CROPS OF KERALA
AN OVERVIEW

Editors

V.V. Radhakrishnan
T.K. Hrideek
A.V. Raghu
K.T. Chandramohanan

Gregor Mendel Foundation
Department of Botany
Calicut University, Kerala - 673 635, India

CROPS OF KERALA
AN OVERVIEW
(Prof. K.V. Mohanan commemoration volume)

Editors

V.V. Radhakrishnan

T.K. Hrideek

A.V. Raghu

K.T. Chandramohanan

Gregor Mendel Foundation

Department of Botany

Calicut University, Kerala- 673635, India

Crops of Kerala- An overview

Editors
V.V. Radhakrishnan
T.K. Hrideek
A.V. Raghu
K.T. Chandramohanan

ISBN
978-81-935133-0-9

Published May 2018

Book design
Ashok Kumar P.K.

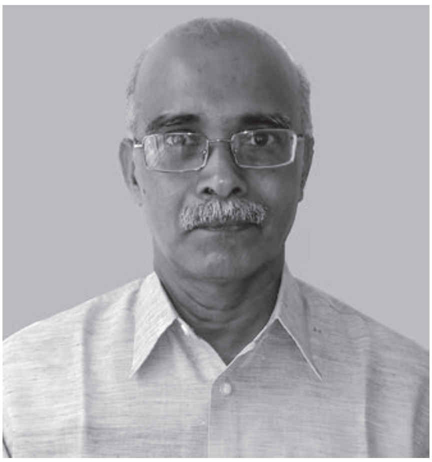
Cover
Sandeep Prabhakara

Printing
Priya offset
Thrissur, Ph : 9526265101

Publisher
Gregor Mendel Foundation,
Department of Botany,
Calicut University, Kerala- 673635, India.

Prof. K.V. Mohanan

Born to Smt. K.V. Meenakshi and Sri. N.V. Sankunni of Mookkuthala village of the present Malappuram District of Kerala State of India in 1958, Prof. K.V. Mohanan had his lower primary education at Government Lower Primary School, Mookkuthala and upper primary and secondary education at Government High School, Mookkuthala. He completed his pre degree education at M.E.S. Ponnani College, Ponnani and undergraduate education at Sreekrishna College, Guruvayur. His post graduate education was at Zamorin's Guruvayurappan College, Calicut and his pre-doctoral and doctoral education was at Department of Botany, University of Calicut. He secured his M.Sc. (Botany), M.Phil. (Genetics & Plant Breeding) and Ph.D. (Genetics & Plant Breeding) degrees from University of Calicut and worked under University of Calicut in various academic capacities from 1982 to 2018 which includes 17 years as Lecturer, Senior Lecturer and Selection Grade Lecturer in the PG Department of Botany of Zamorin's Guruvayurappan College, Calicut affiliated to University of Calicut and 8 years as Reader and more than 11 years as Professor at Department of Botany, University of Calicut. During his career at University of Calicut, he has held different academic positions, memberships in various academic associations and memberships in the editorial boards of some important international journals. During his academic career he officiated as member/chairman of UG and PG Boards of Studies of Botany, Plant Science and Plantation Development of different Universities. He was instrumental in starting a Centre for PG Studies in Plantation Development at University of Calicut and he officiated as its Coordinator from 1999 to 2009. He



established the Interuniversity Centre for Plant Biotechnology at University of Calicut with funding from Government of Kerala and officiated as its Director from 2009 to 2018. He officiated as Head of the Department of Botany, University of Calicut from 2010 to 2012 and as Director, School of Biosciences, University of Calicut from 2015 to 2018. He has worked as a member of the official bodies of the University of Calicut like Planning Board, Faculty of Science, Academic Council and Senate during his academic career. He officiated as secretary of Gregor Mendel Foundation from 2006 to 2018 and during his tenure he reoriented its activities and organized several national seminars. He completed his tenure as secretary of Gregor Mendel Foundation in 2018 and has been inducted as Patron of the foundation from 2018. As on 01-05-2018 he has 175 research publications, 9 books, 3 book chapters, 30 popular science papers, 13 doctoral programmes guided, 5 M.Phil. projects guided and more than 50 PG projects guided. His major areas of interest include genetics, breeding and biotechnology of rice, spices, plantation crops and medicinal plants. His students are placed at academic positions in the universities and colleges of Kerala, scientific positions under Government of India, Government of Kerala and Non-Governmental Research Institutes, extension positions in various commodity boards of Government of India and scientific and technical positions abroad. His major research contributions include studies on tillering behavior, clonal propagation and ratoon cropping in rice, conservation of native rice cultivars, indigenous rice farming systems, salt tolerance in rice and conservation, genetics and breeding of cardamom, vanilla, coffee, tea, medicinal plants and underutilized zingiberaceous tuber crops. He has carried out studies on the agroeconomic situations of the small and marginal farmers of Wayanad District of Kerala and come out with information on the fragility of the agricultural livelihoods of Wayanad.

Contents

भाकृ अनुप - भारतीय मसाला फसल अनुसंधान संस्थान
ICAR - INDIAN INSTITUTE OF SPICES RESEARCH
(भारतीय कृषि अनुसंधान परिषद *Indian Council of Agricultural Research)*
पी. बी संख्या: *Post Bag No:* 1701, मेरिकुन्नु पोस्ट *Marikunnu Post,*
कोषिक्कोड *Kozhikode-673012,* केरल, *Kerala,* भारत *India*
(ISO 9001: 2008 Certified Institute)

Dr. K. Nirmal Babu
Director

FOREWORD

This book 'Crops of Kerala - An overview' is prepared by the colleagues, friends and students of Prof. K.V. Mohanan, to mark his retirement from the service of University of Calicut as Professor of Botany and Director, School of Biosciences. Prof. Mohanan is a geneticist and plant breeder by qualification, experience and training. Pre-breeding and breeding studies on crops grown in Kerala especially rice, plantation crops and spices have been his research domain for more than three decades and he has successfully guided more than a dozen Ph.D. scholars. During his service he has built up a name for himself as a good teacher and researcher producing about 200 research/review papers on conservation, genetics and improvement of crops such as rice, cardamom, coffee, tea, vanilla, rubber, mango ginger, arrowroot and several medicinal plants.

