Johnson Marimuthu
Helena Fernández
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Shibila Thangaiah *Editors*

Ferns

Biotechnology, Propagation, Medicinal Uses and Environmental Regulation

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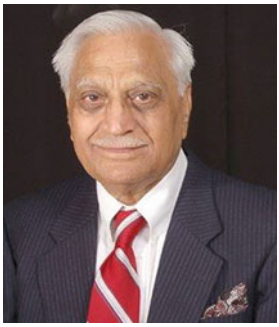
Dedication to Professor S.C. Verma on his 90th Birthday



Dr. Satish Chander Verma *(b. 19 December, 1931), FNASC, FLS, FBS, FSCG, FIFS, former Head and Professor of Botany at Punjab University, Chandigarh, is known (since 1956) for his contributions in cytology, cytogenetics, genetics, and reproductive and evolutionary biology of homosporous ferns and Isoetes. His contribution to the genetics of self-incompatibility in Brassicaceae, nuclear DNA estimations in species of Brassica of U's triangle, Giemsa C-banding studies in Rye, and Lathyrus are exemplary. Supported by the*

British Council he had the distinction of working with Professors Hugh Rees, FRS, and Dan Lewis, FRS. Professor Verma has vast experience of teaching and research, has over 200 publications, and has participated and lectured in several national and international conferences/symposia. He was awarded the Commonwealth Academic staff Fellowship, Royal Society, London, Bursary (UK); Visitorship of British Council (UK) at University College (London) and Queen Mary College (London); and Visiting Professorship at Hiroshima, Tokyo, and Sendai (Japan), University College, London (UK), Colorado College (Colorado Springs, USA), and University of Arizona (Tempe, USA). He was Honorary Research Fellow of University College, London (1977–1984), UGC National Lecturer (1986–87), UGC Emeritus Fellow (1995 & 1996), and recipient of PN Mehra Memorial Medal and DD Pant Oration Medal.

Foreword

I am delighted and honored to be asked to write a foreword to this book on "*Biotechnology, Propagation, Medicinal Uses and Environmental Regulation in Ferns*". Although numerous books have been written over recent decades and centuries about various aspects of the biology, ecology, evolution, and horticulture of ferns, to my knowledge this is the first volume focusing on applied research in ferns spanning the broad fields of biotechnology, propagation, ethnobotany, phytochemistry, and the practical aspects of fern ecology. Despite the overall applied and practical focus of the volume, there are also broad overviews of basic ecology, phylogeny, and evolution of ferns. The editors have assembled a diverse suite of international scholars representing a broad spectrum of expertise in the research areas represented. The chapters comprise various combinations of in-depth reviews of published literature as well as presentations of original research.

The first part of the book is devoted to the wide field of biotechnology, which includes chapters ranging from genomics and molecular phylogenetics to gene evolution in the model fern species *Ceratopteris richardii*, the domestication and uses of *Azolla* spp., and ferns as sources of pesticides. Under propagation of ferns, there are chapters on propagation of various species, including micropropagation, propagation of epiphytic species, gametophyte development, morphogenesis, and the effects of phytohormones and other bioactive compounds on gametophytes. The part on the ethnomedicinal uses of ferns covers diverse areas of investigation including the use of ferns and lycophytes by various human cultures, as well as the description of detailed studies on specific uses of ferns as nutraceuticals, in pharmacology and cosmetics, the potential use for colon cancer treatment, as well as the in vitro antioxidant and antidiabetic activities of some fern extracts. The last part of the book includes chapters dealing with various aspects of environmental regulation.

Every fern expert and enthusiast will find much of interest in this highly informative and thoughtfully devised collection of articles. I recommend this book for academic researchers and students, as well as professionals in applied fields of biotechnology and agriculture.

School of Life Sciences, University of Hawai'i at Mānoa
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Tom A. Ranker

