Bir Bahadur · Manchikatla Venkat Rajam
Leela Sahijram · K.V. Krishnamurthy
Editors

Plant Biology and Biotechnology

Volume I: Plant Diversity, Organization, Function and Improvement

Springer

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Volume I: Plant Diversity, Organization, Function and Improvement

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Foreword

Plants are essential to humanity for food, environmental intensification and personal fulfillment. Plants are also the foundations of healthy ecosystems ranging from the Arctic to the tropics. Plant biology is a living science dealing with the study of the structure and function of plants as living organisms, ranging from the cellular and molecular to the ecological stage.

It concerns the scientific study of plants as organisms and deals with the disciplines of cellular and molecular plant biology and the traditional areas of botany, e.g., anatomy, morphology, systematic physiology, mycology, phycology, ecology, as well as evolution.

The backbone of plant biology resides in its applications and spans from anatomy, plant physiology, and plant ecology to biochemistry, cell biology, and genetics.

Biotechnology is the use of living systems and organisms to develop or make useful products or "any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use." Depending on the tools and applications, it often overlaps with bioengineering and biomedical engineering.

For thousands of years, humankind has exploited biotechnology in agriculture, food production, and medicine. It is believed that the term *biotechnology* was coined in 1919 by Hungarian engineer Károly Ereky. During the twentieth and early twenty-first centuries, biotechnology was expanded to include diverse sciences such as genomics, recombinant gene technologies, applied immunology, and development of pharmaceutical therapies and diagnostic tests.

The past few years have witnessed the establishment of Departments or Institutes of *Plant Biology and Biotechnology* in different parts of the world. As the integration of the two subjects has expanded, undergraduate and postgraduate degrees have been instituted with distinct syllabi. Over the years, extraordinary developments have taken place, and significant advances have been made in biotechnology and plant biology. Unfortunately, there are not many texts on the confluence of the two subjects; hence, there is a dire need for texts that are pertinent for teaching courses and conducting research in this area. The present set of volumes is compiled to fill this gap and is edited by four eminent, talented, and knowledgeable professionals, Profs. Bir Bahadur, M. V. Rajam, Leela Sahijram, and K. V. Krishnamurthy. They have tried

to compile and cover major developmental processes to give the student a feel for scientific research.

Volume 1 contains 33 chapters, describes the past, present, and future of plant biology and the principles and strategies, and summarizes the landmark of research done on various aspects. The same authors have also compiled the first five chapters along with other colleagues to set the stage for the reader to comprehend the ensuing chapters. One chapter gives a comprehensive description of plant biodiversity; two chapters give an overview of plant–microbe interaction. Reproductive strategies of bryophytes, Cycads: an overview constitute the contents of two chapters. A single cohesive chapter on AM fungi describes them as potential tools in present-day technologies required for sustainable agriculture and to lessen the dependence on chemical fertilizers. The use of AM fungi as biofertilizers and bioprotectors to enhance crop production are well accepted, e.g., mining the nutrients, stimulating growth and yield, and providing resistance against water stress and pathogen challenge. The reproduction process by which organisms replicate themselves in a way represents one of the most important concepts in biology. Through this, the continuity of the existence of species is ensured. At the base level, reproduction is chemical replication and with progressive evolution, cells with complexity have arisen and in angiosperms involving complex organs and elaborate hormonal mechanism. Three chapters that exclusively deal with genetics of flower development, pre- and postfertilization growth, and development respectively are written in a masterly way. A single chapter on seed biology and technology should be of special interest to crop breeders and geneticists alike. The role of apomixis in crop improvement is most striking, and attract the attention of crop breeders wanting to secure pure lines.

Physiological aspects spanning from photosynthesis to mineral nutrition, which are important aspects of improving yield, have been reviewed pithily. Four chapters discuss details of induced mutations, polyploidy, and male sterility in major crops, and the potential of the utilization of these techniques is essential to shaping scientific minds. These have been discussed in depth.

Each chapter is compiled by a distinguished faculty who has taken seriously its commitment to satisfy the intellectual urge of lifelong learners. Areas of faculty research interest include cell and molecular biologists, geneticists, environmental biologists, organism biologists, developmental and regenerative biologists, and bioprocess technologists. Each chapter provides an authoritative account of the topic intended to be covered and has been compiled by one or more experts in the field. Each chapter concludes with carefully selected references that contain further information on the topics covered in that chapter. I am privileged to have known some of the authors both professionally and personally and am very excited to see their invaluable contributions.