During his academic career, Prof. Mohanan served as member and chairman of different academic bodies of various universities. He was instrumental in starting a Centre for PG Studies in Plantation Development at University of Calicut and he officiated as its Coordinator from 1999 to 2009. He established the Interuniversity Centre for Plant Biotechnology at University of Calicut and served as its Director from 2009 to 2018. He held the position of Head of the Department of Botany from 2010 to 2012 and is officiating as Director, School of Biosciences from 2015 onwards. As the secretary of Gregor Mendel Foundation from 2006 to 2018, Prof. Mohanan streamlined its activities and contributed in popularising Mendelian Genetics.

A perusal of the chapters of this book reveals the implications of studies on major crops of Kerala. I consider that the contents are the reflection on the personality and vision of Prof. Mohanan who advocates that research on crops should contribute significantly towards food security and social progress of mankind. I hope that the excellent teacher and compassionate human being in Prof. K.V. Mohanan will continue to benefit the students of Botany and the society at large for many more years to come. I appreciate the initiative taken by Prof. V.V. Radhakrishnan, an ardent disciple of Prof. Mohanan and other research students of Prof. Mohanan to bring out this useful book as a token of gratitude to their beloved guide and mentor.

Calicut
19 April 2018.

(K. Nirmal Babu)

Preface

Professor K.V. Mohanan (Professor, Department of Botany; Director, School of Biosciences and Director, Interuniversity Centre for Plant Biotechnology, University of Calicut, Kerala) is retiring from active service of the University on 14th May 2018 after his academic and research career that spread over a period of more than thirty six years. As he used to say, it was hard work that helped him to grow to the position of a university professor from very humble beginnings. For the very same reason, throughout his life and career Prof. K.V. Mohanan has ardently tried to inculcate the culture of hard work, discipline and scientific temper not only in his students, but in his family members, colleagues and friends also. As a true humanist with a deep rooted working class identity he has always been insistent in delivering his duties and responsibilities and whatever administrative authority he held, upholding the principles of equity and natural justice.

He is a good teacher with strong commitment to the academic improvement of his students and a researcher with uncompromised conviction to scientific temper and methodology providing no chance to any unhealthy practice debilitating the true pursuit of knowledge.

Majority of his students both at the post graduate and doctoral levels have got placed at academic positions in the universities and colleges of Kerala, scientific positions under Government of India, Government of Kerala and Non-Governmental Research Institutes, extension positions in various commodity boards of Government of India and scientific and technical positions abroad.

This book contains essays on the most important crops of Kerala State of India like rice, coconut, arecanut, pepper, cardamom, vanilla, coffee, tea, rubber and teak which have formulated the destinies of the people of Kerala from time to time, an essay on grain amaranths which are often referred to as the food crop of future and another essay on *dasamula* group of medicinal plants which is familiar to any keralite as the source materials of the ayurvedic medicinal combination *dasamula*.

The book is a compilation of review papers contributed by different authors and the authors have invariably depended on available literature to prepare the manuscripts. All such sources of information are hereby acknowledged with gratitude.

We the students of Prof. K.V. Mohanan are proud to dedicate this commemorative volume to the farmers across the world and the students of natural science as a token of our affection to our beloved teacher and as the reaffirmation of our commitment to society.

Biology and cultivation of rice

Surekha Y. Pawar
Genetics and Plant Breeding Division, Department of Botany, University of Calicut, Kerala- 673635, India.

Rice is the staple cereal food of about 50% of the world's human population. Rice is considered the second most important grain crop in the world after wheat and it is widely cultivated throughout the world. About 90% of the world's rice is produced and consumed in Asia, remaining 5% in America, 3% in Africa and 1% each in Europe and Oceania. Rice has played an important role in ensuring food security of Asia. Rice is now largely cultivated in most of the tropical, subtropical and mediterranean regions having characteristically warm and humid climatic conditions.

Taxonomy of rice

Rice belongs to Kingdom Plantae, Subkingdom Tracheobionta, Superdivision Spematophyta, Division Magnoliophyta, Class Lilliopsida, Subclass Commelinidae, Order Cyperales, Family Poaceae, Subfamily Oryzoideae, Tribe Oryzeae and Genus *Oryza* L. The genus *Oryza* consists of 23 wild and weedy and two cultivated species. The two cultivated species are the Asian rice known as *Oryza sativa* L. and the African rice known as *Oryza glaberrima* Steud. Asian rice is cultivated in almost all the rice growing areas of the world and African rice is cultivated in western tropical Africa.

Species complex

The species of the genus Oryza are broadly classified into four complexes. They are the following: 1. Sativa; 2. Officinalis; 3. Ridleyi; 4. Meyeriana. The Sativa complex comprises the cultivated species *O. sativa* and *O. glaberrima* and their wild ancestors that are perennial and rhizomatous: *O. longistaminata, O. barthii, O. rufipogon,* etc. The basic chromosome number of the genus is

Species complexes of the genus *Oryza* and their geographical distribution

Species complex	Chromosome number (2n)	Genome	Geographical distribution
I. Sativa complex			
1. *O. sativa* L.	24	AA	Cosmopolitan
2. *O. nivara* Sharma et Shastry	24	AA	South & Southeast Asia
3. *O. rufipogon* Griff.	24	AA	South &Southeast Asia, South China
4. *O. meridionalis* Ng.	24	AA	Tropical Australia