Preface

In our earlier book *Working with Ferns: Issues and Applications* by Helena Fernández, Ashwani Kumar, and Maria Angeles Revilla (eds), some years ago, the focus was on a unique group of plants that provided wider knowledge and applications. The classical pteridological studies are shifting from classical studies such as taxonomy, paleobotany, and morphology, to experimental areas such as ecology, physiology, development, genetics, and biochemistry. Our book offers a glimpse of new Pteridology. The arrival of new and innovative techniques applied to the study of ferns has permitted a more widespread use of sophisticated instrumentation opening up new horizons in the cellular and molecular biology approach to the study of ferns as a result. With the growing knowledge base, particularly the renewed interest in fern genome and platogenomic, DNA marker, evolution, propagation, traditional medicinal uses, and environmental role of ferns prompted us to bring out this second book with additional information. Distinguished contributors and authors, who are masters in the field of Pteridology and Biotechnology, have provided up-to-date information woven in beautiful illustrations, tables, and text to bring all the information under one head. Ferns were first colonizers and are oldest to develop vascular system. However their use in biotechnological investigations involving recombinant DNA technology is very limited. Besides, their use in food or medicine has also remained unexplored. The second largest group of plants after Angiosperms has less frequently been used for genetic manipulations. Ferns have sustained high CO_2 levels and harsh climate of million almost 400 million years ago and may contain repository of genes which might help developing plants having resistance to climate change. The present book provides detailed information about their genomic and phylogenomic studies which might be helpful in locating some important genetic material in ferns to be used to develop plants resistant to climate change. Propagation of ferns in vitro and in vivo is essential for mass multiplication, and the part on propagation outlines achievements in multiplying difficult fern species. Traditional medicinal use of ferns and the secondary metabolites are highlighted in the part on medicinal uses of ferns. Climate change is a biggest problem of mankind in 2021, and ferns are hardy plants and can help us fight problems of climate change in several ways by environmental protection. *Azolla* is one such example to remove heavy metals and provide environmental protection.

The book is dedicated to Professor Emeritus S.C. Verma, oldest Pteridologist on his 90th birthday, for his distinguished services to ferns. We also thank Professor Emeritus S. P. Khullar for his valuable contribution to ferns and acknowledge the *Indian Fern Journal* to provide resource material.

We, the editors, acknowledge with thanks the support of our senior colleagues, fellow colleagues, and students in the preparation of this manuscript and authors for contributing their best articles to the subject. We sincerely hope that book will fill the aspirations of a wide range of readers in the field of "Monilophytes," scholars, researchers, and industry people and general readers.

Palayamkottai, Tamil Nadu, India — Johnson Marimuthu
Oviedo, Spain — Helena Fernández
Jaipur, Rajasthan, India — Ashwani Kumar
Alwarkurichi, Tamil Nadu, India — Shibila Thangaiah

Acknowledgments

We, the editors, are thankful to Professor Emeritus S.C. Verma, senior most Pteridologist from India, and most respected Professor Emeritus S.P. Khullar, Editor of *Indian Fern Journal* from Punjab University, Chandigarh, for suggesting the concept of the book. The editors also thank the distinguished authors who have contributed valuable chapters to this book.

Contents

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Johnson Marimuthu, F.I.F.S., completed his Doctorate in Botany (Plant Tissue Culture) from Manonmaniam Sundaranar University, Tirunelveli District, Tamil Nadu, and is working as Assistant Professor of Botany and Director, Centre for Plant Biotechnology, St. Xavier's College (autonomous), Palayamkottai, Tamil Nadu. He has 21 years of research experience and 18 years of teaching experience. He has published 223 papers in reputed journals, 27 papers in proceedings, and 37 papers as book chapters. He is a recipient of the prestigious SERB Young Scientist—2013, Prof. S.S. Bir Gold Medal—2017, and Certificate of Merit 2014 by Indian Fern Society, India.

Helena Fernández is Associate Professor of Plant Physiology at the University of Oviedo, Spain. She received her PhD in Biology in 1993 from Oviedo University, followed by an EU-funded postgraduate research sojourn at the INRA in Orléans, France, training in HPLC-MS techniques. She got the Ramón y Cajal National Excellence Research Program, dealing with reproduction in ferns. She is guest researcher at the Institute of Plant Biology, University of Zurich, working on apomixes, through omics techniques. She is a member of the dean's team, in the Faculty of Biology at the University of Oviedo. She publishes in relevant journals, having edited two books with Springer.

Ashwani Kumar Alexander von Humboldt Fellow (Germany), MSc (Botany) (Gold Medalist) (1967)), PhD (1971), postdoc AvH Fellow (Germany) and JSPS fellow (Japan) Selected in the Indian Administrative Services (IAS: IPS) (1972) but he opted career in botany. 37 years of teaching & research experience. Guided 39 PhD. research students and published 320 research papers and 26 books. Elected fellow FBS, FPSI, FIMPS and FIFS. Editor in Chief IJLS. V. Puri medal (2008) CEE award (2015). President of CHEC (India), Indian Botanical Society, Society for Promotion of Plant Sciences. Professor Emeritus, Department of University of Rajasthan, Jaipur. Presently, Chair Professor at JVWU, Jaipur and Adj. Professor Modi University, Sikar.