For the students wishing to update themselves in the convergence of biology and biotechnology, the present volume not only furnishes the basics of the life sciences but provides plenty of hands-on functional experience, starting with plant diversity, organization, function, and improvement. Experienced life scientists, biologists, and biotechnologists have collaborated and pooled their talent and long experience in cross-disciplinary topics centered

on recent research focus areas. Interdisciplinary experts have combined their academic talent and strengths to further scientific discoveries in areas such as microbial diversity; divergent roles of microorganisms; overview of bryophytes, cycads, and angiosperms; etc. The strength of the volume lies in reproductive biology e.g., genetics of flower development, pre- and postfertilization reproductive growth, and development in angiosperms.

From finding better ways to deliver crop improvement, perk up the quality of produce, and exploit plant genomics and plant-based technologies to the myriad other ways, the life sciences touch our world, and there has never been a more exciting – or important – time to be a life scientist. If you want to learn more about what biology and biotechnology in plants can do for you, please pick up this volume and browse in depth.

This volume is intended for scientists, professionals, and postgraduate students interested in plant biology and biotechnology or life sciences. The volume will be indispensible for botanists, plant scientists, agronomists, plant breeders, geneticists, evolutionary biologists, and microbiologists.

Advisor (Academics) Prof. C.P. Malik
Jaipur National University
Jaipur, India

Preface

Plant biology has been a fundamental area of biology for many centuries now, but during the last 30 years or so, it has undergone great transformation leading to a better and deeper understanding of many key fundamental processes in plants.

The idea of preparing these two volumes grew out of a need for a suitable book on plant biology and biotechnology for contemporary needs of students and researchers. The present volumes, to the best of our belief and knowledge, cover the most contemporary areas not adequately covered in most, if not all, books currently available on plant biology, plant biotechnology, plant tissue culture and plant molecular biology. Every effort has, therefore, been made to integrate classical knowledge with modern developments in these areas covering several new advances and technologies. This will definitely enable a better understanding of many aspects of plants: molecular biology of vegetative and reproductive development, genetically engineered plants for biotic and abiotic stress tolerance as well as other useful traits, use of molecular markers in breeding, all the '-omics' and various biotechnological aspects of benefit to mankind to meet challenges of the twenty-first century, to mention just a few.

These books have been designed to provide advanced course material for post-graduates in plant sciences and plant biotechnology, applied botany, agricultural sciences, horticulture and plant genetics and molecular biology. These also serve as a source of reference material to research scholars, teachers and others who need to constantly update their knowledge.

Volume 1 of the book provides an in-depth analysis on topical areas of plant biology, with focus on Plant Diversity, Organization, Function and Improvement, including mechanisms of growth, differentiation, development and morphogenesis at the morphological, cellular, biochemical, genetic, molecular and genomic levels.

Contributors to these volumes were selected from a wide range of institutions in order to introduce a diversity of authors, and at the same time, these authors were selected with vast expertise in their specific areas of research to match with the diversity of the topics. These authors not only have a deep understanding of the subject of their choice to write critical reviews by integrating available information from classical to modern sources but have also endured an unending series of editorial suggestions and revisions of their manuscripts. Needless to say, this is as much their book as ours.

We hope these books will help our fellow teachers and a generation of students to enter the fascinating world of plant biology with confidence, as perceived and planned by us.

Hyderabad, Telangana, India — Bir Bahadur
New Delhi, India — Manchikatla Venkat Rajam
Bangalore, Karnataka, India — Leela Sahijram
Bangalore, Karnataka, India — K.V. Krishnamurthy

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First and foremost, we are immensely grateful to all the contributing authors for their positive response. We are also grateful to Prof. C.P. Malik for kindly agreeing and writing a Foreword for this volume.

We wish to express our grateful thanks to a number of friends and colleagues for their invaluable help in many ways and for their suggestions from time to time during the evolution of the two volumes. We also thank research scholars of Prof. M.V. Rajam (University of Delhi South Campus) – Shipra Saxena, Meenakshi Tetorya, Mahak Sachdeva, Bhawna Israni, Mamta, Manish Pareek, Anjali Jaiwal, Jyotsna Naik, Sneha Yogindran and Ami Choubey for their help in formatting the chapters. We also thank Dr John Adams for his help in preparing the subject index.

We wish to express our appreciation for help rendered by Ms. Surabhi Shukla, Ms. Raman, N.S. Pandian and other staff of Springer for their cooperation and valuable suggestions. Above all, their professionalism, which made these books a reality, is greatly appreciated.