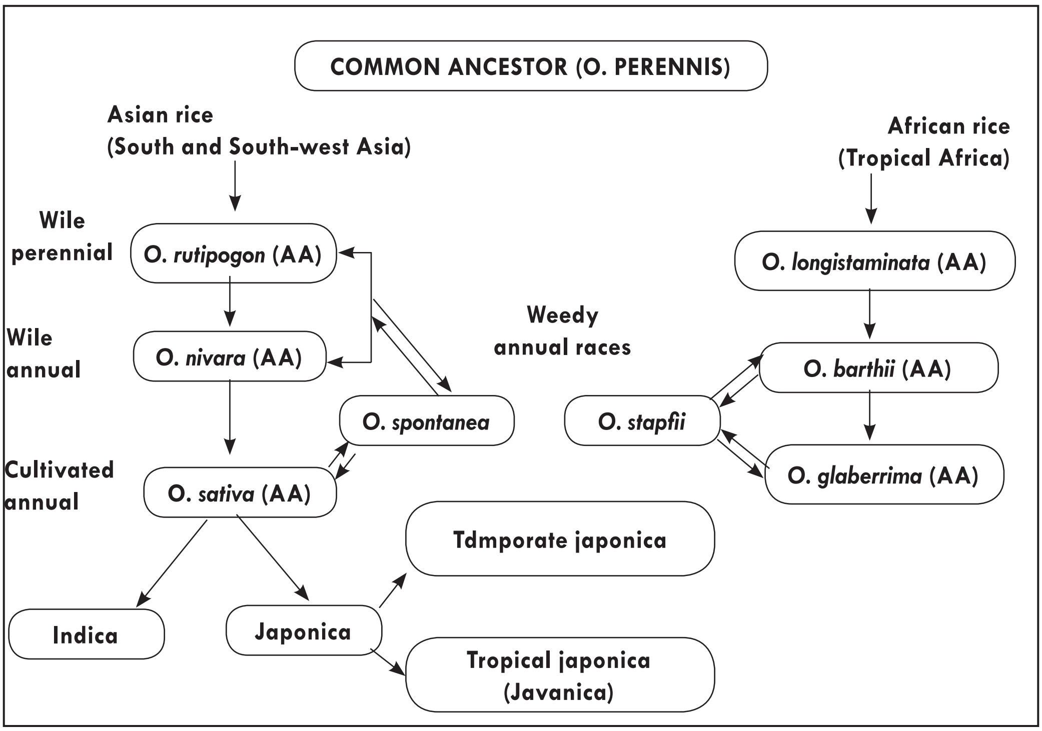
Species complex	Chromosome number (2n)	Genome	Geographical distribution
5. *O. glumaepetula* Steud.	24	AA	Tropical America
6. *O. glaberrima* Steud.	24	AA	Tropical West Africa
7. *O. barthii* A. Chev. et Roehr	24	AA	West Africa
8. *O. longistaminata* A. Chev. et Roehr.	24	AA	Tropical Africa
II. Officinalis complex/ Latifolia complex			
9. *O. punctata* Kotschy ex Steud.	24	BB	East Africa
10. *O. rhizomatis* Vaughan	24	CC	Sri Lanka
11. *O. minuta* J.S.Pesl. Ex C.B. Presl.	48	BBCC	Philippines, New Guinea
12. *O. malamphuzaensis* Krishn. et Chandr.	48	BBCC	Kerala, Tamil Nadu
13. *O. officinalis* Wall. ex Watt	24	CC	South & Southeast Asia
14. *O. eichingeri* A. Peter	24	CC	East Africa, Sri Lanka
15. *O. latifolia* Desv.	48	CCDD	Central &South America
16. *O. alta* Swallen	48	CCDD	Central &South America
17. *O. grandiglumis* (Doell) Prod.	48	CCDD	South America
18. *O. australiensis* Domin.	24	EE	Northern Australia
19. *O. schweinfurthiana* Prod.	48	BBCC	Tropical Africa
III. Meyeriana complex			
20. *O. granulata* Nees et Arn. ex Watt	24	GG	South & Southeast Asia
21. *O. meyeriana* (Zoll.et Mor. Ex Steud.) Baill.	24	GG	Southeast Asia
IV. Ridleyi complex			
22. *O. longiglumis* Jansen	48	HHJJ	Indonesia, New Guinea
23. *O. ridleyi* Hook. f.	48	HHJJ	Southeast Asia
V. Unclassified (belonging to no complex)			
24. *O. brachyantha* A. Chev. et Roehr.	24	FF	West &Central Africa
25. *O. schlechteri* Pilger	48	HHKK	Indonesia, New Guinea

12. The species are either diploid with 2n=24 chromosomes or tetraploid with 2n=48 chromosomes. On the basis of crossability and ease of gene transfer, the species of Sativa complex is the primary gene pool of rice. The species belonging to Officinalis complex constitute the secondary pool. Crosses between *O. sativa* and the species of Officinalis complex can be accomplished through embryo rescue technique. The species belonging to Ridleyi and Meyeriana complexes and *O. schlecteri* (unclassified) constitute the tertiary genepool. Based on genome analysis and degree of sexual compatibility, the species have been grouped under nine distinct genomes and they are A, B, C, D, E, F, G, H and J.