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Introduction

1

Helena Fernández and Ashwani Kumar

Pteridophytes are non-flowering, primitive vascular plants widely used by people all across the globe as they are easily available in large biomass in wild and often grow on relatively poor soils. Ferns, are one of the earliest groups of vascular plants, originated around 400 Mya, attained remarkable levels of diversity and abundance from the Carboniferous period to the Jurassic period (from c. 300 to 150 million years ago). They were especially prevalent in Paleozoic terrestrial ecosystems, before the rise of seed plants and maintained their dominance even into the Early Cretaceous (~145 Mya). Establishing the timescale of early land plant evolution is essential for testing hypotheses on the coevolution of land plants and Earth's System (Qi et al. 2018).

Our earlier books (Fernández et al. 2011; Fernández 2018) have covered basic aspects of ferns, their propagation, molecular diversity, use in medicines, and their role in climate protection. However, this book deals with the latest developments in fern biotechnology, propagation, ethnobotanical uses, and role in climate protection. The content of the present book is distributed in four parts: biotechnology, propagation, medicinal uses, and environmental applications.

Undoubtedly, ferns represent a genetic legacy of great value, being descendants of the first plants that developed vascular tissue, about 470 Mya. This change was due to the need to adapt to the new conditions imposed by the exit of water to the earth, such as the availability of water, the variation in temperatures or the increased exposure to solar radiation. We can say that ferns have been very little studied from a biological point of view. Only a handful of species have been used to delve into

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aspects of plant development, such as photomorphogenesis (Wada 2007), germination (Salmi et al. 2005), cellular polarity (Salmi and Bushart 2010), cell wall composition (Eeckhout et al. 2014), or reproduction (von Aderkas 1984; Wen et al. 1999; Fernández and Revilla 2003; Kaźmierczak 2010; López and Renzaglia 2014; Valledor et al. 2014; de Vries et al. 2016; Grossmann et al. 2017; Wyder et al. 2020), among others. However, it must be said that in recent years we are witnessing a greater approach to this plant group by researchers, since they are plants that have much to offer us. On the one hand, ferns were able to survive atmospheric conditions in which the amount of carbon dioxide was much higher than it is now, and whose levels are increasing (Perez-Martin et al. 2014; Tosens et al. 2016). Likewise, they appealed for their resistance in situations of drought, salinity or contamination of the soil with heavy metals (Rathinasabapathi 2006). Besides this they are generally not attacked by insects (Markham et al. 2006). These species also contain a wide arsenal of secondary metabolites, such as flavonoids, alkaloids, or phenols, sometimes displaying antibacterial, antidiabetic, anticancer, and antioxidant activity (Cao et al. 2017).

Traditionally, taxonomical studies of variation and discrimination of species were established based on their morphological and anatomical characteristics. The limitations in morphological identification systems and the declining pool of taxonomists signal the need for a new approach to recognize taxa.

In the part devoted to Biotechnology, there are seven chapters, including issues such as genomics and plastogenomics, evolution and development, and practical proposals on the use of ferns as fertilizers or alternative to harmful environmental practices as chemical pesticides.

Once again, we must emphasize the need for their application in monilophytes because they have limited blunt variations in morphological characters and high species diversity. Definitively, molecular marker studies have important repercussions in breeding for trait improvement, and detection of adulteration in compounded forms of herbal extracts, among others. The advancement of molecular techniques has generated information on the genetic basis for diversity and variability in organisms. The recent development of molecular markers revolutionized the entire scenario of life sciences, being DNA barcoding an emerging global standard for recognition of taxa, which has drastically simplified the identification process. Indeed, barcoding studies on pteridophytes mostly utilized data from several chloroplast markers. The improvement of molecular techniques has generated information on the genetic basis for diversity and variability in organisms. Several DNA-based fingerprinting techniques have been used such as plastid and nuclear SSRs, RAPD, AFLP, DNA sequencing, and classical taxonomy tools, to study population dynamics, species delimitation, hybridization, and phylogenetics. The gene *rbc*L has been used extensively by various researchers for analyzing the evolutionary relationship of ferns at both generic and familial levels. To study the plastogenomics, will help in understanding the process of evolution in one of the oldest living plants, the impact of reticulate evolution in the early evolution of fern and their interrelationship with angiosperms.

Genomics and plastogenomics supply useful information to revise both the taxonomy and phylogeny based mainly on morphological evidences. New

classifications and evolutionary schemes have been proposed, reflecting different interpretations than previous data. The phylogenetic relationships among these four basal fern orders are the most debated topics in fern phylogeny (Kumar et al. 2022a, b; Janakiraman et al. 2022; Morajikar et al. 2022 this volume). The study of plastogenomics will help in understanding the process of evolution in one of the oldest living plants, the impact of reticulate evolution in the early evolution of fern and their interrelationship with angiosperms. Further analyses of the fern chloroplast genomes should provide new insights into the plastid genome evolution. Phylogenomics based on chloroplast genomes has shown many advantages in plant phylogenetics in the recent years. Integration of evidences from all living and fossil species in morphological as well as molecular data and evolutionary models will provide increased precision. With more nuclear data available recently, chloroplast phylogenomics can provide a framework for testing the impact of reticulate evolution in the early evolution of ferns (Kumar et al. 2022b this volume).