We wish to express our grateful thanks to our respective family members for their cooperation.

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Dr. Bir Bahadur, born 5 April 1938, studied at City College, Hyderabad, for 5 years, including an Intermediate Course (Osmania University), graduated from Nizam College, and postgraduated from University College, Osmania University, both in the first division. He obtained his Ph.D. in Plant Genetics from Osmania University. He was closely associated with late Prof. J.B.S. Haldane, F.R.S., a renowned British geneticist who encouraged him to study heterostyly and incompatibility in Indian plants, a subject first studied by Charles Darwin.

He made significant contributions in several areas, especially heterostyly, incompatibility, plant genetics, mutagenesis, plant tissue culture and biotechnology, morphogenesis, application of SEM in botanical research, plant asymmetry, plant morphology and anatomy and lately the biofuel plants Jatropha and castor.

He served as Lecturer and Reader at Osmania University, Hyderabad, and as Reader and Professor at Kakatiya University, Warangal. He also served as Head of Department; Chairman, Board of Studies; Dean, Faculty of Science; and Coordinating Officer/Dean, UGC Affairs at Kakatiya University. He has over 40 years of teaching and over 50 years of research experience. He has supervised 29 Ph.D. students and 3 M.Phil. students in both these universities

and has published about 250 research papers/reviews, which are well received and cited in national and international journals, textbooks and reference books.

He was a postdoctoral fellow at the Institute of Genetics, Hungarian Academy of Sciences, Budapest, and worked on mutagenesis and chromosome replication in *Rhizobium.* He is a recipient of the direct award from the Royal Society Bursar, London. He also worked at Birmingham University (UK). He was conferred with the title of Honorary Research Fellow by the Birmingham University. He studied species differentiation in wild and cultivated solanums using interspecific hybridization and the enzyme-etched seeds technique in combination with scanning electron microscopy to assess the relationship among various *Solanum* species. At the invitation of the Royal Society, he visited Oxford University, Leeds University, Reading University and London University, including the Royal Botanic Gardens, Kew, and various research labs. He was invited for international conferences by the US Science Foundation at the University of Missouri, St. Louis, and the University of Texas, Houston (USA), and at the SABRO international conference at Tsukuba, Japan. He has extensively visited most countries of Eastern and Western Europe as well as Tanzania and the Middle East.

He has authored/edited ten books. One of his important books is entitled *Jatropha, Challenges for a New Energy Crop*, Vol. 1 and 2, published by Springer, New York, USA, 2013, jointly edited with Dr. M. Sujatha and Dr. Nicolas Carels. These books are considered significant contributions to bioenergy in recent times. He was Chief Editor, Proceedings of Andhra Pradesh Akademi of Sciences, Hyderabad, and Executive Editor, *Journal of Palynology* (Lucknow).

He is the recipient of the Best Teacher Award by the Andhra Pradesh Government for mentoring thousands of students in his teaching career spanning over 40 years. He was honoured with the Prof. Vishwamber Puri Medal of the Indian Botanical Society for his original contributions in various aspects of plant sciences. He has been honoured with the Bharat Jyoti Award at New Delhi for outstanding achievements and sustained contributions in the fields of education and research. He has been listed as 1 of the 39 prominent alumni of City College, a premier institution with a long history of about 90 years as per the latest update on its website. He has been chosen for distinguished standing and has been conferred with an Honorary Appointment to the Research Board of Advisors by the Board of Directors, Governing Board of Editors and Publications Board of the American Biographical Institute, USA.

He is a fellow of over a dozen professional bodies in India and abroad, including the following: Fellow of the Linnean Society, London; Chartered Biologist and Fellow of the Institute of Biology, London. Presently, he is an Independent Board Director of Sri Biotech Laboratories India Ltd., Hyderabad, India.