Origin and distribution

The origin and domestication of rice is not specifically known. Most probably rice originated around 3000 BC in South and South East Asia. The progenitor of rice originated in tropical swamps and was shade-loving. According to archeological and historical evidence, the primary centers of origin of *Oryza sativa* are the foothills of Himalayas in the North and hills in the northeast of India to the mountain ranges of south east Asia and south west China. The primary centre of origin of *O. glaberrima* is considered to be the inner delta of River Niger in Africa. Another school of thought believes that rice might have got domesticated in the 5th millennium BC and it is generally agreed that river valleys of Yangtze and Mekong rivers could be the primary centre of origin of *O. sativa*. The foothills of the eastern Himalayas, Chattisgarh, Jaypore tract of Orissa, northeastern India, northern parts of Myanmar and Thailand, Yunnan province of China etc. are some of the centres of diversity of Asian cultivated rice. Currently, *O. sativa* is cultivated worldwide and it is also grown from sea level to 3000 m in both temperate and tropical climates. Many scientists believe that common wild rice, *O. rufipogon* is the wild ancestor of *O.*

Schematic representation of the evolutionary pathways of Asian and African rices



Characteristic features of the three varietal groups (subspecies) of *O. sativa*

Characteristics	Subspecies		
	Indica	**Japonica**	**Javanica**
Tillering	High	Low	Low
Height	Tall	Medium	Tall
Lodging	Easily	Not easily	Not easily
Photoperiod	Sensitive	Non-sensitive	Non-sensitive
Cold temperature	Sensitive	Tolerant	Tolerant
Grain shattering	Easily	Not easily	Not easily
Grain type	Long to medium	Short and round	Large and bold
Grain texture	Non-sticky	Sticky	Intermediate

sativa and *O. longistaminata* is the wild ancestor of *O. glaberrima*. *Oryza perennis* is considered the common ancestor of both these species. It is believed that *O. sativa* evolved from *O. rufipogon* through *O. nivara* and *O. glaberrima* from *O. longistaminata* through *O. barthii*.

Varietal groups of *Oryza sativa*

Cultivated forms arose out of some wild species resembling the wild species *O. perennis*. Many scientists believe that rice (2n=24) is a balanced secondary polyploid with a basic chromosome number 5. This number got duplicated and two additional chromosomes were added (10+2). This plant on duplication gave rise to the progenitor of rice with 2n=24. From India, rice moved to China where probably for the first time it was domesticated. It moved northward to Japan via Korea. From India, rice also moved to Africa and America with the help of Arabian countries. As a result of centuries of selection by man and nature for desired quality with adaptation to new niches, during the process of domestication *O. sativa* differentiated into three varietal groups: Indica, Japonica and Javanica. Japonica is cultivated in north China, Korea and Japan. Indica is cultivated worldwide and Javanica in Indonesia. Differentiation of *O. sativa* into three forms has been the result of changes in leaf shape and size, grain shape and other plant morphological characters adapting to different ecological conditions. Hence, in the past 20 years plant breeders have changed the entire plant structure based on 'plant ideotype concept'.

Ecology of rice

Rice is grown in a diverse range of agro-ecological and climatic conditions from the wettest areas in the world to the driest deserts. Following are the different types of rice agroecological zones seen in India as well as in different parts of the world: 1) Irrigated agroecological zone; 2) Rainfed lowland agro-ecological zone; 3) Rainfed upland agroecological zone; 4) Flood prone agroecological zone; 5) Coastal saline agroecological zone; 6) Cold/hill agroecological zone.

Irrigated rice is grown in puddled soil in bunded rice fields with one or more crops planted each year. Irrigation is the main source of water in the dry season and rainfall in the wet season. Irrigated rice accounts for 55% of the global rice area and contributes 75% of global rice production. The countries with the largest areas of irrigated rice are China, India, Indonesia and Vietnam. With adequate irrigation water, two or even three crops of rice can be produced in a year. In India, rice is grown under irrigated conditions in the states of Punjab, Haryana, Uttar Pradesh, Jammu & Kashmir, Andhra

Pradesh, Tamil Nadu, Sikkim, Karnataka, Himachal Pradesh and Gujarat. The total area under irrigated rice is about 22 million hectares, which amounts for about nearly 46 percent of the total area under rice crop in the country.

Rainfed lowland rice production is variable because of the lack of technology used. Farmers using rainfed lowland agroecological zone are typically challenged by poor soil quality, drought or flood conditions and erratic yields. It is grown in areas such as east India, Bangladesh, Indonesia, Phillipines and Thailand. Nearly 25 percent of total rice is grown in rainfed lowland agroecological zone. In India, lowland area accounts for 32.4 percent of the total area under the crop in the country and the area is about 14 million hectares. Depending upon the water regimes, the lowland rice agroecological zone can be further divided into three subagroecological zones as follows: 1) Shallow lowland rice: water depth below 50 cm; 2) Semi deep water rice: water depth between 50 and 100 cm; 3) Deep water rice: water depth more than 100 cm in the field. The soil is poor in nutrients such as nitrogen, phosphorous and organic matter. But the soil is very rich in potassium. Deep water rice areas are prone to seasonal floods and duration of which varies from year to year.

Rainfed upland rice fields are generally dry, unbunded and cultivation is directly seeded. Land utilized in upland rice production can be low lying, drought prone, rolling or steep sloping. Upland zones are found in Asia, Africa and Latin America. In India, approximately 13.5% of the total area under rice crops in the country accounts for upland rices. Upland rice areas lie in eastern zone comprising of Assam, Bihar, Chattisgarh, Orissa, eastern Uttar Pradesh, West Bengal and north eastern hill region. In the rainfed upland rice, there is no standing water in the field after a few hours of desistance of rain because of the uneven topography. The upland rice accounts for about 60 million hectares and productivity of upland rice is very low.

Flood prone agroecological rice zones are characterized by periods of extreme flooding and drought. Yields are low and variable in the flood prone agroecological zones. Flood prone ecosystems are prevalent in south and southeast Asia and flooding usually occurs during the wet season from June to November.

Coastal saline agroecological rice zones of India are seen in the coastal zones of Andhra Pradesh, Kerala, Tamil Nadu and West Bengal on the South and East coast and Gujarat and Maharashtra on the West coast. Total coastal saline rice area is estimated to be about 1 million hectares which accounts for 2.3% of area under rice cultivation. More often the coastal saline soils show deficiency of iron and zinc resulting in reduced tillering as well as in chlorosis.

In cold /hill agroecological rice zones the crop is invariably affected by low temperature in the early stage and sometimes at the flowering stage resulting in sterility. Hence, the yield in cold /hill region is reduced. In India, such areas lie in the hill regions comprising Jammu and Kashmir, Uttaranchal and the northeastern hill states. Total cold/ hill area is estimated to be about 1 million hectares, which accounts for approximately 20% of the area under rice cultivation.