A very interesting chapter using the fern model *Ceratopteris richardii*, included in this part of the book, is committed to stress the high value of this plant group, in elucidating evolutionary developmental questions in land plants, in addition to other aspects of plant biology. As it is well known, plants have the competence to produce new organs throughout their life due to persistent proliferation of tissue-specific stem cell populations, being the family of WUSCHEL-related homeobox (WOX) genes recognized as determinant transcription factors for stem cell maintenance. The fact that WOX genes are found in all land plants and some extant algae was the basis to revise the current understanding of the evolution of the WOX gene family in controlling cell proliferation of various meristem domains in distantly related land plant models, *Physcomitrella patens*, *C. richardii*, and *Arabidopsis thaliana* (Youngstrom et al. 2022 this volume).

The next chapter of this part is a chapter devoted to the symbiosis between *Azolla* genus and the filamentous cyanobacteria, *Nostoc azollae,* allowing N_2-fixation and transferring reproductive structures for generations. Ferns from the *Azolla* genus are highly productive without nitrogen fertilizer because filamentous cyanobacteria, *Nostoc azollae,* associated with the shoot stem cells, invade leaf cavities for N_2-fixation, and reproductive structures for generational transfer concluded that for rapid breeding, the next vital development will be genome editing of fern host and cyanobacterial symbiont and described the first steps towards this end (Schluepmann et al. 2022 this volume). The focus is to take benefit of this co-operation for circular economy, including the sustainable production of plant protein, diving into the most recent and also the new proposals, on molecular research. The authors start describing novel investigation areas required to integrate agro system development with domestication, describing the first successes to control the life cycle of the symbiosis in relation to dissemination, storage and pre-breeding, and ending with the identification of key traits of the symbiosis needed to achieve yield stability. Next chapter describes *Azolla* as a biofertilizer and feed for animals, poultry, waterfowl, freshwater fish, and crustacea. Apart from it, *Azolla* increases its biomass so meaningfully that it is able to sequester large amounts of atmospheric CO_2, acquiring the capacity to mitigate anthropogenic climate change through Carbon Capture and Storage

(CCS). Moreover, *Azolla*'s biomass can also be useful as biofuel and a range of products that are urgently needed as our population increase by a billion every 12 years (Bujak and Bujak 2022 this volume).

The phytoecdysteroids have the same structural features as ecdysteroids found in insects or other arthropods. Sahayaraj (2022 this volume) described that ferns are a source of Phytoecdysones and suggested their applications in insect management. As it is well known, insects cause severe damage to numerous economically important crops and their control relies on pesticides. Although chemical pesticides may have beneficial action on agricultural production, but they can also have adverse effect on environment. In concrete, ecdysteroids are very common in Polypodiaceae, and they are reported to act as repellents from these harmful organisms. The chapter revises in depth the potential use of ferns for research on selective biodegradable substances which can be used as green insecticides (Sahayaraj 2022 this volume)

The second part of this book gathers chapters on propagation, which can be used for different purposes: ornamental, medicinal, etc. No doubts, their exquisite foliage patterns and resilient growing make them popular ornamental plants worldwide. Those demanded species for its beauty can be propagated by vegetative or sexual means either by traditional or tissue culture methods (Suneetha and Hegde 2022; Shibila and Johnson 2022; Vallinayagam 2022; Bhatia and Uniyal 2022; Johnson et al. 2022a; Granados et al. 2022; Sánchez et al. 2022).

For the last half of century, micropropagation has emerged as a powerful tool for the rapid propagation of rare and endangered plants, being welcome to employ scientific methods such as tissue culture to conserve and propagate these pteridophytes. A much superior and uniform quality of ferns can be produced independent of the season by this technology (Suneetha and Hegde 2022 this volume). An exhaustive revision is supplied in this work. In line with it, a protocol for the mass multiplication of two epiphytic species *Lepisorus nudus* (Hook.) Ching and *Elaphoglossum stelligerum* (Wall. ex Baker) T. Moore, using in vitro spore culture, is detailed next (Shibila and Johnson 2022 this volume) and also for the ornamental fern *Histiopteris incisa* (Thunb.) J. Sm., which has been identified as metallophytes recently, from spore culture until field establishment (Vallinayagam 2022 this volume).

