), while Leong-Škorničková & al. suggested (Paper X.), that basic chromosome number for the genus is x=7 with 2n=6x=42, 2n=9x=63, 2n=12x=84, 2n=11x=77 and 2n=15x=105, leaving previously reported triploids to be nonaploids.

Genome size in Zingiberales & *Curcuma*

Over the past decades, much work and progress have been done to determine genome sizes in plants, yet our current knowledge is limited as it covers a small percentage of known angiosperms (e.g. Rayburn & al., 1997). Benett and co-workers (1976, 1982, 1991, 1995, 1997, 2000, 2005a,b) provided over the years compilation of data regarding genome sizes of angiosperms. These data are regularly updated and since 1997 accessible through <http://www.kew.org/cval/homepage>.

According to Bharathan & al. (1994) most of the monocot orders including Zingiberales have small genomes, while large genomes (>20 pg) are restricted just to a few monocot orders i.e. Liliales, Asparagales, Alismatales, Arales and Commelinales.

So far, there has been little work on estimation of genome size in members of Zingiberales. A check on the Kew database of C-values (Bennett & Leitch, 2005c, accessed November 2006) revealed that most of the work has been done on Marantaceae where the genome size is known for ten species of *Calathea* (Sharma & Mukhopadhyay, 1984), three species of *Maranta* (Sharma & Mukhopadhyay, 1984; Bharathan & al., 1994; Hanson & al., 1999) and a *Stromanthe* (Hanson & al., 1999).

Six species of Musa (Musaceae) also have been examined (Asif & al., 2001; D'Hont & al., 1999; Doležel & al., 1994; Kamaté & al., 2001). Lysák & al. (1999) demonstrated about 12 percent difference between genomes A (donated from *Musa acuminata*) and B (donated from *M. balbisiana*) present in triploid banana cultivars, and proposed that comparative analysis of genome size in diploids and triploids may be helpful in identifying putative diploid progenitors of cultivated triploid *Musa* clones.

Only two studies of Zingiberaceae have been included so far in Kew database. Rai & al. (1997) estimated genome size from two samples of common ginger (*Zingiber officinale*), while Bharathan & al. (1994) estimated the genome size of *Alpinia speciosa* and *Curcuma zanthorrhiza.* We have only very basic ideas about the genome sizes in other families of this order. Only one species has been so far estimated in each family: Heliconiaceae (Hanson & al., 2001), Strelitziaceae (Hanson & al., 2001), Lowiaceae (Bharathan & al., 1994), Cannaceae (Hanson & al., 2001) and Costaceae (Bharathan & al., 1994). Credibility of some of these values is downgraded due to the lack of vouchers, which enables to verify taxonomic identity of analysed plants. Only eight of all above-mentioned estimations are supported by herbarium vouchers (Table 2).

Despite only one *Curcuma* record in the Plant DNA C-values database (Bharathan & al., 1994), more genome size estimates have been published (Table 1. in paper X.). Das & al.. (1999) analysed using Feulgen densitometry three *Curcuma* species, including *C. caesia* (2n = 22, 4C = 3.120 pg), *C. amada* (2n = 40, 4C = 4.234 pg), and *C. longa* (2n = 48, 4C = 5.100-5.263 pg). The latter species was also investigated by Nayak & al. (2006) who in 17 cultivars reported 4C-values from 4.30 to 8.84 pg (i.e., 2.06-fold variation). However, the results should be treated with caution (details in paper X.). Islam (unpublished thesis, 2004) worked with good amount of material (96 accessions from Bangladesh), however, the determination of the material is often not correct. Islam for example, suggests that six accessions of *C aeruginosa* contain three different ploidy levels. Examination of four accessions used in Islam's study (C 04, C 06, C 07 & G 06) shows, that each represented different species and only C 04 was *C. aeruginosa*. A similar situation occurs in *C. zedoaria* investigated from 35 accessions. Five accessions were examined and none represented *C. zedoaria*. Very recently, Islam & al. (2007) published a paper on genetic diversity and cytogenetic analyses of *Curcuma zedoaria* (Christm.) Roscoe from Bangladesh. They found all populations to be 2n=63 with 2C DNA values ranging from 3.15-3.37 pg. Authors suggest that the phenotypic variation in *C. zedoaria* is very common and can lead to wrong taxonomic treatment of individuals. This is contrary to previous findings (e.g. Prana 1977; Škorničková & al., 2003) that polyploid taxa (2n=63) are phenotypically stable.

Vouchers are not cited in this study, but it is clear that the paper presents part of Islam's thesis (see above). It is thus most likely that the authors have included in their study more than one taxon due to the lack of comprehensive revision of *Curcuma* of Bangladesh and their results on variability of *C. zedoaria* in fact represent variability among several *Curcuma* species.

Genome size and chromosme counts of Indian *Curcuma* are presented and in broad context discussed in paper X.

Family	**Species**	**1C (pg)**	**Reference**
MUSACEAE	*Musa violascens*	0.71	Asif & al., 2001
	Musa textilis	0.63	D'Hont & al., 1999
	Musa ornata	0.62	Kamaté & al., 2001
	Musa acuminata	0.63	Doležel & al., 1994
	Musa balbisiana	0.58	Doležel & al., 1994
	Musa schizocarpa	0.60	D'Hont & al., 1999
HELICONIACEAE	*Heliconia rostrata*	0.45	Hanson & al., 2001
STRELITZIACEAE	*Strelitzia nicolai*	0.58	Hanson & al., 2001
LOWIACEAE	***Orchidantha maxillaroides***	**3.55**	Bharathan & al., 1994
ZINGIBERACEAE	***Zingiber officinale***	**4.93**	Rai & al., 1997
	Zingiber officinale	**6.03**	Rai & al., 1997
	Alpinia officinalis	**2.75**	Bharathan & al., 1994
	Curcuma zanthorrhiza	**1.30**	Bharathan & al., 1994
COSTACEAE	***Monocostus uniflorus***	**1.00**	Bharathan & al., 1994
MARANTACEAE	*Calathea clossoni*	0.38	Sharma & Mukh., 1984
	Calathea kegeliana	0.53	Sharma & Mukh., 1984
	Calathea ornata	0.45	Sharma & Mukh., 1984
	Calathea zebrina	0.35	Sharma & Mukh., 1984
	Calathea lietzei	0.40	Sharma & Mukh., 1984
	Calathea princeps	0.33	Sharma & Mukh., 1984
	Calathea undulata	0.40	Sharma & Mukh., 1984
	Calathea insignis	0.40	Sharma & Mukh., 1984
	Calathea bachemiana	0.38	Sharma & Mukh., 1984
	Calathea picturata	0.38	Sharma & Mukh., 1984
	Maranta leuconeura	**0.55**	Bharathan & al., 1994
	Maranta bicolour	0.53	Hanson & al., 1999
	Maranta arundinacea	0.38	Sharma & Mukh., 1984
	Stromanthe sanguinea	0.68	Hanson & al., 1999
CANNACEAE	***Canna indica***	**0.72**	Hanson & al., 2001

TABLE 2. C-values so far known for the members of the order Zingiberales drawn from C-value Kew database, species documented by voucher are in bold.

2. THE GENUS *CURCUMA*

2.1. GENERAL INTRODUCTION & ECONOMIC IMPORTANCE

This 'earthy herb of the Sun' with the orange-yellow rhizome was regarded as the 'herb of the Sun' by the people of the Vedic period. No wonder the ancients regarded turmeric as the Oushadhi, the healing herb, the most outstanding herb, the one herb above all others.

P. de Jager, 1997

The generic name *Curcuma* originated from the Arabic word *kurkum*, meaning "yellow", and refers to the deep yellow colour of the rhizome of the true turmeric (*Curcuma longa* L.). It originally referred to saffron, but now is exclusively used for turmeric (paper XII.).

Various species are used as spice, medicine, food flavouring and colouring, as a yellow dye for silk, cotton, paper and wood, leather and matting, baskets and various handicrafts, and as a part of religious rites since time immemorial. Nowadays, it has great commercial potential for Asian countries.

The economically most important plant of the genus is *Curcuma longa,* which yields turmeric. The processed underground rhizome is commonly used in Asian cuisine as an important constituent of curry powder (20-25%), as a dye for food and textile, as cosmetics additive (e.g. Dymock & al., 1893; Sopher, 1964; Purseglove, 1974; Purseglove & al., 1981; Dahal & Idris, 1999; Ravindran, 2007). Young shoots, inflorescences or rhizomes can be eaten raw or cooked. For Indians turmeric plays an important role in their lives as it literally accompanies them from birth to death. It is third of the plants of *navapattrikä*, the set of nine sacred plants employed in worshipping the goddess *Durgä* (Hříbek, 2002). It is also present in many rituals perfomed during child-delivery, puberty, marriage and funeral rites (e.g. Sopher, 1964; Chaudhuri & Pal, 1981; Gupta, 1981; Ravindran, 2007). Some of these and other ritual uses of *C. longa* were also reported by Prana (1977) from Indonesia.

Among other *Curcuma* species of economic importance include *C. aromatica* Salisb., *C. amada* Roxb., *C. caesia* Roxb., *C. aeruginosa* Roxb., and *C. zanthorrhiza* Roxb. (e.g. Watt, 1889; Dymock & al., 1893; Heyne, 1927). These are still in cultivation in various Asian countries in large or semi-large scale as sources of spice, condiments, medicines and for extraction of aromatic oils. Native and tribal people in most Asian countries use many more *Curcuma* species as medicinal plants, spices, food (as vegetable and source of starch) and in religious rituals.

Many *Curcuma* species are beautiful and splendid garden plants. Some like *Curcuma alismatifolia* Gagnep., *C. rhabdota* Sirirugsa & Newman., *C. roscoeana* Wall. are popular as cut flowers and are the mainstay of Thai horticultural industry. There has been much recent research on horticultural aspects, genetic diversity and micropropagation techniques on *Curcuma* (e.g. Balachandran & al., 1990; Borthakur & Bordoloi, 1992; Sugaya, 1992; Nayak, 2000; Paisooksantivatana & al., 2001a & 2001b; Salvi & al., 2001 & 2002; Shirgurkar & al., 2001; Wangsomnuk & al., 2003a,b; Yasuda & al., 1988).

FIGURE 3. (Chapter cover page.) *Curcuma* species (from left to right, top to bottom): *C.* aff. *plicata* (Thailand), *C. pierreana* (Thailand), *C. rhabdota* (Laos), *C. parviflora* (Burma), *C. rubrobracteata* (Bangladesh), *C. mutabilis* (India), *C. phaeocaulis* (Indonesia), *C. harmandii* (Thailand), *C. mangga* (Indonesia). Photographed from living collections at RBG Edinburgh (except *C. mutabilis*).

Recently there are many studies on the chemical contents, structure, and composition of curcuminoids, the phenolic compounds with high antioxidant and inflammatory properties occurring especially in yellow rhizome species i.e. *C. longa, C. zanthorrhiza*, and essential oils of various species. Experiments carried out on curcuminoids to counteract cancer, diabetes, cataractogenesis, liver diseases, and even HIV show positive results. However, the taxonomic identity of the species is important in order to search and confirm their potential uses as herbal drugs (Cao & al. 2001, Sasaki & al., 2002).

More details on economically important *Curcuma* species are presented in the paper XI.

2.2. DISTRIBUTION & SPECIES RICHNESS

The genus Curcuma *is a difficult subject for taxonomists and plant explorers owing to its occurrence in remote and inaccessible areas and its short flowering period. Consequently, we do not have realistic estimate of the diversity of the genus except for the information provided in the earlier floras.*

N. Sashidharan & V.V. Sivarajan, 1989

The genus *Curcuma* L. is naturally distributed throughout S and SE Asia with a few species extending to China, Australia, and the South Pacific. However, some popular species can be found cultivated and naturalized all over the tropics. The highest diversity is in India and Thailand, with about 40 species each, followed by Burma, Bangladesh, Indonesia and Vietnam (Table 3).

Geographic area	No. of taxa	Reference
Thailand	38	Sirirugsa & al., 2006
India (under revision)	29 reported	Jain & Prakash, 1995
	c. 45-50 estim.	Škorničková & al., unpubl.
Burma	23	Kress & al., 2003
Bangladesh	20	Yusuf, 2000
Indo-China	17	Gagnepain, 1908
Java	16	Valeton, 1918
Vietnam	14	Hô, 1993
China	12	Wu, 1996; Wu & Larsen, 2000
Malay Peninsula	9	Holttum, 1950; Larsen & al. 1999
Sri Lanka	5	Burtt & Smith, 1983
Timor	4	Spanoghe, 1841
Philippines	3	Madulid, 1996
Bhutan	3	Smith, 1994
Taiwan	3	Moo, 1978
Australia	2	Smith, 1987
Pakistan	2	Ghazanfar & Smith, 1982

TABLE 3. The species diversity in the countries/regions of S and SE Asia based on literature records.

The true number of species in the genus is unknown. Rough presumptions in last 30 years varied from c. 50 (Smith, 1981), 80 (Larsen & al., 1998) to 100 (Sirirugsa, 1996), while Škorničková & al. (2004) suggests, that the number will probably reach 120 as recent explorations in India and SE Asia proceeds. This estimation is being supported as a number of new species have been described recently from SE Asia (Sirirugsa & Newman, 2000; Mood & Larsen, 2001) and India (Škorničková & al. 2003a, b, 2004). The number of species rapidly increases in countries, where the active research or revisions on the genus are in progress. For example, the number of *Curcuma* species in Bangladesh was reported as eight by Rahman & Yusuf (1996), but reached 20 four years later (Yusuf, 2000). Sirirugsa (1996) estimated 40 species in Thailand, however almost half is formed by unidentified material. Larsen listed 34 species in his checklist of Thai Zingiberaceae (1996), and in 2005 Maknoi & al. reported two species as a new record for Thailand. Recently Sirirugsa & al. (2006) reported that there are 38 species of *Curcuma* in Thailand instead. There is only partial information about species richness in less explored countries like Laos, Cambodia and Vietnam, although considering their monsoonal climate, their diversity is expected to be high. Gagnepain (1908) reported 17 species from Indochina (Cambodia, Laos, Vietnam), but Hô (1993) has already recorded 14 species from Vietnam alone. These numbers will surely be higher for Indochina.

2.3. ECOLOGY & CONSERVATION

Due to its high demand, millions of rhizomes [of C. alismatifolia*] have been collected from its natural habitats either for direct use as an ornamental plant or as genetic stock for mass selection and breeding programs. Selective and non-selective over collection, has pushed this species to the brink of extinction in Thailand, especially from the easily accessible lowland habitats.*

Y. Paisooksantivatana & al., 2002

In their native range, monsoonal Asia, *Curcuma* species are an important component of the understorey semi-shaded areas like primary and secondary forests margins, shrubby formations, teak forests, plantations, coconut and arecanut grooves, riverbanks or rarely also in bamboo dominated forests and open grasslands. A number of them are pioneers in disturbed areas such as roadsides and ditches. A few can be found in forest as undergrowth. The ploidy level is quite closely linked to their preferred habitat and while seed-setting species are usually found in primary kind of habitats, sterile species occur in secondary and disturbed ones (Fig. 4). Several species are cultivated. *Curcuma* species are commonly found in lowlands, but can be found in their natural habitats also in higher altitudes up to 1500 m.

There is no realistic data about most of the *Curcuma* species in terms of their real distribution and conservation status - due to problems with their proper identifications and lack of recent revisions. There is no *Curcuma* species listed in IUCN Red List of Threatened Species (2006). But at least one Indian species is highly threatened. *Curcuma bhatii* is steno-endemite of Western Ghats known to occur in two localities only. It is highly specialized to exposed lateritic slopes, where it grows in rock crevices and the plant is highly endangered due to habitat loss (paper IV.). There are several stenoendemics in Western Ghats facing similar threat and some of them may become extinct before they are even discovered. Also, species like *C. angustifolia* and *C. leucorrhiza*, historically reported to be abundant are now hard to find.

About 13 *Curcuma* species in India are used in the production of East Indian Arrowroot. Pure starch is extracted from rhizomes and root tubers of cultivated as well as wild species. Some of these species are becoming rare and endangered due to overexploitation (Sabu & Škorničková, 2003; Islam, 2004; Škorničková & al., 2007).

Prana (1977) warned that the cultivation of *Curcuma* species in Indonesia is not so extensive and the forest or natural habitats have served as alternative sources to meet demands. This has caused high level of genetic erosion especially in Java and Sumatra.

Paisooksantivatana & al. (2001a,b, 2002, Paisooksantivatana & Thepsen 2001) pointed out that the decreasing number of natural populations and the rapid fragmentation of natural habitats have a severe impact on the genetic diversity of *Curcuma* in Thailand. Wangsomnuk & al. (2003a) also noted that the reduction of genetic diversity in the genus is primarily due to habitat depletion caused by agricultural and economic development. Islam (2004) reported the same for Bangladesh.

Generally, it is possible to say that sterile species with the ability to reproduce vegetatively are less likely to face the threat of extinction as they can thrive well in secondary and human-disturbed areas and most of them are now widely distributed all over Asia. The distribution of seed-setting species is usually rather limited and their natural habitats are under imminent threat by civilisation factors.

FIGURE 4. (Following page) Examples of *Curcuma* habitats. A: Dipterocarp forest, Chhattisgharh, Central India, *C. montana*. B: Exposed lateritic slopes, Udupi, South India, *C. bhatii*. C: Shrubby semideciduous slopes, Malwan, West India, *C. decipiens*. D: Open spaces, N. Bongaigaon, North-east India, *C. zedoaria*.


A
B
C
D

2.4. PAINFUL QUESTIONS IN *CURCUMA*

Major problems in the genus *Curcuma* are discussed below.

One for many & many for one: names, types, identities

'For his first sp. C. zedoaria, *he refers to Wildenow, vol. I p. 7.,* Amomum zedoaria, *on a reference to which we find the* Hort. Mal. *xi. 7 cited for a figure of the plant… and as there is no other figure or author referred to by Dr. Roxburgh, we may presume the plant to be ascertained beyond a doubt. But on proceeding to his next species,* C. zerumbet, *we find the same plate of the Hort. Mal. xi. Tab 7, referred to by Dr. R. as a figure of this plant also; a circumstance, which leaves us still in doubt as to which of the two plants is there represent. For a further explanation as to his* Zerumbet, *Dr. Roxburgh has referred us to the figure in Rumphius* Hort. Amboyn. *V. tab. 68; but this, again, is the very figure to which Willdenow has referred (with a query) for his* Zedoaria.*'*

W. Roscoe, 1815

Perhaps the most critical problem in *Curcuma* is the identities of many species, including the names so commonly used in everyday life e.g. *C. zedoaria, C. longa, C. aromatica.* Most species are quite variable, but many look alike. In addition, they may hybridize in the wild, and naturalize. Often there is one name applied to many different species or many names for one species, and the types are not yet designated for most of Curcumas. The absence of a complete revision causes great confusion among taxonomists (Velayudhan & al., 1996).

Many *Curcuma* species have been described in early history but the protologues did not reveale the details necessary for reliable identification of the species. The lack of specimens, which are either not cited, lost, deteriorating or inferior quality, makes retrospective selection of appropriate and useful type often very difficult. Likewise, the early synonymies have been mostly based on descriptions only, rarely based on study of types or original herbarium material. Moreover, an exhaustive search of all literature on published names over the last 200 years is not easy and thus many names and combinations have been published several times by different authors. The elements cited as synonymous often represent heterogeneous materials or one name is cited as synonym of several different species. Sometimes the new combinations were misapplied for a taxon, which has no connection to the basionym (e.g. *C. zedoaria*). Analysis of historical names in *Curcuma* and their synonyms shows that they form a reticulate trap (see Table 1. in paper VII.). Conservation of a name is one of the 'remedies' provided by ICBN to fix the usage of historical name regardless of its nomenclatural history to a taxon for which it is used in today's practice. This is often not applicable in *Curcuma,* as the names are applied to many taxa sharing several superficial characters. The application of another 'remedy' provided by ICBN is the rejection of ambiguous names. But this is also not desirable, as it would eventually lead to deletion of many historically important names. Perhaps the best option is to search the identities of all elements/names mentioned in historical works as proposed by their authors. Then by lectotypification to link the name to a taxon for which the name is applied most often; such choice will not cause further nomenclatural changes. Any ambiguity of existing types should be removed by assigning a suitable epitype (e.g. Paper VIII.).