Major rice producing countries of the world

The top ten paddy rice producing countries in the world are China, India, Indonesia, Bangladesh, Vietnam, Thailand, Burma, Phillipines, Brazil and Japan, where China and India alone contribute rice to nearly half of the world's human population. China is the topmost rice producer in the world. Approximately 90% of the rice cultivation in this country is in the irrigated agroecological zone and the country produces nearly 35% of the total rice of the world. Globally, India stands first in rice area and second in rice production, after China. It contributes 21.5% of global rice production. After India, Indonesia leads in rice production.

Seasons of rice cultivation in India

Season	Sowing period	Harvesting period	Percentage of rice crop grown in the season	Duration of the rice varieties
Pre Kharif rice (Autumn rice)	May to August	September to October	7%	Short duration varieties ranging from 90 to 110 days
Kharif rice (Winter rice)	June to July	November to December	84%	Medium to long duration varieties
Rabi rice (Summer rice)	November to February	March to June	9%	Short duration varieties

Bangladesh is a major rice producer taking the fourth position in the world. The wealth of Vietnam is largely dependent on rice production. Nearly 82% of the nation's land is used for rice cultivation. Red river and Mekong are the two main deltas that mark the main rice growing areas in the country. Thailand is considered as one of the biggest rice exporters in the world. Jasmine rice, an aromatic rice is a variety native to Thailand and is grown throughout the country. It is long grained with a subtle floral aroma and a soft sticky texture when cooked and it is the most popular rice in Thailand as well as in southeast Asian countries. Burma is considered as one of the leading rice producers for over a century. In early 1900s, Burma was the largest rice producer in the world but this was reversed after World War II. Farming in Japan is highly mechanized and the country stands as one of the most industrialized countries with deep attachment to rice farming. But due to the shortage of farmlands, this country is unable to produce enough quantity of rice as other nations. Improved varieties of Japonica rice are cultivated in most of the regions of the country. Rice ecosystems in Japan cover an extensive range of latitudes, including subtropical and temperate regions. Most of the rice fields are on the plains of the major river basins and many are also located in terraces and valleys. In Philipines, rice is a staple food and they are one of the largest rice producers across the globe. It has a share of 2.8% in the total production of rice in the world. Luzon and the western Vasayas are major sites in the country where rice is produced. This rice production helps the country in growing their economy. Brazil is the largest producer and consumer of rice in South America. Irrigated rice is the most important system of production. Increase in rice production is the result of a combination of adequate technology investments, yield improvement and climate. Brazil contributes nearly 1.7% of the world's rice production and the nation is an importer as well as exporter of rice.

Rice growing regions of India

Rice growing regions of India may be broadly grouped into five. The southern region is spread in Andhra Pradesh, Karnataka, Kerala, Tamil Nadu and Pondicherry. Here rice is mainly grown as irrigated crop in the deltas of the rivers Godavari, Krishna and Cauvery. Rice is grown as a rainfed crop in the non-deltaic areas of Tamil Nadu. The western region is spread in the states of Gujarat, Maharashtra and Rajasthan. Here rice is largely grown under rainfed conditions during June/August-October/December. The northern region is spread in Haryana, Himachal Pradesh, Jammu &

Kashmir, Punjab, western Uttar Pradesh and Uttaranchal. Rice is grown from May/ July to September/ December mainly as an irrigated crop. The eastern region is spread in Bihar, Chattisgarh, Madhya Pradesh, Orissa, eastern Uttar Pradesh and West Bengal. This area has the highest intensity of rice cultivation in the country. Here, rice is grown mainly under rainfed conditions due to heavy rainfall. The Northeastern region is spread in Assam and north-eastern states. In Assam, rice is grown in the basin of river Brahmaputra. Rice is grown mainly under rainfed conditions as this region receives very heavy rainfall. Largest rice producing states of India are West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Tamil Nadu, Bihar, Chattisgarh, Odisha, Assam and Karnataka. But rice is grown widely across the nation in more than 15 states in an area of over 400 lakh hectares and top 10 rice producing states account for more than 80% of total rice production in India. West Bengal is the topmost among all rice producing states with more than 13% contribution in India's rice production. Some of the major rice producing districts of West Bengal are Burdwan, Hooghly, Murshidabad, Howrah, and Nadia. Uttar Pradesh is the second leading rice producing state of India. Some of the major rice growing areas of the state are Sharanpur, Budaun, Bareilly, Aligarh, Shahjahanpur and Agra. Andhra Pradesh is another leading rice producer of the country holding a share of more than 12% in total rice production. Rice is an important crop in Punjab. Punjab accounts for about 10% of the total rice production of the country. Basmati, the best quality rice known for its great aroma and taste is grown widely in Punjab. Tamil Nadu is the fifth largest producer of rice in the country and the state holds a share of about 7% of total rice production of the country. Bihar is also one among the largest rice producing states in India and the state has got fertile land and stable climatic conditions. Chattisgarh contributes more than 5% of the total rice production in India. Odisha also accounts for about 5% of the total rice production in India. Almost 65% of the cultivated land of Odisha is dedicated to rice cultivation, which makes rice a very important crop for the state.

Rice growing seasons of India

Rice growing seasons vary in different parts of India, depending upon temperature, rainfall and other climatic conditions. Therefore, two or three crops of rice are grown in a year in different regions of the country according to the climatic conditions. There are three major seasons for growing rice in India. They are 1) Pre Kharif rice (Autumn rice), Kharif rice (Winter rice) and Rabi rice

Vernacular names of rice seasons of India

Region/ State	Autumn rice (Pre-kharif rice)	Winter rice (Kharif rice)	Summer rice (Rabi rice)
West Bengal	Aus	Aman	Boro
Assam	Ahu	Sale	Boro
Odisha	Beali	Sarad	Dalua
Bihar	Bhadai	Agahani	Garma
Kerala	Virippu	Mundakan	Punja
Tamil Nadu	Kuruvai/Ker/ Sornavari	Samba/Thaladi/ Pishanam/ Karthingal	Navrai
Andhra Pradesh		Sarava	Dalwa
Uttarakhand	Chetaki/ Jethi		

(Summer rice).