Bhatia and Uniyal (2022 this volume) studied the reproductive biology in a few ferns and the effects of Nitric oxide on the development of gametophyte and gametangial production in *Ceratopteris thalictroides*. In the same work, the effect of sodium nitroprusside (SNP—a nitric oxide donor) on spore germination is also reported as well as the effect on vegetative and sexual organ development.

Different morphogenetic events of ferns, viz., vegetative propagation, apogamy, apospory, somatic embryogenesis, and polyembryony have been reviewed. Finally, a molecular approach on some of these processes is uncovered, to give evidence about new promising research lines, committed to deciphering the molecular clues operating behind them, and also to envisage important biotechnological repercussions (Johnson et al. 2022a this volume). Apogamy is a peculiar case of apomixis, very frequent in ferns, in which an asexual embryo derived from somatic

cells of the gametophyte generation. Two reports of this event in the obligate apogamous species *Dryopteris affinis* ssp. *affinis* are included (Sánchez et al. 2022 this volume). The first one talks us about the effect of several phytohormones and inhibitors of their biosynthesis or transport on the gametophyte and the second brings to us some amazing results about the effect of yucasine, an inhibitor of the auxin biosynthesis, and the solvent DMSO, on vegetative gametophyte development and this kind of asexual reproduction. The effect on vegetative and apogamous gametophyte development of 14 phytohormones and inhibitors of their biosynthesis or transport (HBTIs) was analyzed in homogenized gametophytes cultured in liquid Murashige and Skoog (MS) medium (Granados et al. 2022 this volume).

The third part of the book is dedicated to the medicinal uses of ferns. Ethnic communities all over the world use ferns for various ailments such as dysentery, malaria, stomach-ache, urinary disorders, burns, etc. (Abraham and Thomas 2022; Kholia and Balkrishnan 2022; Antony and Suresh 2022; Johnson et al. 2022b, c; Giri et al. 2022; Sara and Ruby 2022; Patil et al. 2022; Sureshkumar and Ayyanar 2022 this volume). In recent times, many phytochemical and pharmacological studies of ferns are being carried out providing new information about the bioactive components with properties such as antimicrobial, anti-inflammatory, antidiabetic, anticancerous, etc. Certainly, India is one of the countries with a longer tradition in the use of pteridophytes, probably due to the fact to have around 1200 taxa, of which nearly 800 occur in the Himalayan region (Kholia and Balkrishna 2022 this volume). Recent development and modernization of societies completely change the social status and way of life of people and this traditional knowledge is being diminishing generation by generation. Keeping this in mind, the socioeconomically useful of ferns are documented (Raju and Suresh this volume 2022).

Consistent with it, an update on the phytochemistry of Indian pteridophytes is provided, covering the recent findings concerning the phytochemical composition of crude extracts, their histochemical, spectroscopic, and chromatographic profiles . A report of 168 species of preliminary phytochemical analysis, quantitative profiles of 115 species, histochemical profiles of 61 species, chromatographic profile (amino acids and sugar) of 43 species, TLC profile of 14 species, HPLC and HPTLC profiles of 23 species, and GC-MS profiles of 32 species are included in the review (Johnson et al. 2022b this volume). The available literature on phytochemistry confirmed that Indian Pteridophytes are a pool of therapeutic agents. In addition, another review summarizes the available biopotential of Pteridophytes from 2000 to 2021 from a total of 244 species, hoping it might be useful for pteridologist, phytochemist, and pharmacist further research (Johnson et al. 2022b this volume). In this study, the antioxidant, antibacterial, and antifungal activities of several pteridophytes, as well cytotoxic and hepatoprotective properties, their anticancer, anti-inflammatory, antidiabetic, and wound healing potential, and larvicidal activity are recorded.

The successive chapters left of this third part of the book focus either on some species or some particular compounds. Thus, it is included a work focusing on the Omega-3 and Omega-6 fatty acids (FAs) distribution in pteridophytes and its significance in *nutraceutical,* pharmaceutical, and cosmetic industry (Giri et al. 2022 this volume). These macromolecules act as a source of energy as well as

play a vital role in human health and nutrition. The most commonly considered plant sources of polyunsaturated fatty acids PUFAs are micro- and macroalgae. Among the terrestrial plants, pteridophytes have some intriguing long chain PUFAs (arachidonic and eicosapentaenoic acids) (Giri et al. 2022 this volume). However, the cultivation and handling of algae have some complication. Monilophytes can be a great source of fatty acids, which are starting to be evaluated in major depth, and to be taken into account for the welfare of human beings.

The book stares at important concerns in the world population today as it is cancer. A study was carried out in *Angiopteris evecta* (G. Forst.) Hoffm., commonly called as giant or king fern, and its anti-proliferative activity of extracts against malignant Colon cancer cells (HT-29) and non-malignant colon cancer cells (L929) (Sara and Ruby 2022 this volume). The findings support the ethnomedicinal observations of these plants for management of cancer, and open new projects committed to isolation and purification of the active elements in the extracts, to investigate the synergy and additive pharmacological effect in killing cancer cells.