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Dr. Manchikatla Venkat Rajam is currently Professor and Head, Department of Genetics, University of Delhi South Campus, New Delhi, India. He obtained his Ph.D. in Botany (1983) from Kakatiya University, Warangal, India. He was a postdoctoral fellow at the prestigious Yale University, New Haven (1984–1985), and also worked at BTI (Cornell University, Ithaca) for a couple of months as a visiting research associate. At Yale University, his work led to the discovery of a new method for the control of fungal plant infections through selective inhibition of fungal polyamine biosynthesis. This novel method has been adapted by several research groups globally for the control of a variety of fungal infections, and a large number of research articles have been published in this line of work. He returned to India to join as Pool Officer (CSIR) and worked for about 2 years (1986–1987) at Kakatiya University. Subsequently, he joined the University of Delhi South Campus, where he has been on the faculty since 1987. He had worked in ICGEB, New Delhi, for 6 months as a National Associate of DBT (1994). He made several short visits to various countries including France, Italy, China and Indonesia under collaborative projects supported by the Europeon Union and Indo-French organizations. He is a Fellow of the prestigious Indian National Science Academy (FNA), National Academy of Sciences, India (FNASc); National Academy of Agricultural Sciences (FNAAS); Andhra Pradesh Akademi of Sciences (FAPAS); and Association of Biotechnology and Pharmacy (FABAP) and is an elected member of the Plant Tissue Culture Association, India, since 1995. He was awarded the Rockefeller Foundation Biotech Career Fellowship in 1998 (but could not avail it); the 'Shiksha Rattan Puraskar' by the India International Friendship Society in 2011; Department of Biotechnology National Associateship in 1994; and National Scholarship for Study Abroad (Government of India) in 1984 and for Research in 1985 by the Rotary International Club of Hyderabad. He is serving as an Associate Editor and member of the editorial board of several reputed journals including *BMC Biotechnology* and the OMICS journal *Cell and Developmental Biology* and is a member of the advisory or other committees of some universities, institutions as well as other bodies. He has guided

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Dr. Leela Sahijram

Dr. Leela Sahijram is currently Principal Scientist, Division of Biotechnology, Indian Institute of Horticultural Research, Bangalore, India, and heading the Plant Tissue Culture Laboratory. She obtained her M.Sc. in Botany (Plant Physiology) with distinction from Osmania University, Hyderabad, India (1976), and her Ph.D. in Plant Physiology (1983) from the Indian Agricultural Research Institute, New Delhi, India. She was deputed under the USAID Program to the University of California at Davis, USA (1992), for plant transformation. She has also undergone training in bioinformatics at IISR, Calicut, India (2003). She has published several papers in national and international journals and has guided students for their master's and doctoral degree programmes. She was identified by the Department of Biotechnology (DBT), New Delhi, for training on 'Biotechnology and Intellectual Property Rights (IPR)' at the National Law School of India University (NLSIU), Bangalore (2003). She attended a residential course on 'Creative Writing in Agriculture' at the Indian Institute of Mass Communication (IIMC), New Delhi (2011).

Her team pioneered the micropropagation of banana (globally, the leading tissue culture–propagated fruit crop), which has spawned a multibillion-dollar industry worldwide. In 1990, she successfully demonstrated over 20 choice clones of banana from across India to be 'micropropagatable', including cultivars of the Cavendish Group. She was member of the Task Force for the rehabilitation of Nanjangud Rasabale (Pride of Karnataka) syn. Rasthali, 'Silk' group – a clone threatened with extinction. She has also worked extensively on micropropagation and 'specific-pathogen-free' (SPF) plantlet production through meristem culture/micrografting in crops like citrus, caladium, bougainvillea and chrysanthemum besides bananas and plantains. She specializes in hybrid embryo rescue in perennial horticultural crops

(intergeneric/interspecific/intervarietal crosses), particularly in fruit crops, namely, mango, seedless grapes/citrus, banana and papaya. In 2000–2001, she pioneered hybrid embryo culture and *ex vitro* grafting in controlled crosses of mango.

She was conferred with the Dr. Vikram Govind Prasad Award 1999–2000 for research on molecular diagnostics of viruses in micropropagated bananas. She was also honoured with the Horticultural Society of India Award 2006–2007 for research on hybrid embryo rescue in seedless grapes and with the Rashtriya Samman Award 2007 for developing biotechnologies for horticultural crops. She has been editing the *Journal of Horticultural Sciences*, an international journal, for the past 9 years as a Founder Editor. She has also edited a book entitled *Biotechnology in Horticultural and Plantation Crops*. She has several book chapters in national and international publications to her credit. She is the author of many technical and semi-technical popular articles and a laboratory manual besides having trained hundreds of personnel from development departments for setting up commercial plant tissue culture laboratories. She has travelled widely.