Most of above-metioned problems were not specifically expressed until recently and were not addressed in most works, as it will take years to solve a single matter. The original materials are scattered in many different herbaria libraries and archives.

Not surprisingly, in spite of the few revisions for particular areas (e.g. Mangaly & Sabu, 1993; Sabu, 2006) and several theses on *Curcuma* (Prana, 1977; Ardiyani, 2002; Islam 2004), the types were not examined for most taxa and their details noted as "not known" or " not recorded". Generally the types for most of the *Curcuma* species described prior 1958 have not been resolved or designated.

Part of the problem is addressed in the paper IX., which deals with proposed types for names in Indian *Curcuma*.

The genus *Curcuma* and its pretenders: where are the borders?

Among all the natural orders, there is none, in which the genera seem less precisely ascertained by clear essential characters, than in that, which (for want of better denomination) has been called Scitamineous; and the judicious Retz, after confessing himself rather dissatisfied with his own generick arrangement, which he takes from the border of the corol, from the stamen, and principally from the anther, declares his fixed opinion that the genera in this order will never be determined with absolute certainity, until all the scitamineous plants of India shall be perfectly described.

W. Jones, 1795

Several genera like *Smithatris, Laosanthus, Paracautleya* or *Hitchenia* can be called without any hesitation ' *Curcuma* pretenders'. They possess characters responsible for the nickname. But are they really pretenders? Or are the 'borders' of the genera wrong? Is there a well-defined set of characters clearly specifying what makes a genus *Curcuma*? Perhaps it is a 'maybe' or 'who knows' to the first two questions, but it is a definite 'no' to the third.

Linnaeus did the first generic description of *Curcuma* in *Musa cliffortiana* (1736) to accommodate the only species *Curcuma rotunda* L., which is now in *Boesenbergia*. In 1753, Linnaeus added C. *longa* as a second species, without adjusting the generic diagnosis there or in his *Genera Plantarum* in 1754. It is obvious that *Boesenbergia rotunda* and *Curcuma longa* are different plants, yet the diagnosis was short and general, and left little room to contradict the difference between the two species.

Burtt & Smith vividly discussed rejecting *Curcuma* L. and conserving the generic name from later author, i.e. *Curcuma* Roxb. and submitted two proposals (1972c, 1981). However, both proposals were rejected (Committee for spermatophyta, 1974, 1984) and the genus *Curcuma* L. was conserved with *C. longa* as its conserved type (details in paper VIII.).

Burtt's & Smith's proposals show, that is was indeed Roxburgh (1810, 1820), who provided first reasonable description of the genus. Nevertheless, it is important to point out, that Roxburgh, while compiling his generic description, was familiar with only 14 species collected within British India and two species sent from Sumatra and Amboina, both likely to be introduced rather than native there. Most of these species were with prominent coma, yellow flowers, all of them falling clearly under subgenus *Curcuma* and most of them were sterile polyploids species. Roxburgh himself (1810) actually emphasized only few characters as diagnostic:

"*Corolla* with both borders three-parted. *Anther* double, base bicalcarate. Capsule 3-celled. Seeds numerous, arilled."

These are obviously not sufficient to distinguish *Curcuma* from genera like e.g. *Roscoea, Cautleya* and *Camptandra.* It was Roxburgh's detailed description of the genus (1810), which served as a pool of generic diagnostic characters used as a tool for delimitation of *Curcuma*. These usually included some of the characters as bracts connated to a neighbouring one and forming pouches, presence of bracteoles, well developed coma, anther with anther spurs, two and more flowers per bract (e.g. Valeton, 1918; Smith, 1977; 1981; Velayudhan & al., 1999; Apavatjrut & al., 1999; Ardiyani, 2002; Islam 2004). Even though the exploration of Asia was progressing and various plants were assigned to the genus, little seem to happen to the commonly accepted delimitation of *Curcuma*. In fact, few species of the genus bear all 'classical *Curcuma*' characters as understood from commonly accepted concept, while most of the species qualify to be *Curcuma* on only partial match.

Newman (1988) pointed out that at the generic level this lack of characters in Zingiberaceae leads to the separation of genera on single characters, something which may not lead to a natural grouping. However, only the complex knowledge of presence or absence of the morphological characters further supported by cytological and molecular evidence in remaining genera within the family/subfamily will enable to set the limits for each genus.

Kress & al. (2002) already mentioned, that pouched inflorescences are neither unique nor universal in the genus *Curcuma* and it was also pointed out previously, that some *Curcuma* species do not have anther spurs or coma.

Paper IV. focused on examination several morphological characters in Indian *Curcma* and concluded, that even presence of bracts and at least two flowers within fertile bracts are not 'a must' in the genus, consequently reducing the monotypic *Paracautleya* to synonymy with *Curcuma.* The full re-circumscription of the genus *Curcuma* and its delimitation against other genera is a big task yet to be successfully finished. Hopefully in the near future this will be done.

Pitfalls of infrageneric classification

> *'The species of this genus are very difficult of determination and the characters are taken almost without exception from published or unpublished drawings. Many of Sect.I [Exantha] are probably varieties, but this can be determined only by comparison of living specimens. I have failed my endeavours to subdivide the species of the several sections.'*
>
> J. G. Baker, 1890

The history of *Curcuma* infrageneric classification started was by **Roxburgh (1810, 1820)**. He simply divided the genus into two sections based on position of the spike, one consisting of plants that flower laterally and second for plants flowering centrally. It is surprising that this character was so widely used inspite of Roxburgh's early remark in (1810) '*C. rubescens 'blossoms in May, and sometimes from the centre of leaves, in September.'* This statement suggests, that some of the species are capable of producing inflorescence twice and from both positions, laterally and centrally. It also reveals, that central inflorescence may not be observed every year as it most likely depends on amount of rainfall during the monsoon season. ' Perhaps for these reasons he placed this species into the first group.

Yet, most authors who ever attempted the infrageneric classification of *Curcuma*, employed, at least up to some extent, this unfortunate character (Roxburgh, 1810; Horaninow, 1862; Baker, 1890; Valeton, 1918; Velayudhan & al., 1996). Velayudhan & al. (1996 & 1999) proposed new classification based predominantly on rhizome characters, but he still uses the position of the spike on subsectional level. An overview of the existing classifications is presented in Table 4. including the diagnostic characters for the subgenera, sections and subsection and species attributed to the respective sections by their authors.

Horaninow (1862) was aware that not only Roxburgh's *C. rubescens*, but also Dalzell's *C. decipiens* (Dalzell, 1850) exhibits double flowering from both positions and improved Roxburgh's systems by introducing the new section *Amphiantha* to accommodate such species.

However, section *Amphiantha* was soon abandoned by **Baker (1890)**, who specified '*Flower spike vernal or aestival, distinct from the leaves…*' for sect. *Exantha*, and '*Flower spike autumnal, in the center of the tuft of leaves…*' for section sect. *Mesantha*. He treated *C. rubescens* in section *Exantha*, perhaps following Roxburgh, but without justification he placed *C. decipiens* to the section *Mesantha*, even though he claimed that *C. decipiens* has spikes aestival, lateral and later central. Baker admitted that he had taken most of the characters from published and unpublished drawings. And it was perhaps the drawings that inspired him to group the species with '*Spike autumnal, from the center of the tuft of leaves, very obtuse bracts, adnate at sides and spreading at the tip*' into section *Hitcheniopsis*. Baker, who dealt only with non-living material, sensed that the classical approach of herbarium taxonomy is not at all suitable for solving the questions in the genus *Curcuma*. Looking back into Baker's attempt, there are at least another four species placed in either of the sections, but according to later reports or my observations are able to flower twice from both positions (*C. reclinata, C. oligantha, C. neilgherrensis, C. albiflora*). *Curcuma kunstleri*, placed in *Mesantha* is member of *Scaphochlamys*.

Gagnepain (1903) was unable to place his two new species *C. gracillima* and *C. sparganifolia*, to any of Bakers sections. He proposed a new section *Ecalcarata* to accommodate these two species he considered to be an imtermediate between *Curcuma* and *Hitchenia* (not tabulated). However, from Gagnepains later works (1905, 1907) it is obvious that he found difficulties with Baker's sections as he was describing more new species from Indochina. These did not fit clearly into any of them. In his *Flore Generale d' Indo-chine* Gagnepain did not mention any infrageneric classification in *Curcuma*.

Schumann (1904) mostly upheld Baker's treatment, but felt that members of sections *Exantha* and *Mesantha* are closer to each other than to a third section *Hitcheniopsis*, and thus introduced the subgeneric concept. He placed the first two sections into *Eucurcuma* (has to be corrected to *Curcuma*) and Baker's section *Hitcheniopsis* was brought up to the subgeneric level. He added presence of anther spurs (*Curcuma*) and its absence (*Hitchenipsis*) to diagnostic characters of these two subgenera. Again, Schumann worked exclusively on herbarium specimens, descriptions and perhaps some drawings. And so again, several species are not placed where they should be. He placed some species differently from Baker (e.g. *C. oligantha* is under *Mesantha* of Baker, but under Exantha of Schumann; *C. kunstleri* is under Baker's *Mesantha*, but Schumann's *Hitcheniopsis*). Schumann also placed some species in contradiction with his own subgeneric delimitation (e.g. *C. sylvestris* - now *Scaphochlamys sylvestris* - has no anther spurs, yet is in subg. *Curcuma*, or *C. petiolata* was clearly described with anther spurs as depicted on the drawings, which Schumann cited, but yet it was placed in the subgenus *Hitcheniopsis*).

Valeton (1918) criticized both Baker (1890) and Schumann (1904), for the delimitation of the section/subgenus *Hitcheniopsis*. Baker, according to Valeton, established the section mostly based on *C. roscoeana*. Valeton argues, that *C. roscoeana* was transferred to *Hitchenia* by Bentham (Bentham & Hooker, 1883) and this was followed also by Petersen (1889). Valeton did not consider *C. roscoeana* as a member of *Curcuma*. He pointed out Schuman's mistake in placement of C. *petiolata* and criticised the adnation ratio of the bracts as a vague character. He considered the species that Schumann combined into the subgenus *Hitcheniopsis* (following Baker's, Ridley's and Gagnepain's description) as belonging to a very heterogeneous group. Valeton proposed to keep the subgenus *Curcuma*, but to abandon *Hitcheniopsis* as drawn by Schumann and instead to establish a new subgenus *Paracurcuma* (partly based on Baker's *Hitcheniopsis*), to include the species receding from what he considers the 'original *Curcuma* type'. His descriptions of both subgenera were long and set on whole complex of characters. Yet, even Valeton's attempt is not satisfactory. Firstly, he worked with limited material from Malesian region only, and thus could not cover the whole variability of the characters occurring in the genus. Secondly, he uses bract adnation ratio as a character, even though he criticised it in Schumann's work. Thirdly, even Valeton placed several species incorrectly within his own subgenera e.g. *C. latifolia* or *C. montana*, which does not fit to the subgenus *Paracurcuma* in most of the characters and are actually fairly good examples of subg. *Curcuma.*

Velayudhan & al. **(1996, 1999)** attempted to propose infrageneric classification based on Indian *Curcuma* species only. They have published their first attempt in 1996 and refined it three years later (1999) with one adjustment in a subsectional level (introducing the subsection *Tuberoamphiantha*). They proposed names for all subsections as well as adjustment of placement of several species into different sections/subsections (compare in Table 3). Velayudhan & al. (1996) concluded, that Valeton's two subgenera *Curcuma* and *Paracurcuma* can be upheld, but the diagnostic characters have to be changed to include presence of anther spurs (*Curcuma*) and their absence (*Paracurcuma*). In this work, they also divided the subgenus *Curcuma* into three sections based on rhizome characters. A further subdivision of these sections was again based on the position of the inflorescence. In 1999 authors newly introduced subsection *Tuberoamphiantha* for species with branched rhizomes exhibiting both, lateral and central inflorescence, with cited example of *C. caesia.* This species is however sterile species (2n=63) flowering exclusively laterally. To date the only description of any Indian species described with branched rhizome producing both types of inflorescence is that of *C. rubescens*. However, others have not observed the central inflorescence in *C. rubescens* since Roxburgh. Another subsection *Nontuberomesantha* referred to species with simple ovoid rhizome and exclusively central spikes, naming *C. pseudmontana*, *C. decipiens* and *C. vellanikarensis* as typical examples. However, the first two species exhibit both types of inflorescences (lateral and central) as elaborated by Santapau (1945) for *C. pseudomontana* and mentioned in protologue of *C. decipiens*. *Curcuma vellanikarensis* was not validly published yet (nom inval., in Velayudhan & al., 1999). However, it is clear that it represents one of the seed-setting species of Western Ghats close to *C. karnatakensis* (Velyudhan, pers. comm.) and it is most likely that this species (*C. vellanikarensis*) also displays both types of inflorescence if observed for prolonged period. From Indian representatives only recently reported *C. roscoeana* (paper V.) and *C. aurantiaca* would fit to this subsection, but the latter was placed by the authors to the subgenus *Paracurcuma*.

Velayudhan & al. (1996) pointed out that previous classifications of the genus are incomplete as not all entities of the entire range of variation are included. Their own work (1996, 1999) suffered from the same limitation as they have created infrageneric classification for Indian species only, without considering vast variability of Thai taxa. Number of Thai species would fall by rhizome characters into the sections

Stolonifera and *Nontuberomesantha/Nontuberoexantha*, but by general appearance and many morphological characters would be out of place in the groups assigned.

In 1999 (Velayudhan & al.) attempted evaluate relationships by numerical methods, but the results did not support proposed classification.

The conclusion is that none of the previously proposed infrageneric classifications is suitable. None is natural, i.e. reflects the phylogenetic relationships among species, nor is convenient.

The meaningful infrageneric classification only can be done when:

1) The genus *Curcuma* is well defined and delimited from related genera, and will comprise only of members forming monophyletic group.
2) All or at least most of the members sampled throughout the whole distribution range of the genus will be involved and their morphology will be thoroughly examined from living flowering material, supported by cytological and molecular studies. When performing any kind of phylogenetic analysis, all samples should be linked to voucher specimens.
3) Only correctly identified material is used. This presumes to have type for each name and be able to link the correct names to each taxon.

TABLE 4. Overview of existing infrageneric classifications in *Curcuma*. Diagnostic characters of subgenera and sections are in italic bold, authorities given only if different from today's perception or could be confused. Colours of the groups correspond across the table.

ROXBURGH 1810, 1820	HORANINOW 1862	BAKER 1890
Sect. 1 ***Spikes lateral, appearing before or with leaves.*** Species included: *C. zedoaria* sensu Roxb., *C. zerumbet, C. caesia, C. aeruginosa, C. ferruginea, C. rubescens, C. leucorrhiza, C. angustifolia,C. zanthorrhiza, C. elata, C. comosa*	**Sect. *Exantha*** ***Scapi laterales s. juxtafoliacei, passim praecoces; folia plurium rubro-liturata.*** Species included: *C. neilgherrensis, C. angustifolia, C. leucorrhiza, C. caesia, C. aeruginosa, C. amarissima, C. elata, C. aromatica, C. comosa, C. zanthorrhiza, C. latifolia, C. zedoaria* Roscoe, *C. ferruginea*	**Sect. *Exantha* Horan.** ***Flower spike vernal or aestival, distinct from the leaves, and usually developed before they appear; peduncle sheathed by scariose bract-leaves.*** Species included: *C. angustifolia, C. neilgherrensis, C. aromatica, C. zedoaria* Roscoe, *C. elata, C. comosa, C. ornata, C. latifolia, C. leucorrhiza, C. caesia, C. aeruginosa, C. amarissima, C. ferruginea, C. rubescens*
Sect. 2 ***With Spikes central.*** Species included: *C. longa, C. amada, C. montana, C. reclinata, C. viridiflora, C. petiolata*	**Sect. *Mesantha*** *Scapus centralis; folia plerumque pure viridis et longe petiolata.* Species included: *C. longa, C. viridiflora, C. amada, C. montana, C. petiolata, C. cordata, C. parviflora, C. roscoeana, C. reclinata, C. purpurascens?*	**Sect. *Mesantha* Horan.,** ***Flower spike autumnal, in the centre of the tuft of leaves; bracts not recurved at the tip.*** Species included: *C. attenuata, C. plicata, C. amada, C. longa, C. montana, C. kunstleri, C. reclinata, C. decipiens, C. albiflora, C. oligantha*
	Sect. *Amphiantha* ***Scapi laterales et centrals.*** Species included: *C. rubescens, C. decipiens*	**Sect. *Hitcheniopsis* Baker** ***Spike autumnal, from the centre of the tuft of leaves; bracts very obtuse, adnate at the sides and spreading at the tip.*** Species included: *C. parviflora, C. strobilifera, C. grandiflora, C. petiolata, C. roscoeana*

Continue on next page.

TABLE 4. Contd. Overview of existing infrageneric classifications in *Curcuma*. Diagnostic characters of subgenera and sections are in italic bold, authorities given only if different from today's perception or could be confused. Colours of the groups correspond across the table.

SCHUMANN 1904	VALETON 1918
Subg. *Eucurcuma* Schum. (*Curcuma*) ***Bracteae basi tantumaxi et bracteis contiguis adnatae, apice haud anguste recurvatae, antherae ubique calcaratae.*** **Sect. *Exantha* Horan.** ***Spica vernalis foliis antecedens vel cum iis oriunda.*** Species included: *C. angustifolia, C. neilgherrensis, C. oligantha, C. leucorrhiza, C. zedoaria* Roscoe, *C. elata, C. latifolia, C. aromatica, C. caesia, C. aeruginosa, C. zanthorrhiza, C. comosa, C. ornata, C. ceratotheca, C. rubescens, C. amarissima, C. ferruginea, C. porphyrotaenia, C. rotunda* sensu Lour., *C. pallida* **Sect. *Mesantha* Horan.** ***Spica autumnalis i.e. cum foliis et e centro eorum.*** Species included: *C. sylvestris* Ridl., *C. attenuatta, C. plicata, C. reclinata, C. decipiens, C. albiflora, C. coerulea, C. montana, C. purpurascens, C. australasica, C. amada, C. longa, C. sumatrana*	**Subg. *Eucurcuma* Schum. (*Curcuma*)** ***Bracts mostly not adnate over the middle, long coma bracts. Staminodia longitudinally grooved, folded under the cuculate and pointed dorsal lobe. Anthers calcarate. Full grown leaves acuminate at the base. Rhizomes lenghtened, consisting of merithalia and forming lateral branches.*** **[excerpted, full descript. in orig.]** **Sect. *Exantha* Horan.** ***Inflorescence originatig laterally from the rhizome, non foliate.*** Species included: *C. zedoaria* Roxb., *C. zanthorrhiza, C. phaeocaulis, C. aeruginosa, C. mangga, C. mangaa var. rubrinervia, C. manga var. sylvestris, C. heyneana, C. lorzingii* **Sect. *Mesantha* Horan.** ***Inflorescence originating from the centre of the foliate stem.*** Species included: *C.domestica, C, purpurascens, C. viridiflora, C. colorata, C. euchroma, C. soloensis, C. brog, C. ochrorrhiza*
Subg. *Hitcheniopsis* Baker ***Spica autumnalis e medio foliorum, bracteae tota longitudine lateraliter adnatae apice liberae et divaricantes et recurvatae, antherae basi ecalcaratae.*** Species included: *C. grandiflora, C. strobilifera, C.parviflora, C. petiolata, C. kunstleri, C. roscoeana, C. gracillima, C. sparganiifolia, C. alismatifolia*	**Subg. *Paracurcuma* Valeton** ***Bracts very numerous, connected beyond the middle, short coma bracts, bracteoles small, staminodia straight, larger than the dorsal petal, dorsal petal not clasping the staminodes. Anthers attaches near the base, not or very short calcarate. Stem short, leaves spreading, short or long stalked, the base mostly rounded. Rhizome short or wanting, bulbs or tubers on groups.*** **[excerpted, full descript. in orig.]** Species included: *C. aurantiaca, C. petiolata, C. cordifolia (cordata), C. meraukensis, C. latifolia, C. australasica, C. montana, C. longa* sensu Bentl. & Trimen

TABLE 4. Contd.