Another example of ferns with important bioactivity of the secondary metabolites is the genus *Adiantum*, belonging to the Adiantaceae family, and very popular of folk medicines (Patil et al. 2022 this volume). It is a rich source of many compounds with multiple pharmacological activities such as analgesic, antibacterial, anticancer, antifungal, antidiabetic, and antipyretics. *Nephrolepis auriculata* (L.) has also been checked for phytochemical analysis in vitro antioxidant activity using eight different assays, and antidiabetic activity by α-glucosidase and α-amylase inhibitory assays (Sureshkumar and Ayaanar 2022 this volume). *Nephrolepis auriculata* (L.) was reported to have strong antioxidant and metal chelating activity. In addition, the α-glucosidase and α-amylase inhibitory assays also showed potent antidiabetic properties.

The fourth and last block of the book accumulates knowledge about the useful of ferns as environmental evaluators. To start with, it is the consideration of ferns as potential ecological indicators due to the correlation between their geographic distribution and abiotic variables. They can be easily measurable substitutes for unmeasured ecological values or when extensive studies (with big scales) are nonviable due to budget and time constraints. In the next chapter, a brief introduction on the discovery of fern diversity is provided, and it pursuits to highlight important questions such as giving an overview of fern species richness at a global scale or discussing their distribution across several environmental gradients. The author worries about how the habitat destruction and land use change are the major threats to fern diversity (Della 2022; Mehltreter 2022 this volume).

The fact that pteridophytes have grown efficiently in ever-changing environmental conditions and soils rich in toxic metals. The adaptation of the pteridophytes to anthropogenic activities indicates its evolutionary resilience to various abiotic stress factors, including their high hyperaccumulation capacity, particularly in the fronds, which is called as phytoremediation. Regarding to this topic, there are two contributions. In the first one, the use of ferns as phytoremediators of organic and inorganic environmental pollutants from soil and water is reviewed (Della 2022; Mehltreter 2022; Sajeev et al. 2022; Prabhu and Hegde 2022; Fernández and Sierra

2022 this volume). The wide geographical spread, high environmental adaptation, resilience in toxicity, and bioaccumulation potential of pteridophytes facilitate broad application in the field of phytoremediation since two decades ago. Sajeev et al. (2022 this volume) reported an alternative technique to phytoremediation. In this technique the grounded, non-living, processed pteridophyte-based biosorbents, are applied to remediate the point-source of pollution, in situ. Biosorbents are efficient when the biomass is cost-effective, easy to grow, or harvest, plentiful in availability, and usage of the same quality. Pteridophytes qualify these criteria, making them good biosorbent candidates (Smruthi and Hegde 2022 this volume).

In this book we also bringout the threat which is generally not taken into account: the fern *Pteridium aquilinum,* commonly named bracken, which has been distributed worldwide for ~23.8 Mys. It belonged to open forest communities long before human impact on forests and landscapes took place. However, today the prevalence of bracken has expanded considerably partly not only due to human land use, but also due to the natural aggressiveness of the fern towards competing grasses, herbs, and trees. In addition, bracken is toxic to livestock and humans. The overall geographical distribution and the local abundance of bracken seem to be increasing in many places of the world due to several causes like cultural modifications. Climate change seems to favor bracken spread, somewhere, and given the negative consequences this fern might cause to humans and animals, care must be taken to avoid over-exposition to its dangerous chemicals (Fernández and Sierra 2022 this volume).

References

Abraham S, Thomas T (2022) Ferns: a potential of source medicine and future prospects. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Antony R, Suresh S (2022) Ethnobotanical uses of ferns and lycophytes of Kerala. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Bhatia M, Uniyal PL (2022) In vitro gametophyte development, reproductive biology and nitric oxide signaling in ferns. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Bujak A, Bujak J (2022) Azolla's use as a biofertilizer and livestock feed. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Cao H, Chai TT, Wang X et al (2017) Phytochemicals from fern species: potential for medicine applications. Phytochem Rev 16:379–440. https://doi.org/10.1007/s11101-016-9488-7

de Vries J, Fischer AM, Roettger M, Rommel S, Schluepmann H, Bräutigam A, Carlsbecker A, Gould SB (2016) Cytokinin-induced promotion of root meristem size in the fern *Azolla* supports a shoot-like origin of euphyllophyte roots. New Phytol 209(2):705–720