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Dr. K.V. Krishnamurthy is currently an Adjunct Professor at the Institute of Trans-Disciplinary Health Science and Technology (IHST), Bangalore, India, and offering consultancy services in Ayurvedic Pharmacognosy. He obtained his M.Sc. in Botany with University First Rank from Madras University, Chennai, in 1966 and his Ph.D. in Developmental Plant Anatomy from the same university in 1973. After a brief stint in government colleges in Tamil Nadu, he joined the present Bharathidasan University, Tiruchirappalli, in 1977 and became a Full Professor in 1989. He has an overall teaching and research experience of more than 47 years and has guided 32 Ph.D. scholars, more than 50 M.Phil. scholars and hundreds of master's degree holders. He has published more than 180 research papers and 25 books, including *Methods in Cell Wall Cytochemistry* (CRC Press, USA) and a textbook on biodiversity (Science Publishers, USA), *Bioresources of Eastern Ghats: Their Conservation and Management* (with Bishen Singh Mahendra Pal Singh, Dehradun). His major research areas include plant morphology and morphogenesis, biodiversity,

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Plant Biology: Past, Present and Future

1

Bir Bahadur and K.V. Krishnamurthy

Abstract

This chapter deals with a history of botanical science. Major advancements made in the ancient, medieval, Renaissance and modern periods in different subdisciplines are detailed. Particular emphasis has been provided to the importance of instruments and techniques that enabled these advancements. The importance of *Arabidopsis* as a model plant in contributing to modern botanical knowledge and in plant molecular biology is emphasized. The future of plant biology is briefly discussed. *Arabidopsis*-like researches must be extended to other plant taxa, especially those that are of economic value. Plants and ecosystems must be continued to be studied in order to save and sustain the earth in the context of population explosion not only of human but of animals as well.

Keywords

Ancient period • *Arabidopsis* • Future of plant biology • Medieval period • Model plant • Modern period • Plant biology • Renaissance period

1.1 Introduction

Botany, often also called *plant science(s)* or *plant biology,* may be defined as the science of plant life. This, along with zoology (science of animals), historically forms the core discipline of *biology* (*bios* = life; *logos* = discourse or science), a term coined by Lamarck. The history of biology is closely associated with *natural sciences* (or *natural history*) of chemistry, physics, mathematics and geology (Krishnamurthy 2005).

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The term 'botany' is derived from the ancient Greek word '*βοτανη*' (= botane), which means 'pasture', 'grass' or 'fodder' (Morton 1981), and also from the medieval Latin word 'botanicus', which means a herb or plant. *Βοτανη*, in turn, is derived from 'βόσκιεν' (= *boskein*), which means 'to feed' or 'to graze'. The science of botany involves observing, recording and describing of plants and their morphological features; classifying them; analyzing their structure, development, physiology and function and reproduction; and exploiting them because of their economic uses and value. Now, botanists examine both the internal functions and processes within cell organelles, cells, tissues, organs, whole plants, plant populations, plant communities (made by different species and their populations), ecosystems (of which plants form a part), landscapes (made of many ecosystems) and the whole biome of the earth.

The above account naturally leads to the questions: What are plants? How to define a plant? Historically, plants represented all organisms other than animals. Hence, plants at one time included viruses, bacteria, fungi, lichens, algae, bryophytes, pteridophytes, gymnosperms and angiosperms. According to some researchers, the strictest definition of plants should include only 'land plants' or embryophytes. But today, viruses have been removed from the list of plants because they are acellular and bacteria have been removed as they are prokaryotic. Whittaker's (1969) five kingdom concept excluded fungi from plants and treated them as a separate kingdom based on their absorptive mode of nutrition as different from the photosynthetic mode of plants. However, detailed research have enabled us to fix the following characteristic/diagnostic features of plants: stationary habit, eukaryotic cells, presence of microfibrillar cell walls, presence of vacuoles, presence of plastids (particularly chloroplasts with chlorophyll), oxygenic photosynthesis (that releases oxygen through an oxygen-evolving complex), presence of photosystem I and photosystem II, invariable presence of starch as a principal reserve material, etc. (Krishnamurthy 2010). Embryophytic land plants share all these features. Algae share the most, if not all, of all the above characteristics. Lichens are autotrophic as they have a photosynthetic partner. Fungi are heterotrophic and non-photosynthetic, but yet they are included by many under plants as they possess eukaryotic cells, microfibrillar cell walls and vacuoles. Even today fungi and photosynthetic protists are usually covered in introductory botany courses, and researchers working on these taxa form the core botany faculty in many botany departments of universities throughout the world. Hence, botany is treated here as including fungi and photosynthetic protists.