VELAYUDHAN & AL. 1996	VELAYUDHAN & AL. 1999
Subg. *Eucurcuma* Val. (*Curcuma*) **Sect. *Tuberosa* Velay. & al.** ***Sessile tubers present.*** **Subsect. 1.** ***Flower spikes born on the tip of sessile tubers during the of- season.*** Species included: *C.zedoaria* Roscoe, *C. latifolia, C. comosa, C. aeruginosa, C. malabarica, C. raktakanta, C. amada, C. haritha, C. sylvatica* Val.,*C. aromatica, C. caesia* **Subsect. 2.** ***Flower spikes born on the tip of primary mother rhizomes (primary root stocks) or on secondary mother rhizomes (secondary root stocks).*** Species included: *C. longa, C. montana, C. brog, C. soloensis* **Sect. *Nontuberosa* Velay. & al.** ***Sessile tubers absent.*** **Subsect. 1.** ***Flower spikes born on the buds arising from the sides of the primary or the secondary mother rhizomes (root stocks).*** Species included: *C.neilgherrensis, C. coriacea, C. kudagensis* **Subsect. 2.** ***Flowe spikes born on the tip of the primary or secondary mother rhizomes (primary root stocks).*** Species included: *C. pseudomontana, C. decipiens, C. vellanikarensis* **Subsect. 3.** ***Flower spikes arising both from the tip and from the sides of the mother rhizomes in different seasons.*** Species included: *C. albiflora, C. cannanorensis, C. karnatakensis, C. lutea, C. thalakaveriensis, C. oligantha, C. nilamburensis* **Sect. *Stolonifera* Velay. & al.** ***Stoloniferous tubers arising from the rhizomes.*** Species included: *C. vamana*	**Subg. *Eucurcuma* Val. (*Curcuma*)** **Sect. *Tuberosa* Velay. & al.** ***Sessile tubers present.*** **Subsect. 1. *Tuberoexantha*** ***Species have both sessile fingers and lateral spikes.*** Species included: *C. zedoaria* Roscoe, *C. latifolia, C. comosa, C. aeruginosa, C. malabarica, C. raktakanta, C. amada, C. haritha, C. sylvatica* Val..,*C. aromatica* **Subsect. 2. *Tuberomesantha*** ***Species have both sessile fingers and central spikes.*** Species included: *C. longa, C. montana, C. brog, C. soloensis* **Subsect. 3. *Tuberoamphianta*** ***Species have sessile fingers and both, central and lateral spikes.*** Species included: *C. caesia* **Sect. *Nontuberosa* Velay. & al.** ***Sessile tubers absent.*** **Subsect. 1. *Nontuberoexantha*** ***Sessile tubers absent and spikes lateral.*** Species included: *C. angustifolia, C. coriacea, C. kudagensis* **Subsect. 2. *Nontuberomesantha*** ***Sessile tubers absent and spikes central.*** Species included: *C. pseudomontana, C. decipiens, C. vellanikarensis* **Subsect. 3. *Nontuberoamphianta*** ***Sessile tubers absent and both lateral and central spikes are present.*** Species included: *C. albiflora, C. cannanorensis, C. karnatakensis, C. lutea, C. thalakaveriensis, C. oligantha, C. nilamburensis* **Sect. *Stolonifera* Velay. & al.** ***Tubers stoloniferous.*** Species included: *C. vamana*
Subg. *Paracurcuma* Valeton Species included: *C. aurantiaca, C. ecalcarata*	**Subg. *Paracurcuma* Valeton** Species included: *C. aurantiaca, C. ecalcarata*

Lateral, central or both?

The question as to whether the spike is vernal or autumnal, lateral or central seems also to have vexed many of the authors who have written on the Scitaminaceae; but the cause of such a confusion must be attributed to defective observation of the plant, which has the 'unfortunate' habit of bursting into flower during the most unpleasant part of the year.

H. Santapau, 1945

All *Curcuma* species exhibit one of the three modes of the flowering, i.e. lateral (in the beginning of the rainy season), central (later in the season) or both (Fig. 5). This character, however, is not useful as a key character (as which is often used) or for evaluation of herbarium specimens. Firstly, the specimens are often collected in a way, which do not reveal the position of the inflorescence. And secondly, it is still impossible to verify, whether mounted specimen is able to produce both types of inflorescence later in the season, if left on the locality. This character is observable only during prolonged period (several years), on the locality itself, in cultivation or preferably both. Burtt (in Burtt & Smith, 1972b) suggested that for practical reasons it is probably best to key out *Amphiantha*-type species under both *Mesantha* and *Exantha*, rather than to have an independent group, which can only be recognized by round-the-season observation.

Even though the capability of some species to produce inflorescence twice in one season have been reported for the number of species by several authors (e.g. Dalzell, 1850; Santapau, 1945; Chavan & Oza, 1960; Mangaly & Sabu, 1987, 1993; Velayudhan, 1996, 1999) a full overview is not known.

Results of field/cultivation observations on flowering behaviour of Indian *Curcuma* species correlating to their ploidy level and basic rhizome architecture and relative variability are summarized in Table 5.

According to my observations, all sterile species (with 2n=9x=63) exhibit only one mode of flowering, either lateral (most of Indian species) or central (*C. longa* and number of Javanese species), but never both. The situation is different in seed-setting species (2n=42); most of them are capable to flower twice, first laterally and then centrally later in the season. On the other hand, there are several seed-setting species in India, which exclusively flower either laterally (e.g. *Curcuma angustifolia, C. mangga* and two potential spp. with insufficient data) or only from the center of the leaves (e.g. *C. aurantiaca*, *C. montana, C. bhatii, C. caulina, C. rubrobracteata* and several more are known from Thailand).

TABLE 5. (Following page) Position of inflorescence in relation to the ploidy level, rhizome structure and variability in Indian species. Values assigned '?' were not confirmed, but cannot be ruled out yet, value assigned '?R' was reported in literature, but was not confirmed by direct observation. (both= central & lateral, infl.pos. = inflorescence position, informal names are author's preliminary working names)

Species	Infl. Pos.	Rhizome	Variability	Reprod.
2n=2x=22				
C. vamana (= C. peethapushpa)	Central	Branched	Low	Veg./Sex.
2n=6x=42				
C. angustifolia	Lateral	Ovoid	Medium	Sexual
C. sp. 3 'teesta'	Lateral	Ovoid	Medium	Sexual
C. mangga	Lateral	Branched	Low	Veg./Sex.
C. aff. aromatica 1.	Lat./Cent.?	Branched	Low	Veg./Sex.
C. prakasha	Lat./Cent.?	Branched	High	Veg./Sex.
C. aurantiaca (= C. ecalcarata)	Central	Ovoid	High	Sexual
C. caulina	Central	Ovoid	Medium	Sexual
C. roscoeana	Central	Ovoid	Low	Sexual?
C. amada	Central	Branched	Medium	Veg./Sex
C. bhatii	Central	Branched	Low	Veg./Sex.
C. rubrobracteata	Central	Branched	Low	Veg./Sex.
C. cananorensis (= C. lutea)	Both	Ovoid	High	Sexual
C. coriacea	Both	Ovoid	Medium	Sexual
C. decipiens	Both	Ovoid	High	Sexual
C. inodora (= C. purpurea)	Both	Ovoid	High	Sexual
C. karnatakensis	Both	Ovoid	Medium	Sexual
C. kudagensis (= C. thalakaveriensis)	Both	Ovoid	Medium	Sexual
C. mutabilis	Both	Ovoid	High	Sexual
C. neilgherrensis	Both	Ovoid	Medium	Sexual
C. pseudomontana (= C. ranadei)	Both	Ovoid	High	Sexual
C. reclinata (= *C. sulcata*)	Both	Ovoid	High	Sexual
C. rubescens	Both ?R	Branched	Medium?	Veg./Sex.
C. sp. 7 'repens'	?	Branched	?	Veg./Sex.?
C. sp. 8 'sulphurea'	?	Branched	?	Veg./Sex.?
2n=9x=63				
C. aeruginosa	Lateral	Branched	Low	Vegetative
C. aff. amarisima	Lateral	Branched	Low	Vegetative
C. aff. aromatica 2.	Lateral	Branched	Low	Vegetative
C. aff. aromatica 3.	Lateral	Branched	Low	Vegetative
C. haritha	Lateral	Branched	Low	Vegetative
C. caesia	Lateral	Branched	Low	Vegetative
C. codonantha	Lateral	Branched	Low	Vegetative
C. elata	Lateral	Branched	Low	Vegetative
C. ferruginea	Lateral	Branched	Low	Vegetative
C. latifolia	Lateral	Branched	Low	Vegetative
C. leucorrhiza	Lateral	Branched	Low	Vegetative
C. 'picta' [C. zerumbet sensu Roxb.*]*	Lateral	Branched	Low	Vegetative
C. zanthorrhiza	Lateral	Branched	Low	Vegetative
C. sp. 1 'ela-latif'	Lateral	Branched	Low	Vegetative
C. sp. 4 'man-and'	Lateral	Branched	Low	Vegetative
C. sp. 9 'tikhur'	Lateral	Branched	Low	Vegetative
C. longa	Central	Branched	Low	Vegetative
C. sp. 10 'zanthorrhiza aff.'	?	Branched	?	Veget./Sex.?
2n=11x=77				
C. oligantha (Sri Lanka)	Both	Branched	Medium	Veg./Sex.
2n=15x=105				
C. raktakanta (= C. malabarica)	Lateral	Branched	Low	Vegetative
C. sp. 5 'bongai'	Central	Branched	Low	Vegetative
Unknown				
C. sp. 2 'fucata' (2n > 70)	Lateral	Branched	Low	Veg./ Sex.?
C. sp. 6 'roxburgh'	Lateral	Branched	Low	Veg./ Sex.?

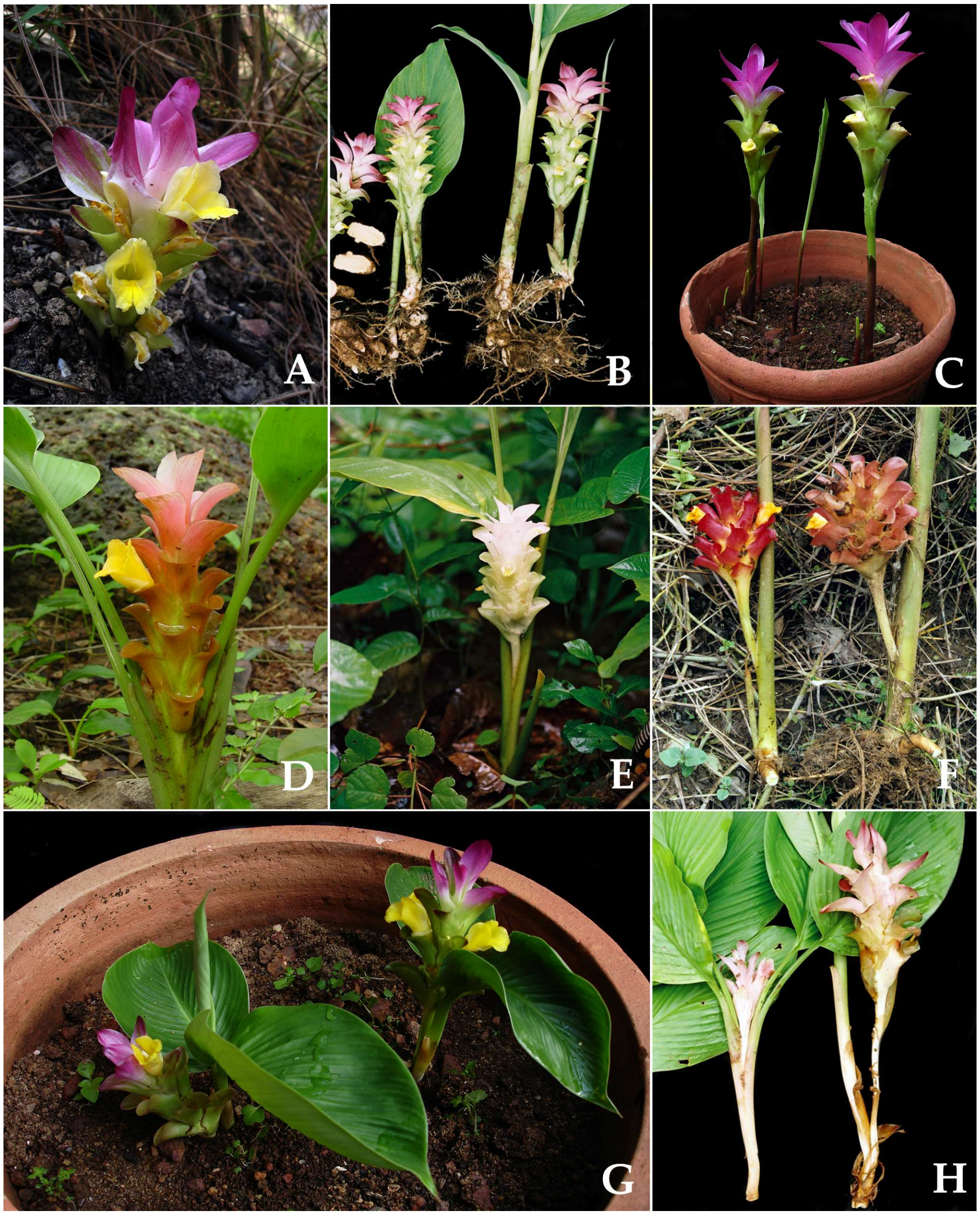


FIGURE 5. Position of inflorescences in *Curcuma*. Lateral inflorecence - A: *C. angustifolia*; B: *C. aromatica aff. 1*; C: *C. raktakanta/zedoaria*. Central inflorescence - D: *C. aurantiaca*; E: *C. montana*. Central infl. prodtruding throught the pseudostem - F: *C. rubrobracteata.* Species capable to produce both types of inflorescence G: *C. pseudomontana*, lateral inflorescence (left) and central inflorescence (right); H: *C. reclinata* lateral inflorescence (right) and central inflorescence (left).

Too much & too little: variability issues

The specific epithet refers to the extremely variable colour of floral parts and size of the plants.

Etymology of *Curcuma mutabilis*, 2003

This section provides an insight into different levels of variability in various *Curcuma* species as observed in the field and links it to the ploidy level, rhizome architecture and possible mode of reproductions of these species in Table 5.

Members of the genus *Curcuma* were thought to look very much alike and that it is difficult to recognize them unless through direct comparison with living plants. Yet, *Curcuma* species do have subtle, yet consistent and permanent differences (Roxburgh 1810; Wight, 1853; Valeton, 1918). This impression is understandable, if we realize, that most of the species described in early history were sterile polyploids reproducing vegetatively. Naturally, their variability was very limited. In fact, these sterile species may represent just a few clones and were distributed over many areas during migrations over the years. All sterile species thrive well in rural conditions and secondary habitats. Many are cultivated in home gardens - perhaps another reason why these were likely to be collected and studied in the early history.

Roxburgh (1810, 1820) described just a few seed-setting species. Out of them only *C. reclinata* exhibits higher variability at the natural localities. However, this species was not collected by Roxburgh himself but was brought to him by H.T. Coolebrooke in 1802 from central India. Roxburgh was thus perhaps exposed to only a few specimens and he could not have ascertained the real variability of this seed-setting species.

Valeton (1918) was in a similar position. He worked on Javanese Curcumas, which all but two were sterile. Yet he observed rather high variability in *C. aurantiaca*, which set seeds freely. Valeton considered it as perhaps the only native species.

Santapau (1945, 1952) was next to notice rather high infrapopulation variability. He observed populations of *Curcuma pseudomontana* for several years. This is a seed setting species exhibiting both types of inflorescences (lateral and central). In 1996 Sivarajan & Matthew observed high variability in plants they considered to be *C. neilgherensis*. These plants were later described as *C. mutabilis* (Škorničková & al., 2004) where the problem of variability of seed setting 'diploids' (now hexaploids with 2n=42) has been discussed.

The infrapopulation variability was underestimated by Ansari & al. (1982) when they described *C. cannanorensis.* They recognized two varieties – a white-flowered var. *cannanorensis* and a yellow-flowered var. *lutea*. They distingushed these two varieties based on broader corolla lobes, slightly different shape of staminodes and lip, and a larger lip. This was supported by Velayudhan & al. (1991a) and further exaggerated by Amalraj & al. (1992b), who argued that 'colour of the staminodes are prominent in giving the overall appearance to the flower and thus colour of flower or staminodes is an important character in *Curcuma*'. In line with this statement they proposed to warrant a species rank for var. *lutea.* They tabulated nine minor differences in bract and flower, which appeared to be done from very few plants. A visit to the type locality of *C. cannanorensis* showed huge population of plants, which exhibited a whole range of flower/bract features with colours, shapes and sizes. All these plants were growing intermixed in populations covering tens of square metres. It is thus not sensible to keep the yellow-flowered and white-flowered plants as separate varieties, much less at species level (Fig. 6).

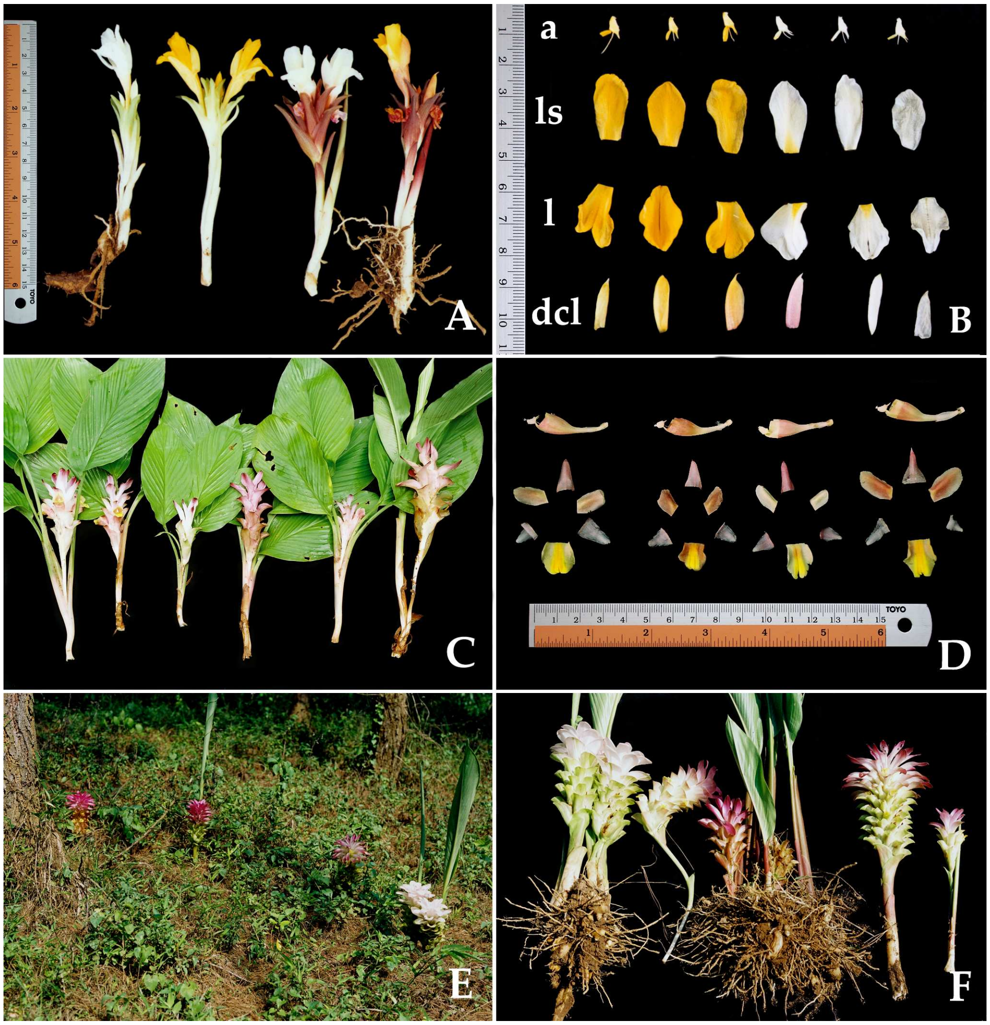


FIGURE 6. Examples of variability in seed-setting species. A & B: *C. cannanorensis*, type loc. (a – anther; ls – lateral staminodes; l – labellum; dcl – dorsal corolla lobe). C& D: *C. reclinata*. E & F: *C. prakasha* aff.

Another example of variability potential is a species related to *C. prakasha*, occurring in Meghalaya in NE India, where it is very common in pine forests. (Fig. 6). While the colour and shape of the flowers are more or less stable, the bracts are white to deep pink and have shapes from very long, lanceolate and spreading to broad, short and obtuse. The leaves are green, with a red patch, protruding to lower side or not with various level of pubescence on either side, both or none. The rhizome is almost always branched, but branches may be few or many, differ in size, and exhibit considerable degree of colour variation from almost white to yellow and light creamy-orange.