Della AP (2022) Ferns as ecological indicators. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Eeckhout S, Leroux O, Willats WGT, Popper ZA, Viane RLL (2014) Comparative glycan profiling of *Ceratopteris richardii* C-Fern gametophytes and sporophytes links cell-wall composition to functional specialization. Ann Bot 114(6):1.295–1.307

Fernández H (ed) (2018) Current advances in fern research. Springer, Cham, p 544. ISBN 978-3-319-75102-3

Fernández H, Revilla MA (2003) *In vitro* culture of ornamental ferns. Plant Cell Tissue Organ Cult 73:1–13

Fernández H, Sierra M (2022) Pteridium aquilinum: a threat for biodiversity, and human and animal health. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Fernández H, Kumar A, Revilla MA (eds) (2011) Working with ferns: issues and applications. Springer, New York, p 386. ISBN 978-1-4419-7161-6

Giri P, Kumar A, Uniyal PL (2022) Omega-3 and Omega-6 fatty acids distribution in Pteridophytes and its significance in nutraceutical, pharmacology and cosmetic industry. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Granados S, Alejandro Rivera M, Cañal J, Fernández H (2022) The Effect of phytohormones and inhibitors on apogamous gametophytes of Dryopteris affinis ssp. affinis. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Grossmann J, Fernández H, Chaubey PM, Valdés AE, Gagliardini V, Cañal MJ, Russo G, Grossniklaus U (2017) Proteogenomic analysis greatly expands the identification of proteins related to reproduction in the apogamous fern *Dryopteris affinis* ssp. *affinis*. Front Plant Sci 8(336):1–16

Janakiraman N, Narayani M, Johnson M (2022) A review on molecular phylogeny of Pteridophytes using DNA barcoding. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Johnson M, Fernández H, Shibila T (2022a) Morphogenesis in ferns. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Johnson M, Janakiraman N, Chandra Saleride J, Sivaraman A, Shivananthini B, Paulraj K (2022b) Phytochemistry of Indian Pteridophytes—a review. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Johnson M, Janakiraman N, Chandra Saleride J, Sivaraman A, Shivananthini B, Paulraj K (2022c) Biopotency of ferns. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Kaźmierczak A (2010) Gibberellic acid and ethylene control male sex determination and development of Anemia phyllitidis gametophytes. In: Fernández H, Kumar A, Revilla MA (eds) Working with ferns. Issues and applications. Springer, New York, pp 49–65

Kholia RS, Balkrishnan A (2022) Pteridophytes used by peoples of Indian Himalayan region and northern India. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Kumar A, Giri P, Uniyal PL (2022a) Genome evolution in ferns: molecular phylogenomics—a review. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Springer, Singapore. (this volume)

Kumar A, Giri P, Uniyal PL (2022b) Plastogenomics provides a tool to study phylogenetic interrelationships of monilophytes: a review. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

López RA, Renzaglia KS (2014) Multiflagellated sperm cells of *Ceratopteris richardii* are bathed in arabinogalactan proteins throughout development. Am J Bot 101(12):2.052–2.061

Markham K, Chalk T, Neal Stewart C Jr (2006) Evaluation of fern and moss protein-based defenses against phytophagous insects. Int J Plant Sci 167(1):111–117

Mehltreter K (2022) Diversity of ferns and lycophytes at different spatial scales, along environmental gradients and in the anthropogenic landscape. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Morajikar S, Suneetha C, Harish Kumar TG, Hedge S (2022) Molecular markers in Pteridophytes. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Patil S, Lavate R, Raole V, Rajput K (2022) Adiantum L.: Overview on taxonomy, distribution, conservation status ethnomedicinal uses, phytochemistry and pharmacognosy from India. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns-biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Perez-Martin A, Michelazzo C, Torres-Ruiz JM, Flexas J, Fernández JE, Sebastiani L, Diaz-Espejo A (2014) Regulation of photosynthesis and stomatal and mesophyll conductance under water stress and recovery in olive trees: correlation with gene expression of carbonic anhydrase and aquaporins. J Exp Bot 65(12):3143–3156. https://doi.org/10.1093/jxb/eru160

Prabhu S, Hegde S (2022) Pteridophytes as effective biosorption agents of heavy metals. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Qi X, Kuo L-Y, Guo C, Li H, Li Z, Qi J et al (2018) A well-resolved fern nuclear phylogeny reveals the evolution history of numerous transcription factor families. Mol Phylogenet Evol 127:961–977. https://doi.org/10.1016/j.ympev.2018.06.043

Rathinasabapathi B (2006) Ferns represent an untapped biodiversity for improving crops for environmental stress tolerance. New Phytol 172:385–390. https://doi.org/10.1111/j.1469-8137.2006.01889.x