However, the time of sowing as well as harvesting slightly differs from state to state according to climatic conditions and rainfall pattern. Autumn rice, winter rice and summer rice have different names in different parts of the country. Some of them are list below:

In the north-eastern and southern region, rice is grown in all the three seasons. In some eastern and southern regions, two crops of rice are taken in a year. But in the north and western regions where winter temperatures are fairly low only one crop of rice is taken during the Kharif season.

Growth and development of rice

Depending upon the variety and the environment under which rice is grown, it usually takes 3 to 6 months from germination to maturity. The growth of the rice plant can

Rice cropping seasons of different states/regions of India

Region	Autumn/ Pre Kharif		Winter/ Kharif		Summer/Rabi	
	Sowing	Harvesting	Sowing	Harvesting	Sowing	Harvesting
A. Northern Region						
Haryana			Jun-July	Nov-Dec		
Punjab			Jun-July	Nov-Dec		
West UP			Jun-July	Nov-Dec		
H P			Jun-July	Nov-Dec		
J & K			Jun-July	Nov-Dec		
B. Western Region						
Gujarat			Jun-July	Nov-Dec		
Maharashtra			Jun-July	Nov-Dec		
Rajasthan			Jun-July	Nov-Dec		
C. North Eastern Region						
Assam	Apr-May	Aug-Sept	Jun-July	Nov-Dec	Nov-Feb	Mar-June
East M.P.			Jun-July	Nov-Dec		
Orissa	May-Aug	Sep-Dec	Jun-Aug	Dec-Jan	Dec-Jan	Apr-May
East U.P	May-Aug	Sep-Dec	Jun-July	Nov-Dec	Jan-Feb	Apr-June
West Bengal	Apr-Aug	Sep-Dec	Jun-July	Nov-Dec	Oct-Feb	Mar-May

D. Southern Region

Andhra Pradesh	May-June	Sep-Oct	Jun-July	Nov-Dec	Nov-Jan	Mar-May
Karnataka	May-Aug	Sep-Dec	June	Nov-Feb	Dec-Feb	Mar-June
Kerala	Apri-Jun	Aug-Oct	Sept-Oct	Jan-Feb	Dec-Jan	Mar-Apr
Tamil Nadu	Apr-May	July-Aug	Jun-July	Nov-Dec	Oct-Jan	Mar-May
Sornavari	Apr-May	July-Aug	Sept-Oct	Dec-Jan		
Kar	May-Jun	Aug-Sept	Oct	March		
Kuruvai	Jun-July	Sep-Oct	July-Aug	Dec-Jan		

be divided into three stages or phases: 1) Vegetative phase: the period from germination to the initiation of panicle primordia. 2) Reproductive phase: the period from panicle primordial initiation to heading (flowering). 3) Ripening phase: the period from heading to mature grain. The vegetative phase of the rice plant begins with germination of grain which is signified by the emergence of the radicle or coleoptile and plumule from the germinating embryo. The seedling stage starts right after emergence and lasts until just before the first tiller appears. The stage is characterised by active tillering, gradual increase in plant height and leaf emergence at regular intervals. Tillers emerge from auxiliary buds of the nodes and displace the leaf as they grow and develop. The vegetative stage may be divided into two phases: (a) active vegetative phase (from germination to maximum tiller number) and (b) lag vegetative phase (from maximum tiller number to stem elongation and then later to panicle initiation stage). Active tillering refers to a stage when the increase in tiller number per unit of time is high. Primary tillers emerge first and then they give rise to secondary tillers. In some varieties, tertiary tillers are also produced and they arise from the secondary tillers as the plant grows longer and larger. Active tillering results in stem elongation but no appreciable senescence of leaves will be noticeable.

The reproductive growth stage is characterised by culm elongation (increase in plant height), decline in tiller production, emergence of the flag leaf (the last leaf that develop about 18 days before heading), booting, heading and flowering. The initiation of the panicle primordium at the tip of the growing shoot marks the start of the reproductive phase. Initiation of panicle primordia usually takes place about 30 days before heading, which can be recognized only under a microscope. Panicle development continues and the young panicle primordium becomes visible to the naked eye in a few days as a transparent structure 1 mm to 2 mm long with a spongy tip. The developing spikelets then become distinguishable. The increase in the size of the young panicle and its upward extension inside the upper leaf sheaths is detectable as a bulge in the rapidly elongating culms. This is called the booting stage and is followed by panicle emergence from the flag leaf sheath, commonly called heading. Heading means panicle exertion. Spikelet anthesis (or opening) begins on the following day. It takes 10 to 14 days for a crop to complete heading because of variation in panicle exertion within tillers of the same plant and between plants in the same field. Anthesis or blooming refers to a series of events between the opening and closing of the spikelet lasting about 1 to 2.5 hours. It begins with the protrusion of the first dehiscing anthers in the terminal spikelets on the panicle branches. Pollination and fertilization follow. Anthesis normally occurs between 8 and 13 hours in tropical environment. Fertilization is completed within 5 to 6 hours later. Only a very few spikelets have anthesis in the afternoon.

The ripening stage starts with fertilization. Based on the texture and colour of the growing grains, the stage can be subdivided into milky, dough, yellow-ripe and maturity stages. Ripening is characterised by leaf senescence, grain growth, increase in grain size and weight and change of grain colour. In the milk grain stage, the grains begin to get filled with a milky material which can be squeezed out by pressing the grain between the fingers. The panicle looks green and starts to bend. Senescence at the base of the tillers is progressing. During the dough grain stage, the milky grain portion of the grain first turns into soft dough and later into hard dough. The grains in the panicle begin to change from green to yellow. In the mature grain stage, the individual grains become matured, fully developed and turn yellow and hard. The upper leaves dry rapidly although the leaves of some varieties remain green. The time duration of the vegetative, reproductive and ripening phases change based on varietal differences.