My field observations are summarized in Table 5. Low variability represents taxa with stable or no variation in the colour of the floral and vegetative parts, indumentum of the lamina as well as size of the plants within population. Taxa with high variability vary in all or most characters/group of characters mentioned above. Medium variability represents cases, where there is some notable variability in one or few characters though not so prominent at glance.

In summary, all sterile species (2n=63, 105) have branched rhizomes and exhibit low variability. This is not surprising as they can reproduce exclusively vegetatively. Various seed-setting (2n=22, 42, 77) species however exhibit any of the three different levels of variability and one of two rhizome architectures. Seed-setting species with branched rhizomes usually exhibit medium to low level of variability (with the exception of *C. prakasha* with high variability), while seed-setting taxa with unbranched (simple ovoid) rhizomes exhibit mostly high to medium variability. This makes sense as the latter rely on sexual reproduction thus explaining their higher variability, while seed-setting species with branched rhizomes reproduces either generatively or vegetatively. Species with ovoid rhizome can reproduce within limits vegetatively as more than one plant can appear from the main rhizome. But in this case the plant's ability to spread spacially is low, as the two plants from the same rhizome are attached close to each other.

It is plausible to hypothesize that vegetative reproduction evolved as a consequence of disturbed sexual reproduction of the hybridogenous taxa.

Sterility in *Curcuma* species

Sterility in *Curcuma* species is common in many polyploid species, particularly those previously reported as 'triploids' (nonaploids with 2n=63). This has severe implications for crop selection of commercially utilized species (including the most important *C. longa*), as the genetic improvement through the conventional breeding is handicapped (Joseph & al., 1999). Various authors searched for the cause of sterility in *Curcuma*.

Valeton (1918) noticed the failure in fruit and seed setting in many Javanese *Curcuma* species, but he suspected the absence of pollinators to be the cause.

Ramachandran (1961) opined that sterility in *C. domestica* [*C. longa*] is due to autotriploid condition (with 2n=63, now regared as nonaploids). Autotriploids may not necessarily be sterile, but with a higher basic number for the genus, the chances for sterility are higher (Darlington, 1973) and if *C. longa* is allotriploid (2n=63, now nonaploid), the chance is even higher.

Panchaksharappa (1961) observed in *C. aromatica* [not stated which ploidy level, but it is assumed it was not seed-setting species] various abnormalities in size of the embryo sacs and disposition of nucellar nuclei, which led to invariable degeneration of the ovules. Contrary to that Sastrapradja & Aminah (1970) observed embryo sac development, meiosis and anther development in seed-setting *C. aurantiaca* and non-seed-setting *C. loerzingii* to determine the cause of unfruitfulness so commonly found in the genus. They observed, that embryo sac development in both *C. aurantiaca* and *C. loerzengii* follows the *Polygonum*-type as reported in several genera of Zingiberaceae by Panchaksharappa (1962b) and Sachar & Arora (1962). No abnormalities in embryo sac development were observed in these two species. Thus they concluded that failure to set fruit is not due to failure of embryo sac development. Male sterility as a factor in limiting fruit setting includes absence of anther dehiscence, staminal sterility or sterility due to pollen abortion, the latter apparently present in genus *Curcuma*. While microspore mother cells in *C. aurantiaca* undergo normal meiotic division, resulting in normal pollen grains, meiotic process in *C. loerzingii* is highly disturbed by chromosome bridges with fragments at A-I and A-II, and the presence of laggards, leading to formation of non-viable pollen.

Prana (1977) observed that contrary to Valeton's report on lack of pollinators, bees tend to visit *Curcuma* flowers frequently, yet seed setting has been observed only in *C. aurantiaca*. His tests on stainability and germination of pollen showed that the highest percentage of stainable pollen was observed in *C. aurantiaca* (97%), followed by *C. mangga* (28%), *C. aeruginosa* (28%), *C. zanthorrhiza* (19%) and *C. petiolata* (12%). The rest of the Javanese species show levels below 10% and pollen in *C. soloensis* and *C. brog* are almost exclusively aborted. Pollen of *C. aurantiaca* and *C. manga* is highly homogeneous in size and shape, while the rest of the species exhibited heterogenity in pollen. The germination test confirmed the fertility of pollen in *C. auratiaca* as good, and in *C. mangga* as fairly good, while the rest of the species were scored as bad, very bad or none. Nasir Udin (2000) observed pollen in *C. longa* and reported that about 52% of pollen grains are stainable.

Although Prana (1977) found 'diploid' (now hexaploid with 2n=42) *C. aurantiaca* as highly fertile, the other two Javanese 'diploids' (2n=42) *C. mangga* and *C. petiolata* showed very low fertility. Joseph & al. (1999) also mentioned that not only vegetatively reproducing 'triploid' (2n=63) *Curcuma* species, but even some 'diploids' (2n=42) and 'tetraploids' (2n=84) have been reported not to produce or rarely produce seeds due to incompatibility and high pollen sterility.

It is notable that both *C. mangga* and *C. petiolata* have branched rhizomes and are also capable of vegetative reproduction, while *C. aurantiaca* fully depends on seed-setting reproduction. The observation on Indian species similarly suggests that species with 2n=42 and simple unbranched rhizomes set seeds easily and have high infrapopulation variability, while most of the species 2n=42 with branched rhizomes set seeds less often and their infrapopulation variability is lower (see Table 5).

Species concept in *Curcuma*: Pluralistic approach?

The genus Curcuma*, so far as regards the determination of species, is rather difficult, but to distinguish a* Curcuma *from any other genus of the order is easy after any one of its species is known. The peculiar formation of the spike, and very characteristic bracteal sacks which are common to all, proclaim at once the genus….Neither having roots nor growing plants before me, I find it most difficult to indicate characters by which the following species can be distinguished from the 20 others of the genus, though, so far as I can detect, it does not accord with any of them.*

R. Wight, 1853

Backer & Bakhuizen (1968), while working on Flora of Java were unable to recognize the boundaries between most of the Javanese *Curcuma* species. In their treatment, all species flowering laterally were considered as intraspecific taxa of *C. zedoaria*, while all species exhibiting central flowering as intraspecific taxa of *C. viridiflora*. The seed-setting *C. aurantiaca* was treated on species level. This was however merely based on herbarium studies, undoubtedly inadequate as far as *Curcuma* is concerned (Prana, 1977). Prana (1977) claims that most of the Javanese species can be distinguished from each other merely by their vegetative characters and that there is no significant intraspecific variation observed within any of the species. Even the variability of two 'diploid' species (hexaploid with 2n=42) *C. aurantiaca* and *C. mangga* var. *rubrinervia* is according to Prana low, while Valeton claims variability of *C. aurantiaca* to be high.

Ardiyani (2002) in her thesis expressed opinion that all Javanese species from subgenus *Curcuma* are varieties/hybrids of *C. longa*. However, this conclusion was drawn from limited material. Most (if not all) Javanese *Curcuma* species are not likely to be native and all but three are sterile (with 2n=63). Their distribution in Java is likely to be the result of human migrations, which occurred between South and Southeast Asia in early centuries AD. Parentage of these polyploid taxa is not clear and cannot be solved on Javanese material, as there are no species, which could be possible parents of *C. longa* or any of other Javanese species. Species in India and Java overlap in distribution and in India there are several seed-setting species from subgenus *Curcuma*, potentially the parental species of *C. longa* and other sterile nonaploids species (with 2n=63). Preliminary results from genome size of Indian *Curcuma* spp. suggest that polyploids are derived from the seed-setting species (2n=42) of NE Indian group (see paper X.).

The presence of different ploidy levels of which some species reproduce exclusively asexually and many seed-setting species freely hybridize in overlapping areas are in conflict with ***Biological concept*** (Mayr, 1963), which presumes that a species 'is a group of interbreeding populations which are reproductively isolated from other such groups'. Sterile taxa are not breeding even within its own population while seed-sets interbreed with other closely related species freely.

Morphological concept (Cronquist, 1978) is considered as outdated yet it is usually employed implicitly at least in the beginning by most of the taxonomic studies. It presumes that species are the smallest groups that are consistently and persistently distinct, and distinquishable by ordinary means. ***Phenetic concept*** (Sokal & Crovello, 1970) requires gap in the phenetic variation between species. ***Diagnosibility concept*** presumes a unique combination of character states (Nixon & Wheeler, 1990). All these three concepts can be used for delimitation of sterile species in *Curcuma* and their application will probably identify the same set of species as *Curcuma* sterile species possess unique combination of characters, which are also stable in populations much distanced. Moreover the number of these taxa seems to be infinite. Only a few of them are widespread all over S and SE Asia, while many of them are rather localized in their distribution. Their recognition is not a real problem once the full descriptions with pohotographic documentation are made available. The decision if they should be treated on specific level is more or less matter of personal preference. Further indices provided by modern approaches (e.g. details on parentage of individual sterile taxa) can assist in the treatment.

The real problem in *Curcuma* is in delimiting certain seed-setting species growing within the same geographic area (Western Ghats, NE India). Recent radiation of highly variable seed-setting species of which the descriptions were usually based on just a few indiviuals and did not cover entire variability of the population/adjacent populations adds to the confusion. It is difficult at the moment to say, how many taxa are involved. In current treatment the names have been applied to taxa recollected from the type or as close to type localities as possible. Further comparative morphological investigations supported by evidence from genome size and molecular work will hopefully shed more light into relationships and synonymy of these entities (paper X.).

It is possible to conclude, that all authors working from herbarium material or on very limited number of living material opted for rejecting recognition of sterile species on specific level. On the contrary, authors working mostly on living flowering material (including present author) are of the opinion that the sterile polyploids are recognizable entities. These should be thus at least for now treated at the specific level, until any reliable information about parentage of individual taxa will be available. The problems concerning recognition and delimitation of seed-setting species were not mentioned before. More studies and collections are required in future to get the real picture about possible discontinuities within seed setting taxa (2n=42) in the critical areas (Western Ghats, NE India, and perhaps some parts of Thailand). The different levels of variability among different ploidies will be necessary to be considered when recognizing *Curcuma* species and may result in the employment of different concepts for delimiting of seed-setting and sterile taxa.

Cultural & botanical origin of turmeric

The study of origin and spread of cultivated plants is an interdisciplinary venture based on evidence from numerous sources. Disciplines such as archaeology, botany, genetics, chemistry, anthropology, agronomy, and linguistics are involved.

D. Zohary & M. Hopf, 1993

Turmeric (*Curcuma longa*) has been grown and used in Asia since ancient times. Its exact origin is unknown, but it is thought to originate from South or South-East Asia, most probably from India. India is considered a centre of its domestication as turmeric has been grown here since time immemorial (Sopher, 1964; Dahal & Idris, 1999) dating back 6,000 years to the Vedic culture, where it was used as medicine as well as in many socio-religious practices (Shirgurkar & al., 2001, Ravindran, 2007). In the Sanskrit language, turmeric has about 55 synonyms associated to its religious or medicinal uses (Ravindran, 2007). Valeton (1918) mentioned its occurrence in wild state in teak forests of Eastern Java. Burkill (1966) dismissed this and Purseglove (1974), who considered these populations naturalized, as all teak forests in Java are of man-made origin (Prana, 1977). Vavilov (1992) placed origin of cultivated turmeric both in an Indian centre and also in an Indo-Malayan centre.

Most (if not all) of the members of the genus *Curcuma* are well adapted for surviving several months of dry period and probably originated in monsoonal areas with a distinct dry season of 3-5 months. Such areas, usually covered with semi-evergreen or deciduous forest, are found in a number of countries in South & South East Asia. This corresponds to the current understanding, that the majority of species is found in Thailand and India, where both, seed-setting species as well vegetatively reproducing species are richly represented.

For many centuries, turmeric and perhaps several other *Curcuma* species have been part of trade, or carried by people as sacred plants during the massive migration within South Asia as well as between South and Southeast Asia. In Asia it carried many Sanskrit names as well as Hebrew, Arabic and Chinese names (e.g. Watson, 1886; Watt, 1889). Turmeric reached China before the 7th Century, East Africa in the 8th Century and West Africa in 13th Century (Dahal & Idris, 1999). Edwards introduced turmeric to Jamaica in 1783, where it became naturalized (Purseglove, 1974; Purseglove & al., 1981).

Sopher (1950, 1964) pointed out, that early dispersal manifested by distribution and similarities of uses of turmeric in domestic sites outside India, especially in Celebes, the Moluccas and Polynesia, hints its antiquity. This suggests an early cultural connection between the people of these areas and the indigenous, pre-Aryan cultivators of India. He argues further that the turmeric spread east to Polynesia, where it was widely cultivated and used as a dye and pigment and perhaps also far westward to Madagascar. Tessmann (1920) and Yacovleff & Herrera (1934-1935) have reported, that turmeric is grown and used by forest people in remote parts of Peruvian Andes in South America, where it was used in similar ways as in Asia and that is called 'azafran de los Andes'. Sorenson & Johannessen (2004, 2006) concluded from the available evidences that turmeric was one of the plants transferred to South America in pre-Columbian times possibly via Polynesians.

Prana (1977) suggested two main centres of domestication. One in India, where *Curcuma amada, C. angustifolia, C. aromatica, C. caesia* and *C. longa* are produced and second in Java with production of *C. zanthorrhiza, C. phaeocaulis, C. brog, C. aeruginosa, C. mangga, C. soloensis, C. colorata, C. heyneana* and *C. purpurascens.* However, subsequent to Prana's work, it is now clear, that at least three species commonly used in Java (*C. zanthorrhiza, C. aeruginosa* and *C. mangga*) are widely found and have been used in S. India for very long time (just their identity was obscure). Other species may in fact be the same as some Indian and Bangladesh species, as comparison of living material progresses. It is likely, that most of the *Curcuma* species in Java were introduced and naturalized in teak forests.

Chikarmane & al. (2003) thought that cultural data and evidence of migratory paterns suggest, that turmeric was introduced into Southeast Asia via Indian Colonization in the early centuries AD. Similar was postulated for another widely distributed species *C. zanthorrhiza* (Škorničková & Sabu, 2005c).

Ravindran (2007) expressed the opinion, that turmeric came to India from the ancient regions of Cochin China (present day Vietnam) or China through the movement of the ancient tribal people during their migrations to Northeast India or perhaps through the Buddhist monks and travellers who reached India during the post-Buddha era, carrying turmeric as a remedy to wounds and stomach troubles. Gradually, turmeric became popular in India and over time replaced the indigenous types that were in use. However, no evidence supports this hypothesis.

The different chromosome counts for *C. aromatica* evoked the idea, that *C. aromatica* appears in 'diploid' (2n=42) as well as in 'tetraploid' (2n=84) form. Thus in most of the hypotheses, *C. aromatica* is a main 'suspect' to be one of the parental species of 'triploid' (2n=63) turmeric (e.g. Purseglove, 1974; Dahal & Idris, 1999, Nasir Udin, 2000). Another theory is that there was a natural cross between *C. aromatica* and *C. longa*, or one of them might have evolved from the other through successive mutations (Ramachandran, 1961). Raghavan & Venkatasubban (1943) suggested, that *C. longa* is likely to be a 'triploid' form of *C. aromatica* as these two are morphologically close. This is a rather strange statement as these two species look nothing alike. The confusion was perhaps caused by misapplication of the name *C. aromatica* to plants known as 'wild turmeric' in India, which was recently identitfied as *C. zanthorrhiza* displaying indeed deep yellow-orange rhizome (paper VI.). We are still left in the dark as to what plant described as *C. aromatica* by Salisbury was. It adds to the confusion when approx. 5-10 taxa in Asia are associated with the name *C. aromatica* and that different chromosome counts published for *C. aromatica* belongs to different species.

Several cultivars of turmeric appear in commercial trade - some of which may not be *C. longa* (Purseglove & al., 1981). Revision of herbarium material confirmed this suspicion (paper VIII.). Indeed the name *C. longa* is applied to several species (obvious misidentifications apart), mostly to those with deep yellow rhizome in Asia and Africa. These species are used in similar ways as true turmeric. Burtt & Smith (1972b) doubted if those used as turmeric in Africa are indeed *C. longa*. Prana (1977) reported, that in Sumatra *C. purpurascens* is used as a substitute for *C. longa*. To a general botanist, however this plant will be most likely identified as *C. longa*. Other so-called 'common' sterile species (e.g. *C. zedoaria, C. aromatica*) are even more misidentified and their names loosely applied.

Most of the species, which can be found all over Asia, are extremely viable sterile vegetatively reproducing taxa. Without doubt humans played a major part in their wide distribution. The questions of their origin, parental species and migration patterns can be answered and supported e.g. through molecular studies. But this can be done only after resolving the identites and names of taxa for which actual comparison of living material from a different parts of the Asia, Africa and other parts of the world – a task yet have to be done.

3. THE GENUS *CURCUMA* IN INDIA

3.1. INDIAN SCENARIO

The plants of this genus are the most easily distinguished of all the Scitaminean tribe. The exact uniformity of the double, crestless, calcarate anther is alone a sufficient mark to know them by. But unfortunately, this uncommonly great similarity extends to almost every other part; which renders it so difficult to distinguish the species, that without the aid of colour, I should despair of making their specific characters discriminative. From daily habit I find no difficulty in recognizing them, yet it is by no means easy to find words that will convey that knowledge to others.

W. Roxburgh, 1810

Taxonomy of Indian *Curcuma* is with no doubt most confusing among genera of Indian Zingiberaceae. Treatment of the genus in Indian local floras is mostly based on misidentified herbarium records, the names are misapplied and descriptions do not fit to the names of the taxon described in about 60-70%. This is being further 'messed up' by descriptions of 'new' species and varieties without understanding what was already described in the past and recent synonymy is completely unreliable.

The last complex taxonomic treatment of the genus *Curcuma* for India is Baker's (1890) in Flora of British India. However, this work was based exclusively on herbarium specimens, published and unpublished drawings and descriptions. Major problem in Indian *Curcuma* is thus connected with obscure identities of species described in early history by C. Linnaeus, A. Salisbury, W. Roxburgh, N. Wallich or others. There are also cases of recently described species from India, where names are not validly published, types are missing (lost or never deposited) or type details as published in protologues do not fit to deposited specimens.

Karthikeyan & al. (1989) listed only 23 *Curcuma* species and 2 varieties. Since then, more species have been described or newly reported for India (e.g. Mangaly & Sabu 1987, 1988, 1989, 1993; Bhat, 1987; Sabu & Mangaly 1988a; Amalraj & al. 1991a,b, 1992a; Škorničková & al., 2003a,b, 2004; Tripathi 2001; Velayudhan & al., 1990a,b,c, 1991b), some names have been overlooked. Preliminary results of an ongoing revision (Leong-Škorničková, in prep.) suggest, that more than 65 names have to be investigated. Presence of holotypes has to be verified (if such have been designated), lectotypes or neotypes need to be designated for most of the names, including suitable epitypes when needed and identity of many species has to be clarified. Several such cases have been already adressed during past few years (see papers V, VI, VII, VIII), but more are yet to be resolved.

A preliminary overview of names relevant for Indian subcontinent and adjacent territories and their proposed types is presented in paper IX.

FIGURE 7. (Chapter cover page) Some of the *Curcuma* species described by William Roxburgh (from left to right, top to bottom): *C. zanthorrhiza*, *C. leucorrhiza*, *C. angustifolia*, *C. rubescens*, *C. reclinata*, *C. ferruginea*, *C. aeruginosa*, *C. caesia* and *C. elata*. Details photographed from *Icones Roxburghianae Ineditae* at Kew.

3.2. MATERIALS & METHODS

The identification of the Indian species of Curcuma *presents very great difficulties. Most of our books have been written from materials preserved in various national and foreign herbaria, and it is plainly admitted, that for the most part such materials are in very poor condition.*

H. Santapau, 1945

Area of study

The fieldwork was focused on the whole India including Andaman Islands. Sri Lanka was also included. However, the revision of herbarium materials was performed for the entire geographical distribution of *Curcuma* species. Living plants from other parts of Asia were also studied in living collections of Royal Botanic Garden's Edinburgh, Prague Botanic Garden Troja and Singapore Botanic Gardens.