Botany is subdivided into subdisciplines based on two important criteria. Either the subdivisions deal with the plant groups in question, such as algology (phycology), mycology, lichenology, bryology, pteridology, Gymnospermae and Angiospermae, or with the different basic aspects of study of plants, such as morphology, anatomy, palynology, taxonomy, physiology, ecology, genetics, cytology, etc. (Sachs 1890), and with the different applied aspects of study of plants, such as agriculture, horticulture, forestry, pharmacognosy, ethnobotany, etc. Since the origin of traditional and applied botany in the ancient period, there has been a progressive increase in the scope of the subject as technology has opened up newer techniques and areas/disciplines of study that increasingly required inter- and multidisciplinary inputs. This chapter examines the human efforts to study and understand plant life on earth by tracing the historical and chronological development of the discipline of botany. In tracing the history of any scientific discipline like botany, it is convenient to divide the past into the following periods (Krishnamurthy 2005): ancient period, medieval period, Renaissance period and modern period. This division has been followed in the present discussion also. Such a historically based study of plants is vital because the plants underpin almost all animal (including human) life on earth by generating a large amount of oxygen and food (through photosynthesis) that provide humans and other organisms with aerobic respiration and the necessary chemical energy which they need for their existence. Hence, a study of plants is crucial to the future of humanity globally.

1.2 Ancient Period

This period might be said to extend from the period of origin of modern man on the planet earth, estimated to be around 200,000 years ago in Olduvai Gorge in the Great Rift Valley of Tanzania, East Africa (excavated by Louis and Mary Leakey in the mid-1950s), until the fifth century CE. This is a very long period, much longer than any historic period. The modern man was nomadic and might have spread to other parts of the African continent, but his movement outside Africa happened only around 70,000 years ago. He moved to different parts of the world including Europe, West Asia, Middle East, Central Asia, India, China, East Indies and Australia. He was a hunter-gatherer, hunting animals and foraging plants for his food. During his hunter-gatherer phase, he was largely using stone implements for hunting and other purposes (and hence this period was called Stone Age). In the Old Stone Age (Palaeolithic period) which extended up to about 12,000 years ago, he gained great knowledge about the animals he hunted and the plants he collected/used for food, shelter, medicines, poisons, ceremonies and rituals, etc. Thus, the initial botanical science began with the empirically based plant lore passed from one generation to the next orally as writing was not invented by then. Botany particularly started with human effort to identify the useful plants and this use of plants might have also influenced the way in which the plants were named and 'classified' according to folk taxonomies that varied in different parts of the world and that were used in everyday communication between each other (Walters 1981). The efforts of the foragers were stated to be mainly focused on exploring the carbohydrate-containing and to some extent fat-containing plant foods such as tubers, fruits and oil seeds since they were able to get enough protein food from hunted animals (Crowe 2005). Today, we still have a few glimpses of how a hunter-gatherer society works from studies of indigenous people of Amazon, New Guinea, Andamans (India) and a few other places. These old-stone age societies are very much plant-based cultures, and it is amazing how many uses for plants they have developed (Prance 2005). Hence, it may be stated with conviction that basic botany started in close association with applied botany in the Palaeolithic Age itself and that knowledge about one was absolutely vital for the other to develop.

In the Neolithic period which started around 12,000 years ago, the nomadic hunter-gatherer lifestyle of humans got drastically changed into settled communities in many parts of the world, particularly in major river banks, although hunter-gatherer communities continued to persist in remote forest areas and islands. The reasons for this change from nomadic to settled life are debated, but most people agree that climate change and associated changes in vegetation at the end of the Pleistocene period about 12,000–13,000 years ago are the major factors responsible, at least for the initial transitions from foraging to farming (Harris 2005). These transitions involved three steps: (1) *cultivation*, which refers to the 'sowing and planting, tending, and harvesting of useful wild or domesticated plants, with or without tillage of the soil'; (2) *domestication*, which means that 'plant have been changed genetically and/or morphologically as a result of human selection (inadvertent or deliberate) and have become dependent on people for their long-term survival'; and (3) *agriculture*, which is defined as the 'growing of crops (i.e. domesticated plants) in systems of cultivation that normally involve systematic tillage of the soil' (Harris 2005). The earliest evidence for these transitions comes from three regions of the world: Southwest Asia, China and India. Legumes were domesticated in almost all the continents, while, among cereals, rice was domesticated in East and Southeast Asia, wheat and barley in the Middle East referred to as 'Golden Crescent', maize in Central and South America and millets mainly in Africa; vegetable and fruit crops were domesticated in many different parts of the world. Thus, 'the cultivated plants are mankind's most vital and precious heritage from remote antiquity' (Stearn 1965), particularly between 12,000 and 2,500 years ago, depending upon the region of the world.