Botany of rice

Rice is a monocotyledonous plant normally grown as an annual crop in tropical regions of the world. It can survive as perennial and can perennate through the production of ratoon tillers. The plant has jointed stem known as culm, with flat leaves and terminal paniculate inflorescences. Soon after planting, rice seeds give out seminal roots from the radicle. These are of temporary nature. The real functional roots are secondary adventitious that are produced from the lower nodes of the culm. The root system is fibrous and generally remains in the top 20 cm of soil in the case of transplanted rice. In direct seeded rice, the roots go deeper depending on the availability of water and soil physical properties. The root system consists of crown roots and the nodal roots. Crown roots (the adventitious roots, including mat roots) develop from nodes below the soil surface and the nodal roots develop from nodes above the soil surface. The main rooting system of the plant develops at later stages of plant growth, when roots develop horizontally from the nodes of the stem below the ground level.

The rice stem, also called as culm is hollow and is made up of nodes and internodes. The culm is more or less erect, cylindrical and hollow except at the nodes. Culms are shorter in direct seeded upland rice varieties than in transplanted low land rice varieties. Primary tillers emerge from the main culm in alternate order. Emergence of the secondary tillers from the first node of the primary tiller also follows the same pattern. Tillering potential of different varieties of rice differs considerably. Tillers emerge continuously during the vegetative stage (up to 60 days after transplanting).

The number of leaves borne on an axis is equal to the number of nodes. The first leaf of the plant is the sheathing leaf or coleoptile. In most rice varieties the leaf sheath may almost completely cover the upper internode. The leaves are born at an angle on every node and they possess two parts viz., the leaf blade and the leaf sheath which wraps the culm. Rice leaf can be distinguished from other rice like grasses by the presence of ligule and a pair of auricles. The white band at the junction of the blade and the sheath is called collar. The ligule is the papery scale located inside the blade and it looks like continuation of the sheath. The auricles are hairy, sickle shaped appendages located at the junction of the collar and the sheath. The shape of the leaf lamina is linear-lanceolate, in which the length of the leaf is much greater than the width that they appear ribbon like.

The inflorescence of rice is borne on terminal shoots known as panicles (compound raceme) with single flowered spikelets. At maturity, it is droopy in nature. The number of panicles present depends upon the varieties. Direct seeded upland low-yielding varieties have generally 3-4 panicles per plant, while the low land high-yielding varieities have 6-10 panicles per plant.

The individual spikelet consists of two short outer glumes (sterile lemma) and a normal fertile lemma and palea. The flower has got two small, oval, thick and fleshing bodies called the lodicules situated at the base of the axis. The spikelet is born on the pedicel which connects with the panicle branch. All the parts found above the outer glumes collectively form the floret. When the floral parts mature the lodicules swell and open so as to expose the mature floral parts. The fertile lemma and palea enclose the sexual organs consisting of six stamens arranged in whorls and a pistil at the centre. The stamens are composed of 2-celled anthers (bilobed anthers) borne on slender filaments, while the pistil consists of ovary, style and feathery bifid stigma. The stigma is a plumose structure borne on the style which, in turn, is an extension of the ovary. The anther present in the stamen includes 4 elongated sacs where pollen grains are stored.

The rice grain, called caryopsis develops after pollination and fertilization are completed. The outer protective covering of grain is called the hull which consists of a lemma, a palea, an awn (tail), a rachilla (grain stem) and two sterile lemmas. The hull is the hard cover of seed, which accounts for 20% of total seed weight. Other parts of the grain are the pericarp, seed coat, nucellus, embryo and endosperm. The embryo is fused with the endosperm. The dehulled rice grain is known as brown rice as brownish pericarp covers it. The pericarp is the outermost layer which envelopes the caryopsis and is removed when rice is fully milled or polished. Beneath the pericarp are two layers of cells representing the seed coat. The embryo lies at the ventral side of the spikelet next to the lemma. The rest of the caryopsis is occupied by the starchy endosperm. The endosperm consists of aleurone layer that encloses the embryo and it is the storehouse of food for the embryo. The white starchy endosperm consists of starch granules embedded is a proteinaceous matrix containing sugar, fats, crude fiber and inorganic matter.

Adjacent to the embryo is a dot called hilum. This makes the point of attachment of the caryopsis to the palea. Another scar at the tip of the caryopsis marks the base of the style. The embryo contains the embryonic leaf (plumule) and embryonic root (radicle). The plumule is enclosed by a sheath (coleoptile) and the radicle is ensheathed by the coleorhiza.

Rice farming

In India, rice can be cultivated in different ways based on the type of region. But the traditional methods are still in use for rice cultivation. Methods of rice cultivation followed in India are broad casting method, drilling method, transplantation method and Japanese method. In broadcasting method, seeds are sown by hands. It is practiced in those areas which are comparatively dry and less fertile and do not have much labourers to work on the fields. Yields are the minimum but it requires minimum inputs. In drilling method, the first step is ploughing of land and then sowing the seeds in the burrows. This method is mostly confined to peninsular India. In transplantation method, the seeds are sown in nursery beds and seedlings are prepared. After 4-5 weeks the seedlings are uprooted and planted in the field which has already been prepared for the purpose. It is a very difficult method and requires heavy inputs. But it gives higher yields and this method is practiced in areas of fertile soil, abundant rainfall and higher labour availability.