Herbaria revision

Over 3,600 specimens (excluding authors collections) from herbaria in India, Europe and Asia were studied. These included – AMH, ASSAM, BHAG, BLATT, BM, BO, BSA, BSD, BSHC, BSI, CAL, CALI, CDRI, DD, E, G, GAT, K, KEP, KLU, LINN, LIV, LWG, MH, PBL, PCM, PDA, PR, SAR and SING. Other herbaria have been enquired for existence of particular original sheets e.g. BR, C, KIEL, L, LD, LE, S, etc. (abbreviations according to Holmgren & al., 1990) and kindly provided images and photocopies of requested sheets. Most of the specimens examined were photographed for further reference and direct comparison. They will be aligned in future to herbarium records at the Zingiberaceae Resource Centre http://rbg-web2.rbge.org.uk/ZRC/home.html.

Bibliographic revision

An extensive bibliographic revision targeted at genus *Curcuma* and allied genera (e.g. *Hitchenia, Laosanthus, Paracautleya, Stahlianthus, Smithatris*) on the world scale was carried out with special attention to the Indian subcontinent. The protologues, regional floras, monographs and existing revisions of particular areas were studied. Special attention was also paid to unpublished materials – letters, manuscripts, originals of published drawings and unpublished ones. The most important libraries for references relevant to Indian *Curcuma* and other resources including manuscripts and drawings were found to be at BM, BO, CAL, E, K, LINN, LIV, MH.

One hundred and two Indian regional floras were scrutinized in the beginning of study. The dataset of 294 *Curcuma* records covered most of the taxa reported for India known by then, with seven species being recorded most frequently (e.g. *C. longa, C. aromatica, C. zedoaria, C. angustifolia, C. neilgherrensis, C. decipiens* and *C. amada*). Many of these so-called species turned out to be complexes as their names are embedded in complicated taxonomic and nomenclatural history. Identifications and descriptions in local floras were confirmed to be misleading, yet the dataset provided a preliminary idea about richness of particular regions and information about phenology.

Field trips

Extensive fieldworks throughout India were carried out between 2001 and 2005. These resulted in over 300 collections and 45-50 taxa. The main collection areas were South West India and North East India, Andaman Islands and Central parts of India (Fig. 8), with special attention to type or near to type localities (as many wild habitats does not exist any more or information about type locality was very vague). However, a number of interesting areas could not be visited for safety reasons (local terrorist groups) or restriction to foreigners due to 'sensitive' army areas (many of the NE states having borders with Burma and China). Permits to several NE Indian states were not granted despite repeated applications to respective authorities.

Field trips to Kerala, Tamil Nadu and Karnataka were organized as short trips lasting one to several days, while trips to other destinations were organized as long collecting trips lasting two weeks to two months.

Herb. acronym	**No. of sheets**	**India related**	**Photo**	**Original mat.**	**Special remarks**
AMH	3	3	-	-	
ASSAM	77	77	-	-	
BHAG	10	10	all	-	
BLATT	71	71	all	T	Blatter, Santapau; types lost
BM	237	110	all	T, Ms, OM, Ic.	Koenig, Linnaeus, Roxburgh
BO	572	-	all	T	Heyne, Valeton, Zijp
BSA	45	45	all	-	
BSD	29	29	-	-	
BSHC	15	15	-	-	
BSI	154	154	all	-	
CAL	312	281	all	T, Ms, OM, Ic.	Roxburgh, Wallich
CALI	185	185	all	T	Mangaly, Sabu, Sivarajan,
CDRI	72	72	all	T	Tripathi
DD	152	128	-	-	-
E	371	68	all	T, OM	Wight
G	113	c. 70	all	OM	Roxburgh
GAT	45 loan	-	all	-	Islam
K	743	387	all	T, Ms, OM, Ic.	Dalzell, Haines, Roxburgh, Thwaites, Wallich etc.
KEP	19	-	all	-	-
KLU	14	-	all	-	-
LINN	13	-	all	T, Ms, OM	Linnaeus, Roscoe
LIV	30	-	all	Ms, OM	Roscoe
LWG	71	71	all	-	-
MH	106	106	all	T, OM	Wight, Mangaly & Sabu, Velyudhan
PBL	11	11	-	-	-
PCM	5	5	-	-	-
PDA	59	15	all	T, Ms, OM	Thwaites, Trimen
SAR	12	12	all	-	-
SING	81	-	all	T	Ridley, Holttum,
Total	**3627**	**1925**	**3318**	**-**	**-**

TABLE 6. Number of *Curcuma* sheets deposited in various herbaria with notes on presence of original materials i.e. types (T), manuscripts (Ms), original materials (OM.) icones and unpublished drawings (Ic.) and special remarks about important *Curcuma* collectors in particular herbarium. Specimens collected by the author of this thesisdistributed to CAL, CALI, MH, K, PR & SING are excluded.

Collections were described (using *Curcuma* descriptor – see appendix A-i) and photographed on the spot including flower dissections and rhizome details, followed by processing specimens using the wet method, with 8-10% formaldehyde solution (or by direct drying in case of short trips or living materials form living collection). Spirit materials as well as rhizomes for further cultivation were also collected (for more details refer to appendix A-ii, iii & iv). Molecular samples were collected from young, healthy leaves. Each sample was cut into small pieces, placed (prostrated) in thin rice paper bag (newly manufactured empty tea bags) and dried in silicagel. Long-term storage is performed in deep freezer.

Two to six sets of voucher speciemens (number of duplicates was subjected to availability) have been prepared and over 1100 specimens distributed among 6 herbaria i.e. CAL, CALI, K, MH, PR & SING. Four most complete sets are placed in CALI, MH, PR & SING. The main living collection is maintained in Calicut University Botanic Gardens.

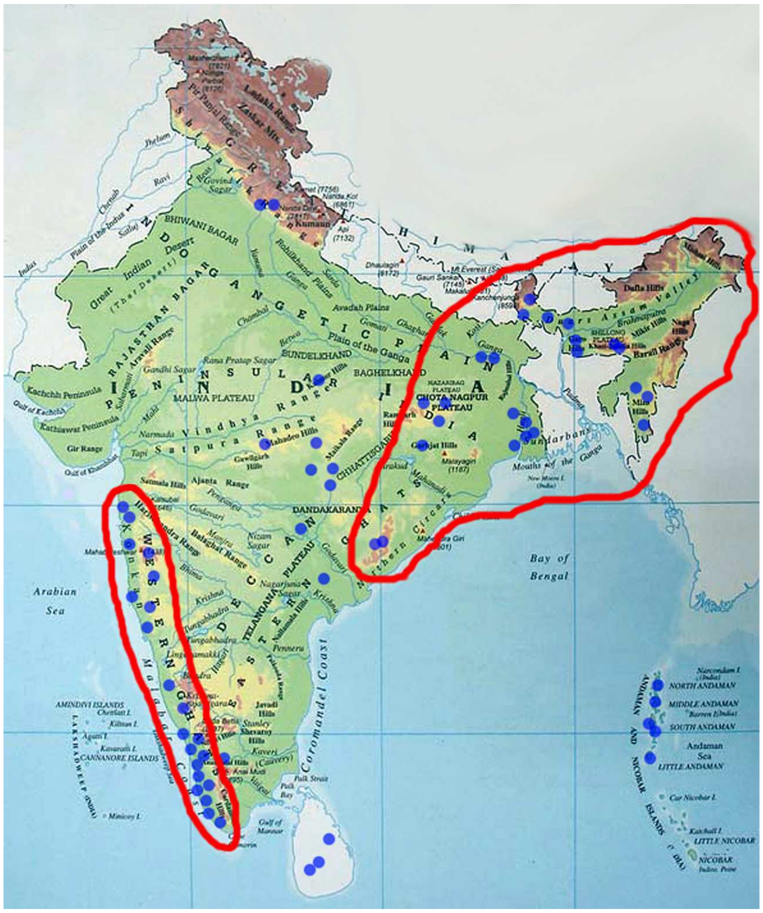


FIGURE 8. Main collection sites visited during the fieldwork between 2001-2005 (blue dots) with major centres of diversity of Indian *Curcuma* (in red).

3.3. THE CURCUMA PLANT

The species descriptions here presented are rather lengthy, but I believe that this is necessary in the present inadequate state of our knowledge of the family. It has been my experience that earlier descriptions frequently omitted data, which appeared to me necessary for a proper characterization of the species.

R.E.Holttum, 1950

Aim of this section is to provide an overview of the *Curcuma* plant based on materials collected from India, to stress the important characters and variability observed during the fieldwork, and in few cases also to question the correctness of currently used terminology.

Habit

Curcumas are perennial rhizomatous herbs. The leafy shoot die back during the dry period in monsoonal areas. Most are medium-sized c. 0.5 to 1.5 m tall, but the smallest species are just about 10 – 20 cm (e.g. *C. bhatii, C. reclinata*), while the stately ones can reach up to 2.5 - 3.5 m (e.g. *C. zanthorrhiza, C. latifolia*).

Rhizome

The rhizome is an underground stem. Morphologically it is a much-condensed axis that develops a vascular plexus at the base (Kumar, 1974). It can be either simple or branched. A simple rhizome is ovoid. Its total size vary with the age of the plant, but width-length ratio can vary approximately between 1:1.5 to 1:7 and seem to be rather specific (i.e. plants of the same species will not exhibit both extreme of this range).

A branched rhizome consists of ovoid rhizome (the main axis) and primary, secondary or tertiary axillary branches (Shah & Raju, 1975). The main rhizome is known as the main rhizome, mother rhizome, primary rhizome or corm, or incorrectly as a primary 'tuber' or 'bulb'. Axillary branches have often been incorrectly quoted in the literature as lateral or palmate tubers, sessile tubers, or fingers (a term obviously not aceptable in plant morphology). Branches are either short and stout, or in some species developed in slender creeping runners, all capable to initiate new shoots well away from the mother rhizome. The size, shape and architecture are specific characters (Fig. 9).

Rhizomes are externally usually light brown in colour. Internally they are either white, cream, all shades of light and sulphur yellow to dark orange yellow, greyish, bluish, violet, deep blue or aeruginous, or yellow with green borders. This character is quite specific in sterile species. However it can be quite variable in few seed-setting species (e.g. *C. montana, C. prakasha*). Colour intensity can vary. It is influenced by age of the plant and perhaps also by the ecological factors. However no study is so far available on this subject.

Specific aromatic scent of the rhizomes as well as taste can be very helpful, but such characters are even more subjective than the colour characters and thus are difficult to describe and assess.

Ngwe (1971) studied anatomy and histology of eight Burmese *Curcuma* species and concluded, that microscopic identification can be made among the specimens studied.

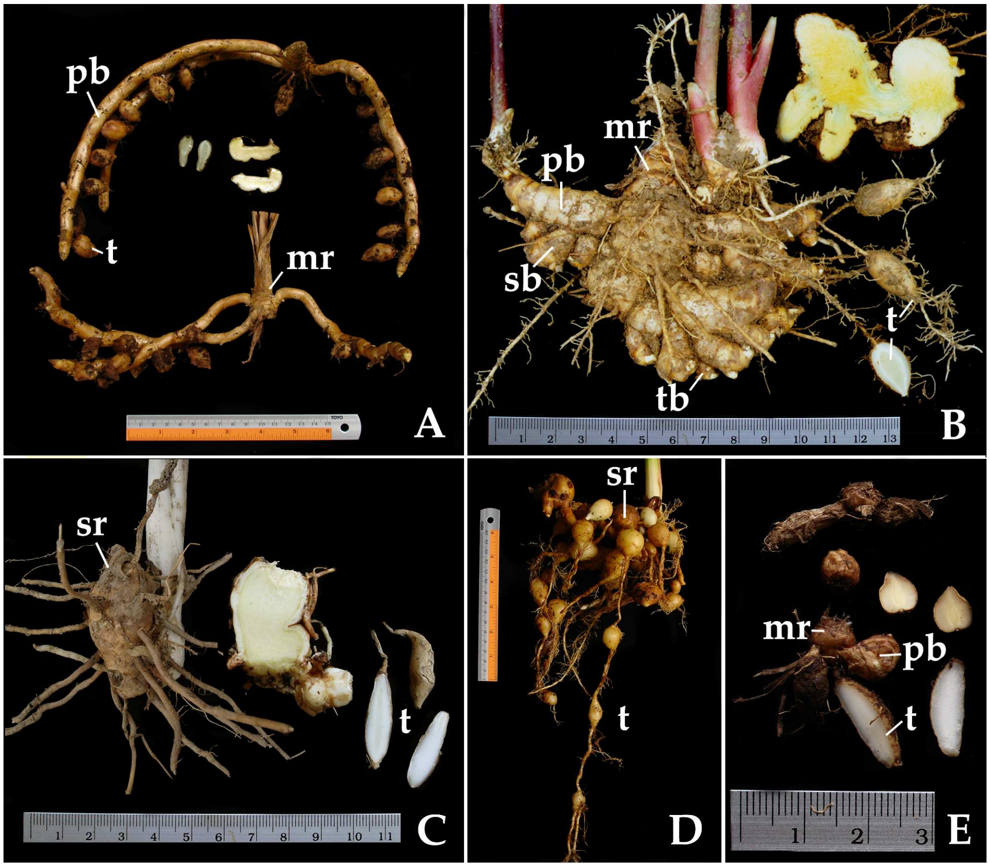


FIGURE 9. *Curcuma* rhizomes. A: *C. rubrobracteata* – branched rhizome with creeping branches and sessile root tubers. B: *C. amarissima* aff. – branched rhizome with short and stout branches and root tubers distanced frombranches. C: *C. angustifolia* – simple ovoid rhizome; root tubers distanced from the rhizome. D: *Curcuma sp.* – simple ovoid rhizome, root tubers arranged serially on one root. E: *C. bhatii* – branched rhizome with sessile root tubers. Legend: mr – main rhizome, sr – simple rhizome, pb – primary branch, sb – secondary branch, tb – tertiary branch, t – tuber.

Root tubers

Root tubers are present in all *Curcuma* species. They are located either close or even sessile to the branches (e.g. *C. rubrobracteata*), but more often they are found at the end of the roots about 5 - 30 (-50) cm from the rhizome. There is usually one tuber on one root, but sometimes there can be several tubers on one root placed in series. Tubers are morphologically roots. They are formed by the expansion of the ground parenchyma and dilatation of the stelar portion (Kumar, 1974). They contain mostly starch and sustain the plant throughout the dry period, when the leafy shoot dries up and plant gets dormant. Root tubers are not capable of sprouting. They are externally light brown, but internally usually white to creamy white colour or yellowish; rarely deep orange (e.g. *C. zanthorrhiza*, see paper VI.).

It is difficult to dig out the plant with undisturbed rhizome and root tubers. At the very beginning of the season tubers can also be completely exhausted. Tubers are thus often not mentioned in protologues and descriptions or some species have been explicitly described as lacking the root tubers (e.g. *C. prakasha*, Tripathi, 2001). I have not yet met with a species in India or elsewhere including mentioned *C. prakasha*, which would not form the tubers under favourable conditions.

Pseudostem

A pseudostem (false stem) is made up of closely embracing leaf sheaths. It differs between species. It is well-developed in all sterile species, but can be either well developed or not so in seed-setting species. In extreme cases the pseudostem appears to be missing. It is almost always visible in the beginning of the season and deteriorates as the central inflorescence protrudes from the middle of the leaves. Depending on the general size and habit of a particular species, low to the ground or rather high up. It can be pure green or with a pink or deep red tinge. The colour of the pseudostem is a rather stable character in sterile species, but vary in several seed-set species. In *Curcuma,* there are no peculiar structures of diagnostic quality on the surface of the stems like heavy reticulation, which appear in some other ginger genera (e.g. *Etlingera, Hornstedtia* etc.).

Leaf

Curcuma leaves are either sessile or petiolate, having a basal sheath. A ligule is present at the junction of petiole and sheath or blade with sheath (when the petiole is reduced). However, it should be noted, that this terminology of leaf parts traditionally used in family Zingiberaceae (e.g. Holttum, 1950; Larsen & Larsen, 2006; Poulsen, 2006) differs from the terms used in other monocotyledons, i.e. usage of the term petiole is not correct as even leaf sheath is in fact part of the petiole.

The ligule in sterile species is usually poorly developed, c. 1-3 mm, and is obscurely bilobed, while ligules of many seed-setting species are mostly well developed and the bilobate.

The lamina is usually lanceolate, oblong or ovate, rarely linear; bright green to deep green above and usually paler green beneath. Venation is usually prominent, and in many species beautifully sulcate. The presence of an indumentum is quite variable in seed-setting species, often even within the population. Some species have a purple or violet patch on the upper side of the lamina, which penetrates to the lower surface in some species. The size, shape, relative placement of this patch on the lamina (e.g., the upper half of the lamina near the midrib or the full length), colour, and density is constant and is helpful in the determining many sterile species. However, it is highly variable in some seed-setting species.

Inflorescence

Inflorescence in Zingiberaceae is always terminal (Kiew, 1977). It arises either on the vegetative leafy shoot (called as inflorescence central) or on a separate non-leafy shoot (called as inflorescence lateral). Lateral inflorescence in *Curcuma* appears just after the pre-monsoon showers or soon after the rainy season starts; in some species, even sometimes before the leaves develop. Species with central inflorescences bloom later, between the leaf sheaths, as the monsoon progresses. A central, terminal inflorescence with a short peduncle may appear at ground level, which may seem lateral. A central inflorescence protruding from the pseudostem through lateral slits has been observed in *Curcuma rubrobracteata* by Škorničková & al. (2003a).

Indian Curcumas either bloom in the very beginning or in the middle of the rainy season, only few towards the end of monsoon, e.g., *C. longa*, *C. amada*, and *C. roscoeana*. Many species are capable to bloom twice — once in the beginning of the season (laterally) and also centrally later in the summer if the monsoon rains are sufficient (more on this subject under chapter 2.4.).

The inflorescence of all Zingiberaceae is in principle thyrse, composed of partial inflorescences of cymose type and these are called cincinni. The inflorescence in *Curcuma* is conspicuous as the bracts are spirally arranged, at its base are adnated to the axis and in majority of *Curcuma* species are also connate (fused) further up at their sides to the neighboring bracts, resulting in pouches. Sometimes the pouches are shallow as they are formed just by the adnation of basal part of bract to the axis (Škorničková & Sabu, 2005a). In most cases the bracts in the lower portion of the inflorescence are usually less coloured, often green, and more connate than the top series of bracts. They are called ***fertile bracts*** and enclose one cincinnus usually consisting of two to many flowers, but in few species the number of flowers in cinncinnus can be reduced to one (Škorničková & Sabu, 2005b). The top bracts are usually much larger, longer, and more brightly coloured and called ***coma***. It is believed that they serve the purpose of attracting pollinators. This inflorescence model can be observed among both seed-setting as well as sterile species (e.g. *C. aeruginosa*-sterile; *C. pseudomontana*-seed-setting). But several species, so far all of them seed-setting species, have no distinctive coma bracts. In these all bracts are of the same colour, their spikes are fertile almost to the top except a few uppermost bracts, which are usually smaller (e.g. *C. roscoeana, C. mutabilis, C. oligantha, C. rubrobracteata*).

The flowers in each cinncincnus open consequently one at the time. The absolute length of the flower can vary within the species, but more informative is the relative length of the flower to the fertile bract and level of its exsertion out of the fertile bract. This character is stable for sterile, but vary in some seed-setting species.

Each flower in a cinncincnus is embraced by one membraneous, usually translucent and boatshaped ***bracteole***. There is a notable difference in sizes of bracteoles, which are well-developed in all sterile species and also in several seed-sets. Some other seed-setting species have strongly reduced bracteoles (paper IV.).

The shape of the inflorescence and colour of the bracts are stable characters in sterile taxa, but may vary tremendously in some seed-sets (e.g. *C. pseudomontana, C. mutabilis, C. cannanorensis*) while in others may be quite stable (e.g. *C. vamana, C. roscoeana, C. rubrobracteata*). The approximate number of flowers per cinncinus is useful as an additional character (few vs. many), but in several species the number of the flowers in cinncincus can slightly vary within one inflorescence.