Sahayaraj K (2022) Ferns: a source of phytoecdysones and their applications in pestiferous insect's management. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Sajeev S, Roshni PT, Mathias RC, Morajkar S, Prabhu S, Hegde S (2022) Pteridophytes: effective agents of phytoremediation. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Salmi ML, Bushart TJ (2010) Cellular, molecular, and genetic changes during the development of *Ceratopteris richardii* gametophytes. In: Fernández H, Kumar A, Revilla MA (eds) Working with ferns. Issues and applications. Springer, New York, pp 11–24

Salmi ML, Bushart TJ, Stout SC, Roux SJ (2005) Profile and analysis of gene expression changes during early development in germinating spores of *Ceratopteris richardii*. Plant Physiol 138:1.734–1.745

Sara C, Ruby GD (2022) In vitro antiproliferative effect of Angiopteris evecta (G. Forst.) Hoffm extracts against cultured Ht-29 colon cancer cells. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Sánchez E, Alejandro Menéndez M, Cañal J, Fernández H (2022) Antagonistic action of yucasine and DMSO on apogamy in the fern Dryopteris affinis ssp. affinis. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Schluepmann H, Bigot I, Rijken N, Grifoll AC, Gudde P, Dijkhuizen LW, Güngör E (2022) domestication of the floating fern symbiosis Azolla. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Shibila T, Johnson M (2022) In vitro propagation of epiphytic fern species. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Suneetha C, Hegde S (2022) Micropropagation of Pteridophytes. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Sureshkumar J, Ayyanar M (2022) Phytochemical composition, in vitro antioxidant and antidiabetic activities of Nephrolepis auriculata (L.) Trimen, an unexplored ethnomedicinal fern. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Tosens T, Nishida K, Gago J, Coopman RE, Cabrera HM, Carriquí M, Laanisto L, Morales L, Nadal M, Rojas R, Talts E, Tomas M, Hanba Y, Niinemets Ü, Flexas J (2016) The photosynthetic capacity in 35 ferns and fern allies: mesophyll CO_2 diffusion as a key trait. New Phytol 209:1576–1590. https://doi.org/10.1111/nph.13719

Valledor L, Menéndez V, Canal MJ, Revilla A, Fernández H (2014) Proteomic approaches to sexual development mediated by antheridiogen in the fern *Blechnum spicant* L. Proteomics 14(17–18):2.061–2.071

Vallinayagam S (2022) In vitro propagation of Histiopteris incisa (Thunb.) J. Sm.—an ornamental fern. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

von Aderkas P (1984) Promotion of apogamy in *Matteuccia struthiopteris*, the ostrich fern. Am Fern J 74(1):1–6

Wada M (2007) The fern as a model system to study photomorphogenesis. J Plant Res 120(1):3–16

Wen CK, Smith R, Banks JA (1999) ANI1. A sex pheromone-induced gene in Ceratopteris gametophytes and its possible role in sex determination. Plant Cell 11:1.307–1.317

Wyder S, Rivera A, Valdés AE, Cañal MJ, Gagliardini V, Fernández H, Grossniklaus U (2020) Differential gene expression profiling of one- and two-dimensional apogamous gametophytes of the fern Dryopteris affinis ssp. affinis. Plant Physiol Biochem 148:302–311

Youngstrom CE, Irish EE, Cheng C-L (2022) The crucial role of Ceratopteris richardii in understanding the evolution of the WOX gene family. In: Johnson M, Fernández H, Kumar A, Shibila A (eds) Ferns—biotechnology, propagation, medicinal uses and environmental regulation. Singapore, Singapore. (this volume)

Part I

Biotechnology

Genome Evolution in Ferns: Molecular Phylogenomics – A Review

2

Ashwani Kumar, Priti Giri, and Prem Lal Uniyal

Abstract

Ferns are one of the earliest groups of vascular plants, originated around 400 Ma, that attained remarkable levels of diversity and abundance from the Carboniferous period to the Jurassic period (from c. 300 to 150 million years ago). They were especially prevalent in Paleozoic terrestrial ecosystems, before the rise of seed plants, and maintained their dominance even into the Early Cretaceous (~145 Mya). Many classifications and evolutionary schemes have been proposed reflecting different interpretations based on morphological evidences. Ferns are the only major lineage of vascular plants not represented by a sequenced nuclear genome. However, recent genomic evidences have helped to strengthen the basic understanding of the ideas of possible relationships, and classification has changed accordingly. Now more nuclear data are being available, and new systems of classification are emerging. We have examined such data in the light of available earlier data and systems. This mini review provides an overview of the available information based on nuclear data for future researchers. In another review in this volume, we have attempted to look into chloroplast genome data for the study of the interrelationships of monilophytes.

Keywords

Genome · Ferns · Polypods · Land plants · Phylogenomics

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