Flower

Flowers in Zingiberaceae are zygomorphic and among the most highly derived in angiosperms (Endress, 1994; Kress & al., 2002). The function of attracting pollinators and mechanical assistance to pollination is replaced by an elaborate staminodial structures that have replaced four of the six stamens that were fertile in ancestral Zingiberales. Two anthers of the outer whorl have been transformed into lateral staminodes; two anthers of the inner whorl have developed into labellum. Only one of the inner whorl is functional for reproduction, and the anterior stamen of the outer whorl is supressed and absent (Kirchoff, 1997, 1998). While the basic number and arrangement of parts is quite uniform throughout the family, there is great variation in the size and shape of the parts, especially in the labellum and lateral staminodes (Newman, 1988). Maas (1977) divided the members of the genus *Renealmia* into two groups based on floral morphology i.e. 'Tubular' and 'Exposed'. Newman (1988) proposed another three types i.e. 'Gullet', 'Elongated' and 'Planar' type to accommodate rest of the Zingiberaceae. Flowers of most of the *Curcuma* species fall into 'Gullet' flower type, where corolla lobes, the labellum and the lateral staminodes form the chamber. A pollinator has to enter this chamber in order to gain access to the mouth of the floral tube where the nectar reward is. Meanwhile the pollen will be transferred from anther onto its back (Valeton 1918; Newman, 1988). *Curcuma* flowers are mostly pollinated by bees and flies (Valeton, 1918; Prana, 1977; pers. observation).

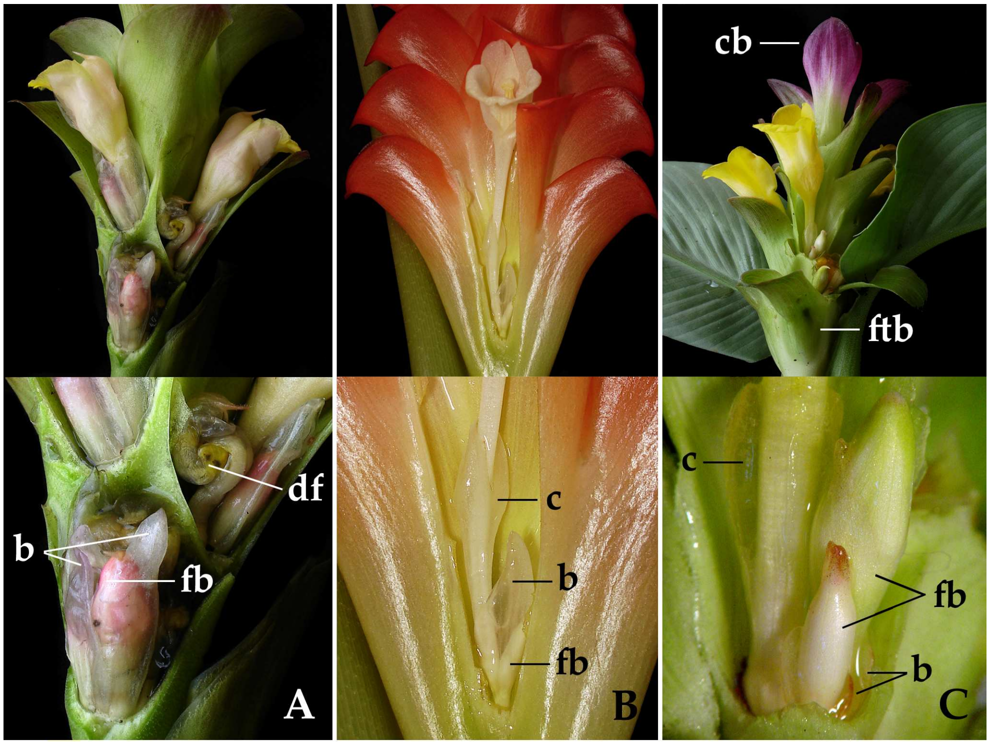


FIGURE 10. Bracts, cincinnus and bracteoles in *Curcuma*. (Enlarged below) A: *C. zedoaria* – many-flowered cincinnus. B: *C. roscoeana* – two-flowered cincinnus. C: *C.pseudomontana* – three-flowered cincinus. Legend: b – bracteole, c – calyx, cb – coma bract, df – decayed flower, fb – flower bud, ftb – fertile bract.

Curcuma flowers in all Indian species last only for a few to 10 hours. One species, *Curcuma scaposa*, exhibits nocturnal anthesis, which is a rather rare feature within the family. Each flower consists of calyx, floral tube, androecial tube (not always present), corolla lobes, lateral staminodes and labellum (both of these are transformed anthers), stamen, epigynous glands, style, stigma and ovary.

Calyx

The outer whorl of perianth (sepals) form a ***calyx.*** Calyx is membraneous, tubular, glabrous or hairy and always three-toothed, teeth being more or less prominent, often with small murco and few hairs at the tip of the tooth, sometimes tinged pink or violet in some species. Calyx is split unilaterally in most species.

Floral & androecial tube

The tubular part of *Curcuma* flower has been commonly called 'corolla tube'. During the dissection of *Curcuma* flowering material it was noticed, that inside and ouside part of this tube is noticeably quite different and it is clearly formed by members of both whorls (inner whorlf of perianth and androeceum) and thus is called here ***floral tube***.

In some *Curcuma* species corolla lobes (inner whorl of perianth) diverge from the apical part of the floral tube either at the same point as labellum, lateral staminodes and filament bearing the anther. But in vast majority of Indian taxa corolla lobes diverge from the floral tube first, while the inner part of this tube, continues for one to several mm before it splits into labellum, two lateral staminodes and filament. This short tube is formed by then only by the basal parts of members of androecial whorl (i.e. lateral staminodes, labellum and filament) and called here *androecial* tube (Fig. 11).

The morphological feature of distinct tube formed by the lower part of labellum and fillament above the insertion of the petals was a key chracter for Burtt & Smith (1986) to unite *Achasma, Nicolaia* and *Geanthus* under the inclusive name *Etlingera*. The distinct tube is also from found in *Geocharis, Pommereschea, Aulotandra, Stadiochillus* and *Globba* (Larsen & al., 1998). Poulsen (2006) named this tube in *Etlingera* as *staminal* tube. However the term ***androecial*** tube is preffered here as in *Curcuma* (and possibly some other Zingiberaceae) such tube is formed by both stamen and staminodes.

The floral tube should be measured from the top of the ovary to where the corolla lobes are detached from the androecial tube. The androecial tube should be measured from that point to the detachment of filament, labellum and staminodes.

The external and internal colour of the floral tube is a good character in sterile species, but can be quite variable in seed-sets. The floral tube s often finely hairy on the outside - the hairs point upwards, downwards, or in both directions. The inside of the floral tube is always hairy at least at the mouth of the tube, where there is often a ring of swollen tissues with a groove for supporting the style. The 'hairy' mouth most probably serves as a barrier to protect nectar reward from nectar robbers. It also perhaps helps mechanically to increase chance of passing the pollen onto the back of the pollinators as the insect has to go really deep and struggle a bit for the nectar reward.

Corolla lobes

The ***dorsal corolla lobe*** is placed above the anther and usually embraces at least part of the lateral staminodes. Dorsal corolla lobe is usually slightly longer than lateral lobes. In most species it has a pointing tip, a mucro. The two ***lateral corolla lobes*** are appressed below labellum and may be slightly overlapping at the inner side of the base with each other.

Labellum & lateral staminodes

Labellum and lateral staminodes are prominent features of a *Curcuma* flower. They diverge from the androecial tube.

Labellum is obscurely trilobed, the lateral lobes are mostly positioned upwards, supported by lateral corolla lobes. The middle lobe is emarginate in the centre. The split, especially in number of seed-setting species, progresses as the flower start wilting in the afternoon. The centre of the labellum is structurally different from the sides. The tissue in the middle is thicker, sometimes swollen froming grooves and often of more prominent colour (so called 'golden median band') sometimes with white strip on each side. This probably serves as a guide for pollinators.

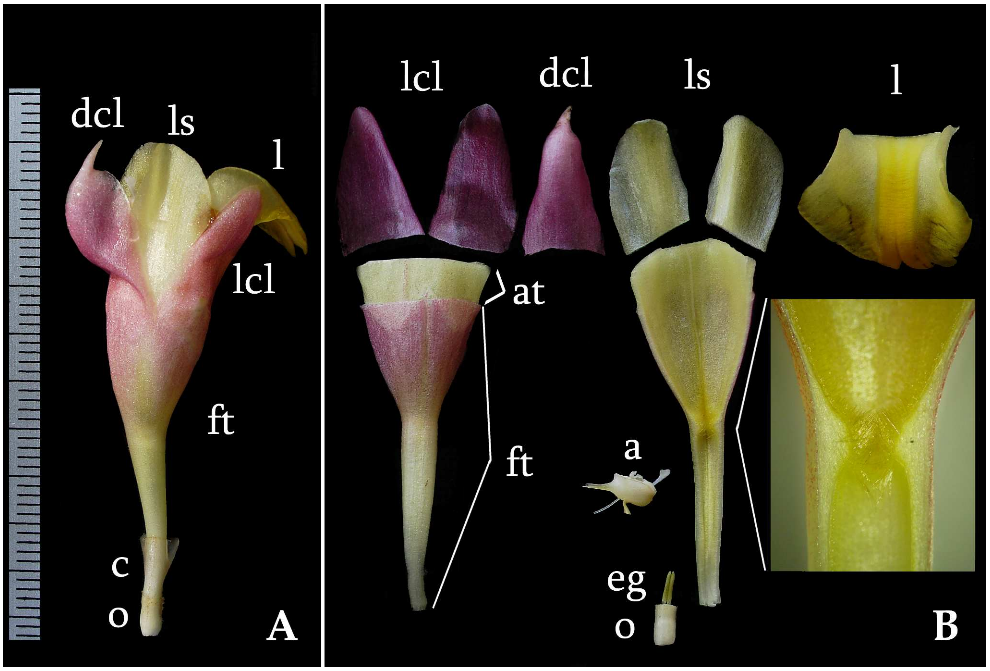


FIGURE 11. *Curcuma* flower (*C. codonantha*). A: Flower from side view. B: Dissected flower with detail of floral tube from inside (inset). Legend: a - anther, at - androecial tube, c - calyx, dcl - dorsal corolla lobes, eg - epigynous glands, ft - floral tube, l - labellum, lcl - lateral corolla lobes, ls-lateral staminodes, o – ovary.

The colour of the labellum is not a reliable character for certain seed-sets, where it can vary from white to yellow with or without red tinge within a population, but is stable in sterile taxa. However, the relative correlation of length of the labellum to the corolla lobes seems to be more informative even in seed-setting species.

Lateral staminodes are placed at both sides of the labellum and are positioned upwards. Mostly they are grooved and have numerous glandular hairs on the side facing into the flower. In many species they are clasped by the dorsal corolla lobe, but sometimes they are too long and are clasped only at its back.

Stamen

The only functioning ***stamen*** has a ***filament*** (sometimes quite short) terminated by an ***anther***, which is in *Curcuma* dorsifixed and versatile (Fig. 12).

The free part of the ***filament*** may be one to few mm long, is usually broader at the base and constricted at the top. The ***anther*** is versatile, often spurred and consists of two anther thecae, each with two closely-alligned microsporangial sacs. These are are placed unilaterally, facing inside the flower and connected by a highly expanded sterile tissue called ***connective.***

Connective may produce a structure beyond the anther thecae called an ***anther*** *crest* and two ***anther spurs*** at the bottom. ***Anther crest*** in *Curcuma* can be well developed, or more commonly can be reduced into a small structure or be absent.

Anther spurs are present in several ginger genera, namely *Caulteya*, *Roscoea, Camptandra, Curcuma, Laosanthus* and *Paracautleya* (recently merged into *Curcuma*). According to Ngamriabsakul (2005) the anther spurs in *Caulteya*, *Roscoea* and *Camptandra* are formed by the connective, while the spurs in *Curcuma, Laosanthus* and *Paracautleya* are formed from the bases of the thecae of the anther. Based on Indian *Curcuma* species (including *Paracautleya*), all but one have spurs clearly formed by the connective tissue, like *Cautleya*, *Roscoea* and *Camptandra.* One difference is that the anther thecae in *Curcuma* reaches to the bottom part of the connective. Only in *C. vamana* the thecae may exceed till the very end of the connective tissue to give the appearance of spurs being formed by the base of the anther thecae. Yet those are well supported by the connective tissue from the bottom.

Pollen grains are ovoid to ellipsoidial, approx. 60-120 x 50-100 •m in size, sulcate, with thin nearly smooth exine, and thick lamellated intine (Mangaly & Nayar, 1990).

The shape of anther and presence/shape of crest, spurs and lateral appendages are considered good characters in various genera by many previous workers. The phylogeny of the genus *Globba* by Williams & al. (2004) clearly showed, that appendages do matter. Also in *Curcuma*, the overall structure and shape of anther, presence and absence of anther spurs and anther crest are valuable diagnostic characters as well as mode of dehiscence of anther thecae.

Style & stigma

The style is long, very thin and thread like. It runs throughout floral tube up to the anther. In the middle of the floral tube it is supported by a ring of swollen tissue or ring formed by hairs. Stigma is capitate, triangular or quadrangular with prominent ostiole (Fig. 13.). The ostiole is always ciliate.

Epigynous glands

Epigynous glands (epigynous nectaries, stylodial glands) are placed above the top of the ovary in antero-lateral position (Fig. 13). They originated from gynoeceum tissue and are derived form gynopleural nectaries (Rao, 1963; Pai, 1961, 1964; Kirchof, 1998). The opinion that these glands are modified sterile stamens (e.g. Raghavan & Venkatasubban, 1941; Patnaik & al., 1960) are an old conception as these are not in any way connected with the androeceum (Rao & al., 1953; Rao & Pai, 1959, 1960).

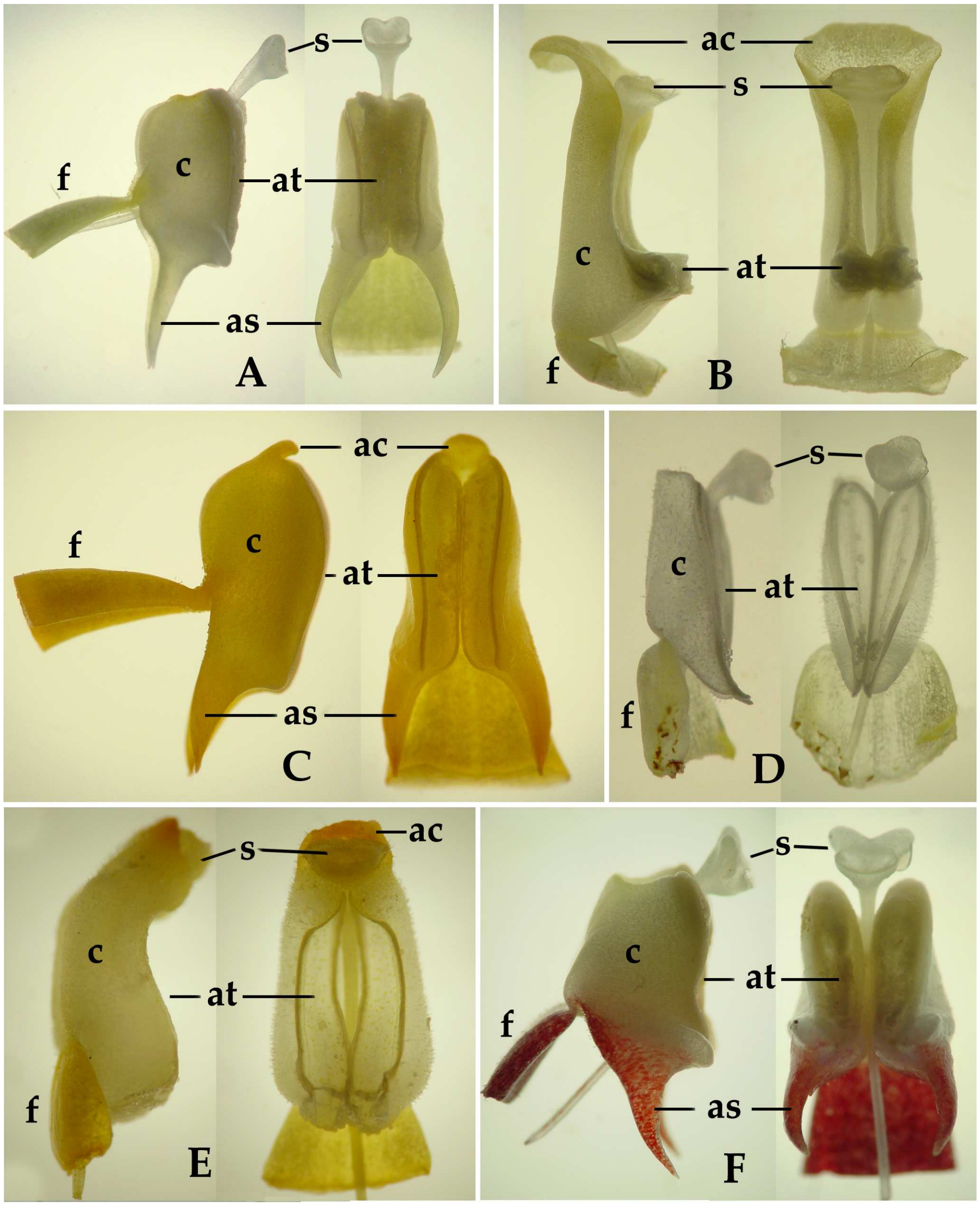


FIGURE 12. Anthers of *Curcuma* spp. A: *C. codonantha*. B: *C. roscoeana*. C: *C. rubrobracteata*. D: *C. vamana*. E: *C. aurantiaca*. F: *C. reclinata*. Legend: ac – anther crest, as – anther spurs, at – anther thecae, c – connective, f – filament, s – stigma.

Epigynous glands in *Curcuma* are always two, usually of linear shape, with sharp or blunt apex. Colour varies from creamy white, ochraceous, and yellowish to yellowish-green. They are present in all but one Indian *Curcuma* species (*C. vamana*). *Curcuma ecalcarata* (= *C. aurantiaca*) was described in protologue as a species lacking epigynous glands. However an examination of the holotype, isotype as well as living plants from type locality showed that epigynous glands are present and well developed in this species. Epigynous glands are absent in many of the SE Asian species placed by Schumann (1904) in the subgenus *Hitcheniopsis*.

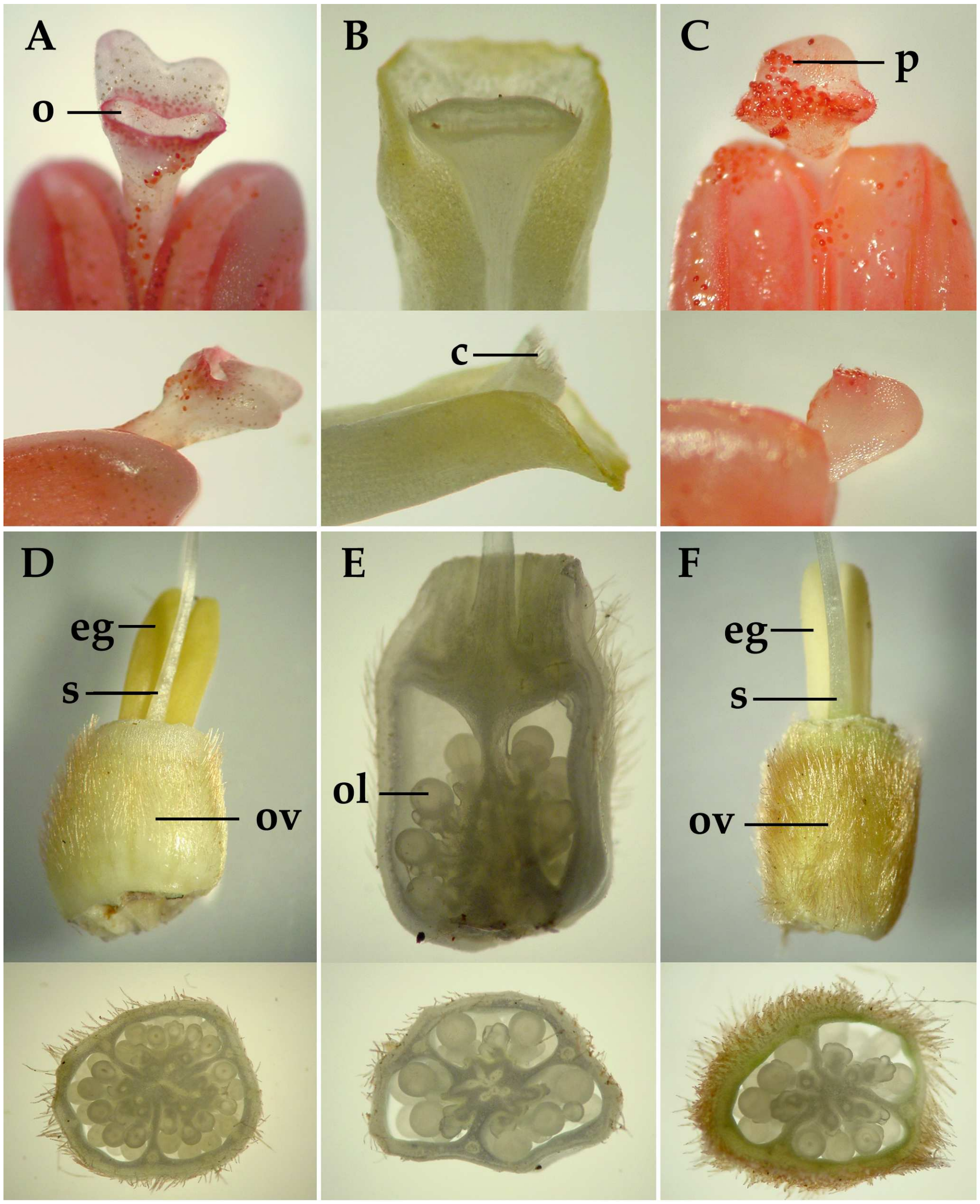


FIGURE 13. Stigma, ovary and epigynous glands in *Curcuma*. A: Stigma of *C. aromatica* aff. B: Stigma of *C. roscoeana*. C: Stigma of *C. montana.* D: Ovary & epigynous glands of *C. zedoaria*. Side view (above) and cross section (below). E: Ovary & epigynous glands of *C.pseudomontana*. Longitudinal section (above) and cross section (below). F: Ovary & epigynous glands of *C. karnatakensis.* Side view (above) and cross section (below). Legend: c - cillia, eg – epigynous glands, o – ostiole, ol – ovule, ov – ovary, p – pollen, s - style.

Ovary

Ovary is inferior, usually hairy at least at apical part, rarely completely glabrous (Fig. 13) It is trilocular with axile placentation, however septation may not be always complete in upper part of the ovary and in such cases this region appears to be unilocular and placentation may appear to be more or less basal (Škorničková & Sabu, 2005a).

Fruit & Seeds

The ***fruit*** is a round capsule, thin-walled, dehiscing, usually green, light, light green, creamy or greenish-white, sometimes tinged pink or violet.

Seeds of *Curcuma* species are ovoid, light brown to dark brown and shiny and always arrilate (Fig. 14). Arillus is white, laciniate, free to the base and rather uniform throughout the genus, although the number of lobes, relative size of the lobes compared to seed and their shape may vary among the species. Contrary to previous records *C. oligantha* has exarilate seeds. An examination of the type material of *C. oligantha* shown that the arillus is present on seeds in unopened fruits (Škorničková & Sabu, 2005a). Once the seeds are ripe and fruit is open, arillus is easily detached from the seed and also will rot easily within few days and thus sometimes the seeds may appear as exarillate.

Note: Rather complicated structure of the inflorescence and modification of anthers into petalloid staminodes resulted in many confusing descriptions in both literature as well as in often misleading notes on herbarium labels. The most common misapplication of the descriptive terms is describing the colourful bracts of the coma as the colour of flowers and describing labellum and lateral staminodes as petals, while corolla lobes are misinterpreted as calyx. Further mistakes occur in description of rhizome structure, due to the wrong application of the term tuber to the rhizome branches.

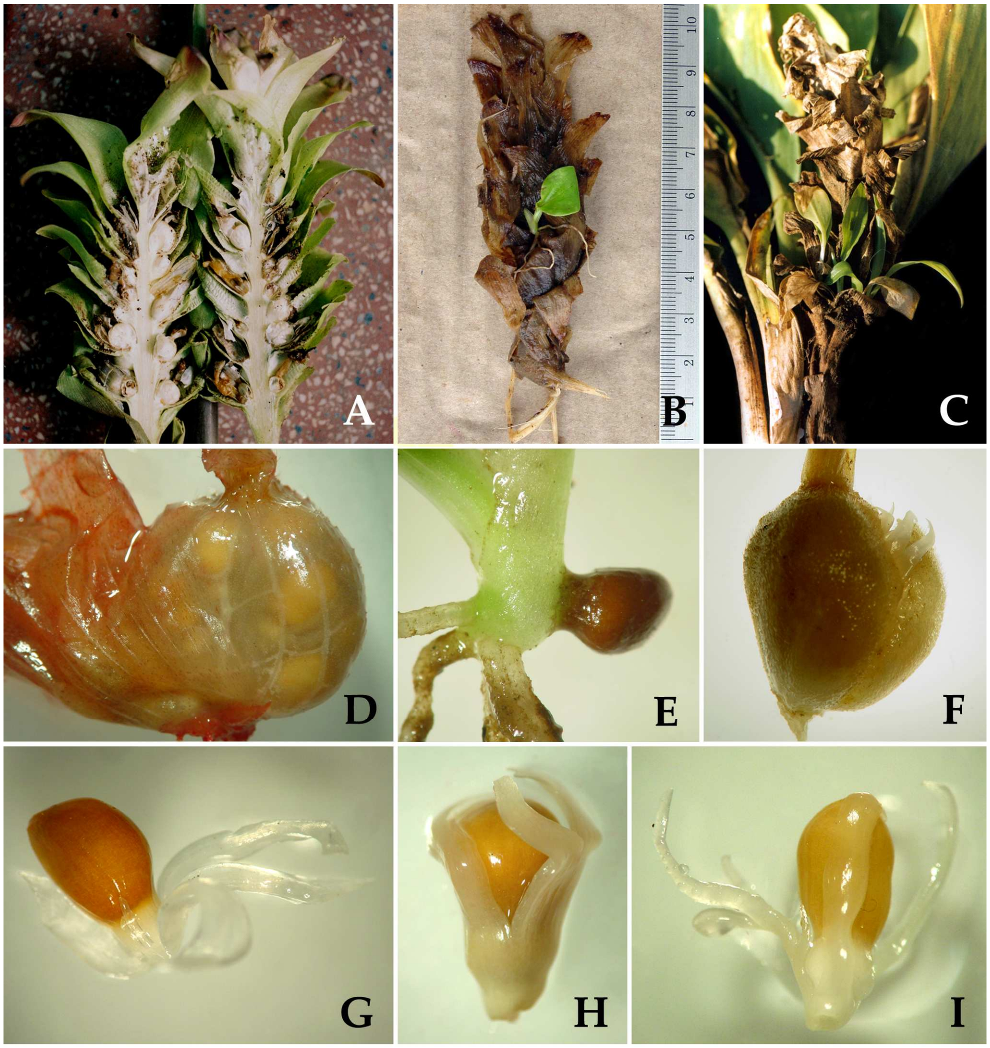


FIGURE 14. Fruits and seeds. A: *C. prakasha* fruiting. B,C: *C. coriacea* - inflorescence with seedlings. D: Fruit of *C. prakasha*, from preserved material. E: Detail of *C. coriacea* seedling. F: Ripe fruit of *C. neilgherrensis*, note protruding arrilus on the right side of the fruit. G: Seed of *C. cannanorensis*. H: Seed of *C. prakasha*. I: Seed of *C. neilgherrensis*.

4. FUTURE PERSPECTIVES

To answer satisfactorily all *Curcuma* question is a hobby of a lifetime. There are several tasks to be completed within near as well as further future.

Complete revision of Indian *Curcuma*.

The main mission of my Indian journey will not be acomplished until the colour revision of Indian *Curcuma* will be published. It will provide an updated nomenclature, types will be clearly indicated and all species will be thoroughly described and documented.

The analytical scoring of the characters and wordy descriptions failed to provide efficient tool in the past. Words do not convey the structures. Very recently, new approaches to morphological characters in phylogenetic analysis using complex data & precise pictorial methods to represent relationships between plant forms are being developed (Kirchoff & al., 2004, 2007-in press, pers. com.). I believe, this might be of immense help to tackle the problems in Zingiberaceae, particularly in *Curcuma*.

Unveiling obscure identities & typifications.

It is necessary to continue unveiling the identities of *Curcuma* species described in early history from the rest of Asia. Only when we fully resolve the past, can we expand our knowledge with the use of all modern approaches. I have been able during my thorough herbarium revision to locate most of the original materials required for the typification of most of the members of the genus in its whole geographic range. However, recollection of the material from the type localities is essential to finish this task successfully. This will be done in close cooperation with others currently working in Thailand and Indonesia. Settling the names and their types and linking them to the respective taxa will finally enable us to provide correct synonymy based on critical comparison of living material.

More morphology studies & updates on terminology needed!

While other aspects of ginger studies are progressing well, the morphology and detailed observations made from living material are legging behind. The terms, some of which were introduced over hundred years back, are used today without questioning their correctness. Several terms in rhizome morphology, leaf structures as well as in floral parts need re-assessing. Not many works have been done on shoot architecture, branching patterns and it is now questioned if the terms petiole and sheath, so commonly used in descriptions of various Zingiberaceae family in different sense than in other monocots, are correct from morphological/developmental point of view.

Wanted! More C-values & more counts.

Cytological investigations in Indian *Curcuma* yield interesting and important results (Paper X). Along with chromosome numbers detected in Indian *Curcuma*, which are paleopolyploids with basic number $x=7$, there are several different numbers reported from SE Asia, e.g. $2n=20$, 24, 28, 32, 34, 36, 56 (see paper X.). It is plausible that evolution of these SE Asian species, which are quite distinct also morphologically, were different than those in the Indian Subcontinent. In order to evaluate the evolution of genome size in entire genus, cytological investigations of more *Curcuma* species focusing on SE Asian species have to be done. It is important to include also members of genera closely related to *Curcuma* as *Laosanthus, Smithatris, Stahlianthus* and also particular members of the genus *Kaempferia* to shed more light on relationship inside the genus as well as to look for additional tools to better delimit the genus *Curcuma*.

Fiddling in the lab.

Since the unique collection of living materials and DNA samples are already available and taxonomic revision of the genus is in progress, it is best to look into the following questions:

Assessment of intra and extra population variability by using AFLP (in progress by E. Záveská)

Aim of this project is to assess infrapopulation variability within and between the populations of selected *Curcuma* species and to gain more information about level of genetic diversity in different ploidy levels. Such results will provide information complementing field observation on preferred mode of reproduction in various taxa as observed in the field. Particularly interesting will be an insight into seed-setting species with branched rhizomes, which are capable of both, sexual as well as vigorous vegetative reproduction.

Phylogenetic analysis of the genus Curcuma *using DNA sequencing and AFLP analysis* (partly in progress by Fér & al.)

To resolve phylogenetic pattern, the comparison and combination of chloroplast (*trnL-F*) and nuclear (ITS) DNA is usually presented. Low-copy nuclear markers (Strand & al. 1997) are increasingly implemented in phylogeny reconstruction in diverse taxonomical plant groups because of faster rate of sequence evolution resulting in higher amount of variable characters compared to the chloroplast regions (Wolfe & al. 1987) and incongruence between phylogeny reconstructions based on more markers can be used to infer evolutionary phenomena such as hybridization or introgression. Due to biparental heritability and lesser tendency to concerted evolution (in comparison with nrDNA) are low-copy nuclear markers ideal for identifying parental donors of suspected hybrids or polyploids. Until now no phylogeny reconstruction based on low-copy markers has been published within the *Zingiberaceae*.

Although AFLP is a dominant marker, it can be a useful tool to get better resolution in inferring phylogeny among closely related taxa (Després & al. 2003). The main advantage of the AFLP markers is their high polymorphisms and wide distribution across the genome. Simultaneous analysis (mainly phenetic) of many loci representing the whole genome has the potential to generate a true species tree (Després & al. 2003) or at least obtain the pattern, which is comparable with phylogenies based on sequencing. It has been successfully used for the genus *Musa* (Wong & al. 2002 & 2003). Optimisation of the AFLP protocol for the genus *Curcuma* has been already done in our laboratory as well as preliminary testing of suitable selective primer combinations for the genus *Curcuma*.

Origin of selected polyploid taxa detected by in-situ hybridization (FISH/GISH)

In-situ hybridization is a widely used method to reveal origin of hybrids or allopolyploids, in composition of karyotypes, introgression etc. (e.g. Baeza & Schrader 2005; Perry & al. 2005; Refoufi & al. 2001). Plausibly in polyploid evolution of *Curcuma* can play an important role the following two factors (a) producion of reduced and unreduced gamete and (b) origin of polyploid species by fusion of gametes produced both of same parental species (autopolyploidy) or of different parental species (allopolyploidy). Composition of karyotype of polyploid taxa can be checked using genomic in-situ hybridization (GISH), where the total DNA of possible parent is used as marked probe applied on expected polyploid derivates.

The results from the Indian subcontinent show, that all but one chromosome numbers are multiples of 7. Using FISH (fluorescent in-situ hybridization) where the ribosomal DNA is used as a probe, should enable testing of possible ancient allopolyploid origin of taxa with 2n=42.

5. EPILOGUE

Nomine si nescis, perit & cognitia rerum. [If you do not know the name of things, the knowledge of them is lost too.]

C. Linnaeus, 1751; transl. S. Freer, 2003

Many works have been previously done on *Curcuma.* However all results, no matter how interesting or important to the human kind, can loose their 'appeal' when not connected to the correctly determined plant. And what more, many of these studies are not well documented by any kind of vouchers (not to talk about valuable and informative vouchers) and thus are not verifiable.

Little, if any, progress can be done on…

- generic boundaries, infrageneric relationships & specific delimitation
- distribution and ecology, in order to assess and propose conservation of rare, endemic and endangered species
- phylogeny, cytology, reproduction biology, finding parental species of hybridogenous taxa etc.
- assessing properties of medicinally, economically or ornamentally important species

…unless and until we have correct names on correct taxa!

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II. **Škorničková, J.**, Sabu, M. & Prasanthkumar, M. G. (2003b): *Curcuma codonantha* (Zingiberaceae) – a new species from Andaman Islands, India. – *Gardens' Bulletin Singapore* 55: 219–228.

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IV. **Škorničková, J.** & Sabu, M. (2005a): The recircumscription of *Curcuma* L. to include the genus *Paracautleya* R. M. Sm. – *Gardens' Bulletin Singapore* 57: 37–46.

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VI. **Škorničková, J.** & Sabu, M. (2005c): The identity and distribution of *Curcuma zanthorrhiza* Roxb. – *Gardens' Bulletin Singapore* 57: 199–210.

VII. **Leong-Škorničková, J.**, Šída, O., Sabu, M. & Marhold, K. (submitted): Taxonomic and nomenclatural puzzles in Indian *Curcuma*: the identity and nomenclatural history of *C. zedoaria* (Christm.) Roscoe and *C. zerumbet* Roxb. – *Taxon*

VIII. **Leong-Škorničková, J.**, Šída, O., Wijesundara, S. & Marhold, K. (submitted): On the identity of turmeric: the typification of *C. longa* L. (Zingiberaceae). – *Botanical Journal of Linnean Society.*

IX. **Leong-Škorničková, J.,** Šída, O. & Marhold, K. (in preparation): Back to types! Towards stability of names in Indian *Curcuma* L. (Zingiberaceae). – *Botanical Journal of Linnean Society.*

X. **Leong-Škorničková, J.,** Šída, O., Jarolímová, V., Sabu, M., Fér, T., Trávníček, P. & Suda, J. (accepted): Chromosome numbers and Genome Size Variation in Indian Species of *Curcuma* (Zingiberaceae). – *Annals of Botany (Oxford).*

XI. **Škorničková, J.** , Rehse, T. & Sabu, M. (2007): Other Economically Important *Curcuma* Species. Chapter 14. In: Ravindran, P.N (ed.) Turmeric: the genus *Curcuma*. CRC Press, Florida Pp. 451-467.

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APPENDIX

A-i. *CURCUMA* DESCRIPTOR

Coll. No. ……………

NAME. ………………………………………………………………..… **DATE**……………….…..…..………

LOCALITY ………………………...……………………..…………………………………………………...…

NOTES……………..……………………………………..……………………………..…………..……..…...

RHIZOME

Main rhizome:	Colour outside:
Branches:	Colour inside:
Notes:	Aroma:

Root tubers

Present/Absent	Shape:	Distance:
Size:	Colour:	Number:

LEAFY SHOOT

Height:	No. of leaves:	Distance between leaves:
Pseudostem:	Notes:	Distance between pseudostems:

LEAVES

Petiole:

Length:	Surface:	Colour:

Lamina:

Length:	Upper surface:	Tip:
Venation:	Lower surface:	Base:
Midrib:	Margin:	Notes:

Ligule:

Size:	No. of lobes:	Surface:
Shape:	Colour:	Notes:

INFLORESCENCE

Position:	Lateral	Central

Peduncle:

Height/Length	Diameter:	Colour:

Sheating Bracts:

Number:	Length:	Colour:
	Width:	Surface:

Spike:
Size: No. of bracts: Notes:

Coma bracts:
Length: Colour: Surface:

Width: Number: Margin:

Connation: Notes:

Fertile bracts:
Length: Number: Cincinnus:

Width: Colour: Surface:

Connation: Margin: Notes:

Bracteoles:

Length: Colour: Number:

Width: Surface: Notes:

FLOWER
Size: Notes:

Calyx
Size: Colour: Teeth:

Hairs: Splitting: Notes:

Corolla tube:
Size: Colour: Hairs:

Throat constriction:

Dorsal Corola lobes: **Lateral Corola lobes:**
Size: Mucro: Size:

Colour: Colour:

Hairs: Hairs:

Labellum:
Size: Colour at periphery: Emarginate:

Colour at centre: Design:

Lateral staminodes:
Size: Shape: Colour:

Glandular hairs: Notes:

Filament
Length: Width at top: Colour:

Width at base: Notes:

Anther:
Size: Colour: Notes:

Anther thecae:
Size: Colour: Notes:

Anther spurs (Present / Absent)
Size: Shape: Colour:

Anther crest (Present / Absent)
Size: Shape: Colour:

Stigma:
Size: Colour: Cilia:

Exserted out of thecae:

Ovary
Size: Locularity: Hairs:

Placentation: Amount of ovules: Style:

Epigynous glands
Number: Size: Colour:

Shape: Notes:

FRUIT
Capsule
Size: Colour: Opening:

Shape: Surface: Notes:

Seeds
Size: Shape: Colour:

Surface: Aroma: Notes:

Arillus
Size: Shape: Colour:

NOTES
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A-ii. HOW TO COLLECT & DESCRIBE *CURCUMA* PLANTS

Burtt & Smith (1976) provided general advice on collecting gingers. However it would be useful to see in future revisions details on how to collect and describe species of particular genera as different characters are of special importance in each genus (recently appeared e.g. for genus *Etlingera* in Poulsen, 2006).

Most of the *Curcuma* species have bulky inflorescences with pouches holding mucous water and extremely delicate *Curcuma* flowers that last just for a few hours. The flowers curl back into bracts in early afternoon and by evening the slimy mass is beyond recovery. It is thus crucial to take detailed notes directly from living material, especially all colour features and sizes as well as peculiarities of arrangement, which may be lost once pressed or in spirit. This makes collecting extremely time consuming. Plant descriptor saves a lot of time and helps not to overlook any important characters (Appendix A-i.). It is also advisable to take measurements of the flower parts on the spot or within next few hours, as the delicate flower tissues tend to shrink in different kinds of preserving solutions. Information about the other vegetative features can be taken later if the plants are still attached to their rhizomes and properly stored. Again, the dimensions obtained from dried material are not identical with measurements obtained form fresh plants.

For short period (e.g. 2-3 days) plants can be kept wrapped in wet newspapers and protected from damage. They can even continue flowering if any flower buds are present, water in the pouches is regularly refilled at least overnight and the plant has access to light during the day at least for couple of hours preferably in the morning. This method can be used to harvest more flower material for spirit collection. Keeping plants in airtight bags does not work wery well in warm weather conditions as it speeds rotting, but works well in higher altitudes. Flowers can be kept for several hours in small airtight container when not exposed to heat.

Flowering materials have to be collected and stored in spirit or other preservative solution. However the colours will be lost and shape will be affected with turgor loss. Good material should preferably contain the whole inflorescence, but this is difficult on long field trips due to storage constraints. A minimum valuable collection should consist of a few separate flowers and at least one fertile bract with whole cincinnus and a coma bract.

It is essential to make on the spot photo-documentation of flowers in bract from various angles as well as dissected flowers with a measurement scale. Further details can be later obtained using stereomicrospe. Such photo-documentation has proven to be of immense value as an additional aid to specimens & spirit collections. Dissections (see e.g. paper VI, VIII) allows quick comparison of colour, size and shape of floral parts of similar looking taxa from different localities, as well as comparing features of the same plant from the original locality and later from cultivated material. It is also very useful when working with variable seed-setting population in order to capture the extent of infrapopulation variability.

Rhizomes also possess important characters for the species. They can be rather sizeable and some grow rather deep, thus difficult to remove them from the ground including root tubers without breaking them apart. Photographic documentation of rhziome size and structure, colour of the inner part of rhizome and root tubers in the field is valuable. Observations show, that rhizomes of several species (observed especially on light yellow-coloured rhizomes) change colour within several minutes, so they have to be freshly cut prior photographing. It is also necessary to bear in mind, that rhizome structure can be up to some extent influenced by the habitat and type of substrate, and that the shape of the branching rhizome taken from the plants cultivated in pots usually differs from the plants freely growing in soil.

A-iii. FLAT & DEAD, YET USEFUL: tips for preserving herbarium specimen

Preparing a useful herbarium specimen of *Curcuma* is a challenge due to their bulky inflorescences as well as sizeable rhizomes. Various authors noted that apart from a few distinct species, herbarium specimens in *Curcuma* are insufficient to enable an exact identification. This is partly due to the improper way of preparing the specimen as well as incompleteness of the materials. There is scarcely any specific information and tips on how to transport plants over long period for later pressing, and what kind of drying method should be used in order to prepare good specimens.

Modern drying machines with good air circulation are rarely available in developing countries in Asia, where the diversity of gingers is highest. Preparing specimens in improvised drying machines requires frequent replacement of blotting papers/newspapers. For bulky and huge *Curcuma* specimens it is advisable to change the blotting papers twice a day for the first two days, and once a day for the next three days (judge by the wetness of paper). Subsequently there is usually no need to change papers provided the plants are well spaced by cardboards or other airflow enabling medium. For plants processed by wet method, once a day change schedule is sufficient.

For long-term fieldwork, diluted formaldehyde (8 – 10% solution) is still the best preserving agent for bulky plants, despite health concerns in some quarters. Alternatives like alcohol-based solutions are not able to prevent rotting of bulky and fleshy parts over longer periods. Most of the colour features (e.g. red path on the leaves) will still be retained in formaldehyde solution unlike when using alcohol-based solutions.

Pressing the bulky *Curcuma* inflorescences is troublesome, as the content of the pouches will usually start to rot before the inflorescence is dry. Shaking off the excess water from the pouches and slicing inflorescence in half including the peduncle will allow quicker drying as well as making duplicate specimen from a single plant. When using the wet collection method plants have to be sliced before they are pickled.

Some of the branched rhizomes can be very huge and it is thus neither always possible nor necessary to dry whole rhizome with tubers as long as detailed notes and photographs/scatches are taken. Generally, *Curcuma* species with bright orange rhizomes will retain their colour if they are properly dried well (without rotting or preserving in any kind of solution prior to drying). But species with creamy, light yellow, straw-coloured, bluish, greenish and violet shades changes/looses colour after cutting perhaps due to oxidation processes and colour further deteriortes by drying. Trials with drying 2 mm thick slices of rhizomes in silica gel yielded quite good results. These can be easily attached in small envelop onto the herbarium specimen.

As many *Curcuma* species look very similar, it is necessary to be extremely careful when processing multiple specimens. In the case of many historical specimens several species are mixed and sometimes mounted on a single sheet. This is less likely to happen when processing plants directly from fresh individuals. However, when many plants from the same fieldtrip are pressed between newspapers and placed with other within the same bag before preserving them, errors like a missing tag or mislplaced specimen can cause a mistake when processed at later date. It is prudent to keep every collection number and its all duplicates pressed, presserved and sealed in its own bag. Otherwise two collections, each of easily recognizable genus e.g. *Curcuma* & *Globba*, can share a bag.

Even though spirit specimens and photographs of flower dissection are definitely of a more informative value for *Curcuma*, it is possible to prepare proper flower specimens to complement the collection. Apart from the classical way to dry flowers (between fine blotting papers), I explored other ways to dry flowers directly in the field. Once flower dissection for photo-taking and measurements are done, all parts can be pasted fresh directly onto white cardboard using delicate brush and white acrylic glue and be left to dry in the open or anywhere suitable (under the fan, in air-con room or even in the train near window). Each card with dried flower is then protected using tracing paper cover and kept in airtight bag during the field trip.

A-iv. LIVING COLLECTION & DORMANCY

Curcumas are rather easy to keep in living collection. Packed properly, the rhizomes are durable and transportable to be brought out from the field for cultivation - even if the field trip lasts for many weeks. Perhaps the best material for transporting rhizomes is damp peatmoss. Another suitable, cheap and always available option is newspapers. The leafy shoot can be cut off c. 10 cm above the rhizome and packed in a few layers of newspapers. Rhizomes shuld not be wet prior to packing. During long journeys, it is advisable to check on rhizomes once a week, check if they are too dry and sprinkle with water if necessary and repack in fresh newspapers.

The soil has to be well drained, to prevent waterlogging and potential rotting of the rhizome. This is particularly important when taking care of seed-setting species, of which the rhizome is often small and unbranched. Once rotting occurs, it is usually beyond recovery. On the other hand, such species can be propagated via seeds. Also they could hybridize with most of the other seed-setting species of the same region if placed within same collection and thus offsprings of uncertain parentage can occur and ‘mess up’ the collection. Seed setting usually does not happen in the greenhouses, unless pollination is faciliated, but is quite common in the open collections in native countries of these species. Most of the species thrive well in sunny to semi-shaded condition, without direct mid-day sun. *Curcumas* should be re-potted towards the end of the dormant period using fresh substrate enriched with a slow releasing fertiliser and be placed into bigger pots, or their rhizome should be reduced to fit the current pot. But flowering generally occurs only in plants, which have well developed rhizomes.

Almost all *Curcuma* species come from monsoonal parts of Asia, and their leaves will die off towards the end of rainy season. Once the leaves have withered through drought, the rhizome enters a dormancy period, which lasts for 3-4 month (or even longer). This period cannot be easily broken by simple restoration of moisture levels (Prana, 1977), which in fact can lead to rotting of the rhizomes rather than ‘waking up’ the plant. The plant will start sprouting shortly after pre-monsoon showers appear. This has to be simulated in the collection by managing the watering regime. In temperate climate, the dormancy can be triggered also by a drop in temperature (Branney, 2005).

According to personal observation, the dormancy period seems certain and timely regardless of different conditions in cultivation, especially for the seed-setting species with simple rhizomes. I have tried over a few years to synchronize the dormancy for all *Curcuma* species in the Singapore collection to allow easy maintenance. However, this was not very successful and plants grow best if they follow monsoon schedule of their country of origin. E.g. *C. oligantha* from Sri Lanka regularly comes up in November, when most of other Curcumas are dormant. The individuals, which were forced to follow climatic patterns of India (dormancy from mid November – aprox. March) either died or had to be 'rescued' from dying.

For certain *Curcuma* species with well-branched rhizome (e.g. *C. aeruginosa*, *C. zanthorrhiza*), their dormancy in the tropics is not obligatory. Regular watering/rainfalls will prevent plants from going dormant and these will continue to grow, although they may not flower at all. However, this does not apply to most of the seed-setting species with simple rhizomes, whose leaves will become yellow and wither regardless of rainfall/watering. If waterlogged, the rhizome will soon rot. In greenhouses of Europe, not only a drop in tempertaure or watering, but perhaps also the shorter length of the day in winter seems to induce dormancy in most of the species (reagrdless of ploidy level and rhizome structure).

Prana (1977) reported that some of the species continued to flower in Bogor whole year around like e.g. *C. aeruginosa* or *C. zanthorrhiza*. I have observed in Singapore, that these two species if kept without dormancy do not usually flower. It is interesting to note that in India these two species flower only for a short period after the pre-monsoon showers (*C. aeruginosa* in April, followed by *C. zanthorrhiza* in April-May). This was observed in both species in two European greenhouses regardless of their origin (Indonesia, India, Bangladesh). On the other hand, Prana (1977) observed 80 clones from 29 accessions of *C. phaeocaulis* in Bogor. These however never flowered and Prana assumed, that this species is completely assexual. However, Javanese collections of *C. phaeocaulis* at RBG Edinburgh flower easily in May.

It is obvious that dormancy and induction of flowering is affected by several factors and more observation and research in the field are needed.

A-v. OVERVIEW OF ZINGIBERACEAE WORKS IN INDIA with special attention to the genus *Curcuma*

One of the first printed records of the Indian plants was **Hendrik Adriaan van Rheede's** *Hortus malabaricus* (1678-1693). Zingiberaceous plants are elaborated in volume XI (1692), and only two *Curcuma* species are included – *Manjella kua* [*C. longa*] and Kua [*C. zedoaria*]. However, this monumental work on plants of the Malabar Coast includes for its era quite detailed descriptions and line drawings of such quality, that some of them were proposed as types, which is also the case of Kua, proposed as lectotype of *C. zedoaria* by Burtt (1977).

Hon. East India Company appointed a string of excellent botanists starting with **Johann Gerhard Koenig.** He travelled to a number of places in India and Ceylon, continuing his journey from Madras via Nicobar Islands to Siam and Malacca, after which he returned to India in 1779, where he lived until his death in 1785. His precise descriptions of gingers from living plants, published by Retzius (1784), were evidently inspiration for the future work of Roxburgh (Holttum, 1970).

William Roxburgh, played a key role in the early ginger research as he understood and clearly promoted the necessity of studying gingers from living material as well as the need to capture essential characters including colours. His major works related to gingers include *Plants of the Coast of Coromandel* (3 Vols, 1795-1820), where he described two *Curcuma* species; *Description of several of the Monandrous Plants of India* (1810) where he listed 14 species, *Hortus Bengalensis* (1814), listing plants cultivated at that time in the East India Company Botanic Garden in Calcutta, including 17 *Curcuma* species. Some of these are *nomina nuda*, which have been validated a few years later in *Flora Indica* (1820), where the same number of species is listed. Roxburgh's works contained not only Indian plants, but also plants obtained from various people from other parts of British India (mostly Burma), and more remote places e.g. Sumatra. The set of his unpublished drawings known as *Icones Roxburghianae* represents a milestone in ginger studies and documentation and depict almost all plants described in *Flora Indica*. Two sets exist; one at K and another at CAL. Unfortunately, the existence and importance of these drawings are still overlooked by many botanists.

Nathaniel Wallich was another eminent botanist employed by the East Indian Company. He spent almost forty years of his life in India (with interruptions) and during this period collected over 9,000 species in numerous sets mainly in British India territories. These are listed in *A numerical list of dried specimens of plants* and are now distributed in about 46 herbaria. Descriptions and splendid figures of many East Indian plants were published in his 3 volumes of *Plantae Asiaticae Rariores* (1829-1832). The first volume contains several Zingiberaceae, three *Curcuma* species among them, but only one of them is so far known to occur in India (*C. roscoeana*). Wallich not only followed Roxburgh's high standard in illustration of plant specimens, but even shared some of Roxburgh's best artists (Noltie, 1999).

William Roscoe was fascinated by plants of the order Scitamineae and dedicated lot of time to study them. A major part of Roscoe's living material was of Indian origin as he had vivid and friendly correspondence with N. Wallich, W. Carey and others, who supplied him with living plants. Roscoe's work was also outstanding, as he too worked with living material cultivated at Liverpool Botanic Garden and recorded descriptions as the plants flowered. Roscoe was probably the first to have specimens, which included well-processed dried flowers. He wrote two papers on Scitamineae (1807, 1815) and his life-long passion culminated into *Monandrian Plants of the order Scitamineae* (1824-1828), depicting nine *Curcuma* species among 112 scitamineous plants.

Robert Wight was working on the flowering plants of South India. He accumulated a large amount of collections amounting to several hundred thousands. These were widely distributed via Kew to many major herbaria of the world (Noltie, 2005). Even though he was not particularly interested in gingers, is work *Icones Plantarum Indiae Orientalis* (1838-1853) is important as in volume six, seven ginger species (including *Curcuma neilgherrensis*) were described as new.

Horaninow's (1862) *Prodromus Monographiae Scitaminearum* does not contain any original work, but is important as a resume of what was known about Scitaminean plants. Twenty five species are listed with short description, taken mostly from

Roxburgh's and Wallich's works, another 18 names are listed under '*dubiae et exclusae*'. These contain plants transferred to another genera as well as plants, which Horaninow was unable to assess, e.g. Graham's Indian species *C. pseudomontana* or *C. caulina*.

Baker (1890) authored Scitamineae in Hooker's *Flora of British India*. His work was mostly carried out from herbarium material. Baker acknowledged he found the study very difficult in *Curcuma* and had to take most of the characters from published and unpublished drawings deposited at Kew. This work, even though very outdated, is still a classic for Indian Zingiberaceae as it represents the only comprehensive work covering the whole Indian subcontinent. Important and often overlooked is Baker's contribution in validating many of Wallich's names (*nomina nuda*) known only from his *Numerical List*. Hooker hoped that publishing *Flora of British India* would facilitate and encourage the preparation of local floras (Burkill, 1965). It indeed did and the first most important floras (including few which were published before FBI) are listed below and grouped together by area.

Several botanists focused on Western part of India, especially Bombay and its vicinity. *A Catalogue of Plants growing in Bombay and its vicinity* was put together by **John Graham** (1839) and represented the first checklist for the area, but was heavily based on Wight & Arnott's *Prodromus* (Burkill, 1965). Most of the species do not have descriptions, except those described for the first time. Fourteen species are enumerated though Nimmo introduced six of them from Wallich [by then in Calcutta]. Two species from around Bombay were described as new (including *C. caulina,* which was mostly treated as a member of the genus *Hitchenia*). **Nicholas A. Dalzell & Alexander Gibson (1861)** published *The Bombay Flora* with short descriptions of plants and mentioned six *Curcuma* species, while **Thomas Cooke (1907)** in his *Flora of presidency of Bombay* (first flora for the region with reasonably long descriptions) encountered seven *Curcuma* species. **Ebelhart Blatter (1930)** was working in the Bombay area and described several new species including two *Curcuma* species. **Santapau (1945, 1952)** was another botanist working in the area. He published two papers resulting from his long years of observing two *Curcuma* species common in the area, namely *C. pseudomotana* and *C. indora.* As he observed several populations, he noticed rather high variability in *C. pseudomontana* and its ability to flower twice.

David Prain (1903) published an account of Bengal Plants, and noted 10 *Curcuma* species, all previously described by Roxburgh. Almost the same species were encountered by **Haines (1924)** from Bihar & Orissa, who also reported 10 species, but differed with Prain's account only in single species. Haines' work is notable as he actively collected and prepared detailed descriptions from living plants, some of which are extant at Kew herbarium attached to the respective herbarium sheets. **Fischer (1928)**, mentioned eight *Curcuma* species in *Flora of the Presidency of Madras*.

After 1930 there are far too many works on the local floras. Only works that are expicitly connected to Zingiberaceae/*Curcuma* are here mentioned.

Series of works on Zingiberaceae of Assam (including NE India) was published by **A.S. Rao & D.M. Verma (e.g. 1969a,b,c, 1971, 1972)** who studied this family in the late sixties and early seventies. Their works were based on living material. They had observed for several years the plants while in cultivation and thus able to provide detailed description. No novelties in *Curcuma* were published in the series of their work.

In 1984 **Balakrishnan & Bhargava** revised the genus *Curcuma* for Andaman Islands. They have reported four species, *C. longa, C. zedoaria*, *C. mangga* and *C.*

petiolata, the latter two as new records for India. Unfortunately, the first two species lacked descriptions as the authors said that 'descriptions are easily available in literature'. While *C. longa* is surely present in Andaman Islands and characters in the determination key was coherent with this species, I did not encounter *C. zedoaria*, even though at least 10 *Curcuma* species have been collected during the fieldwork there in 2002. The characters mentioned in the key however pointed towards *C. latifolia* rather than *C. zeodaria*. The examination of plants determined as *C. petiolata* turned out to be *C. roscoeana* (Škorni•ková & Sabu, 2005b). **Dadar & Singh (1997) Srivastava (1998)** in their accounts on Zingiberaceae in Andaman and Nicobar Islands reported the same as Balakrishnan & Bhargava (1984).

Paper by **S.K. Jain & Ved Prakash (1995)** deals with phytogeography and endemism of Indian Zingiberaceae, all species are listed with tabulation of their distribution in states. However the origin of the data is not clear as there is no methodology included in the paper and perhaps this attempt represents a summary from Indian floras. Twenty-eight *Curcuma* species are listed.

K. Gopalakrishna Bhat is actively collecting and studying plants of Karnataka, especially in Udupi area. His efforts resulted in collection of extremely rare and endemic plant, described by R.M. Smith (1977) as a new monotypic genus *Paracautleya* (now being sunk into *Curcuma*). In 2003 he published *Flora of Udupi*. Bhat always paid special interest to Zingiberaceous plants and result of his collections was the paper on Zingiberaceae of Karnataka (1993), as well as smaller papers on various ginger taxa (Bhat, 1987 & 1988; Bhat & Venugopal, 1987).

Sunil Tripathi focused for his PhD thesis on Zingiberaceae of NE India and published several papers including new species, new distributional records and ethnobotany of gingers of NE India (e.g. Tripathi & Prakash, 1999a, b, c, d, 2000) and two focused on *Curcuma* (Tripathi & Prakash, 1998; Tripathi 2001). However, Škorni•ková & Sabu (2005b) questioned his new record of *C. petiolata* (1998) for India.

Velayudhan and co-workers published a number of papers on Indian *Curcuma* in the last 17 years. Since the work of this team is mostly based on study of living material, it could have been a great contribution to the current knowledge. However, the tragic lack of literature (historic and recent) and protologues, lack of revision of herbarium material at least in major Indian herbaria as well as uncritical evaluation of intraspecific variability, resulted in series of papers in non peer-reviewed journals. These included description of new species (1990a, b; 1991b; Amalraj & al., 1991b), new distributional records for India (Amalraj & al., 1991a, 1992a), notes on identity of certain *Curcuma* species (1990, 1991a, Amalraj & al., 1992b), attempt on new infrageneric classification in *Curcuma* (1996, 1999) and others. Unfortunately, there are too many factual errors, the specimens are rarely cited, vouchers (if prepared) are mostly not deposited in publicly accessible herbaria, plates are of substandard quality and the only means of verification is re-collecting the taxon in question from the locality, if such is mentioned precisely enough. Comments and clarifications on individual papers will be discussed in revision under respective taxa.

The book *Zingiberaceae of Sikkim* by **Survesh Kumar (2001)** suffers a few major drawbacks e.g. no specimens examined are cited, line drawings are often based on herbarium materials, which in several cases were sterile. Several mistakes occur even at generic level, the specific descriptions are usually only 5-12 lines long and not able to convey information needed for specific determination, types are not mentioned, historical literature is not properly scrutinized, which leaves the correct determination of gingers difficult. One of Kumar's previous works (1991) focused on *Curcuma* species of Sikkim Himalayas, but suffered frmo the same.

The only revision of the genus *Curcuma* in India was by Mangaly & Sabu (1993), which focused only on South Indian species. It is mostly based on authors' own collections, descriptions are based on living material and limited herbarium material is cited. However, the question of types for historical taxa remained unresolved. Seventeen *Curcuma* species and one variety are elaborated in this paper. *Curcuma caesia*, previously reported by the same authors as a new record of India (1989) represents actually misidentification of *C. aeruginosa*. Apart from this revision, Mangaly & Sabu also published several other papers on *Curcuma* species (Mangaly & Sabu, 1987, 1988, 1989; Sabu & Mangaly, 1988a) and other Zingiberaceae (Mangaly & Sabu 1992, Sabu & Mangaly, 1988b, 1991; Sabu, 2000). Most of these works were part of Sabu's PhD thesis (1991) on South Indian Zingiberaceae, and represented the first attempt to revise the whole family for larger area after Hookers *Flora of British India*. Fifteen years later after PhD. Sabu prepared the book *Zingiberaceae and Costaceae of South India* (Sabu, 2006). The book definitely represents a contribution to the knowledge of Indian Zingiberaceae, as the majority of the descriptions have been made from living material and colour photographs of many species are published for the first time. Even though the historical literature as well as revision of the herbarium material from Indian herbaria is better than in any of the recent works mentioned earlier, it was still insufficient to resolve taxonomic tasks connected with nomenclature, types, identities and synonymies of historical names in critical groups due to limited access to resources overseas.