Rice is grown on a variety of soils and yield is obtained according to the varying climatic conditions. The climatic factors affecting cultivation of rice are temperature, rainfall and day length. Rice is a tropical as well as sub-tropical crop and temperature influences the development, growth and yield of rice. It requires a fairly high temperature, ranging from 20°C to 37°C. The optimum temperature favourable for the development and growth of the rice crop is 30°C during day time and 20°C during night time. Rainfall is a very important climatic factor as paddy requires more water than any other crop. Rice cultivation is done only in those areas where minimum rainfall is 115 cm. But, regions having average annual rainfall between 175cm to 300cm are the most suitable. Photoperiodically, rice is a short day plant. But there are varieties which are non-sensitive to photoperiodic fluctuations. Direct light from the sun is needed for the development and growth of rice plants. The yield of rice is influenced by the solar radiation particularly during the last 35 to 45 days of its ripening period.

Rice soils should have good water holding capacity. Silt clay, silt clay loam and clay are some of the soil textures that are best for rice farming. Rice is also grown in saline areas of deltaic regions. Fertile riverine alluvial soil is good for rice cultivation. The growing areas of rice should be kept weed free and it should be applied with fertilizers with a source of nitrogen.

Processing and products

Mature rice plants are harvested and the grains are detached from the panicles manually or with the help of machines. The major products of rice harvest include straw and paddy. The straw is dried and kept for future use. The rice is dried and stored. Afterwards the rice is milled and the products include milled rice, husk and bran. Each of the above products has got their own uses and all of them are important in the life and culture of the farmers. Usually, milled rice is considered as the product and the others as byproducts.

Rice straw

Rice straw is a by-product obtained when paddy is harvested and the grains are separated. It is the vegetative part of the rice plant and may be burned or left on the field as a natural manure for the next crop. It is used for several other purposes such as thatching houses, as cattle feed and also in handicraft industry for making fancy products like baskets, wall hangings, etc. It is also used as domestic fuel. Rice straw along with other fibrous materials can be used to prepare pulp for making boards and paper. It is also used for making beds for growing mushrooms.

Rice husk

Rice husks (or rice hulls) are the hard protective coverings of rice grains. The husk protects the seed during the growing season. It is made of hard materials such as silica and lignin which is non-edible to man. Rice husk is used as fuel in the rice mills to generate steam for the parboiling process. It is also used as a fuel for power generation and also as a domestic fuel. Rice husk is used as a fuel in brick production and to make building materials, fertilizers, insulation materials, etc.

Rice bran

Rice bran is the hard outer layer of the grain. It is especially obtained while polishing brown rice. It consists of the combined aleurone layer and pericarp. It can be consumed by humans and cattle. Rice bran is rich in various antioxidants and it is also a good source of Vitamin B. Rice bran is used for enriching breads and breakfast cereals to increase the intake of dietary fibre. It is especially used for oil production, which is used for cooking purposes. It has other health benefits also. Gamma Oryzanol is a powerful antioxidant only found in rice bran oil. It is effective in lowering cholesterol levels in the blood, reducing liver cholesterol synthesis and to an extent treating menopausal disorders. Gamma Oryzanol can impede the progress of melanin pigmentation by restraining the erythematic activity of tyrosinase. The oil is also rich in phytosterols and vitamin E

(Tocopherol and Tocotrienol). Phytosterol reduces cholesterol level, provides anti-inflammatory effects, inhibits the growth of cancer cells and improves the immune system. Tocopherol and Tocotrienol help in preventing oxidation and in fighting free radicals. Vitamin E extracted from rice bran is used in cosmetics and hair products. Rice bran wax obtained from rice bran oil is used instead of carnauba wax in cosmetics, confectionary products, shoe creams and polishing compounds.

Milled rice

Milled rice is the primary source of carbohydrates and milling of paddy rice gives a yield of 50% of milled rice (endosperm) as its major product and 20% of rice husk, 8% of rice bran and 2% of rice germ. Based on the milling process, different types of milled rice are obtained.

Brown rice

When the outermost layer (husk) of rice is removed, the resultant product is the brown rice. It retains its bran and germ layers that give it a characteristic tan brown colour. It is rich in vitamin B_1, B_2, B_3, B_6, iron etc. as compared to polished rice. It generally needs longer cooking time and has a shelf life of about 6 months.

White rice

White rice is polished rice and it is called white rice since the outer brown layer of bran is removed. Polished white rice is mainly consumed as a staple food after cooking.

Parboiled rice

Parboiled rice is rice that has been partially boiled in the husk. The three basic steps of parboiling are soaking, steaming and drying. This process hardens the starch in the grains so that they remain firmer, less sticky and separate when cooked. The process forces the vitamins and minerals from the outer layer of the grains into the endosperm, which is the part we eat. It increases its nutritive value, changes the texture of cooked rice and reduces the breakage in milling. It is a better source of fiber, calcium, potassium and Vitamin B_6 than white rice. Parboiled rice is consumed as a staple food in many regions of India. Puffed rice, beaten rice etc. are value added products made from parboiled rice.

Broken rice

Broken rice is a grade of rice consisting of grains broken in the milling process. Broken rice can be sold as poultry feed as well as it can be converted into products like rice noodles, vermicelli, rice alcohol, rice flour, etc. Broken rice is used to make starch and this starch has applications as a food ingredient, as laundry starch and also in cosmetics and textile industry.

Rice flour

Rice flour is the powdered form produced from white or brown rice. It is widely used as gluten free flour.

Rice starch

Rice starch is produced from the endosperm of the grain and is used as a thickener in sauces and desserts and in the manufacture of rice syrup.

Brewer's rice

Very small broken rice is called brewer's rice and is a mixture of broken rice, rice bran and rice germ. It is an ingredient used in brewing and also for the processing of other fermented products.

Crop improvement in rice

Crop improvement is the development of new varieties which will perform better than the existing ones. Crop improvement programmes of any crop are designed based on certain objectives that are formulated based on the needs and requirements of the farmers and the community at large. The major goals of crop improvement generally include increasing the yield of crops, improving the crop quality to meet consumer demands, developing crops that will adapt to climatic and environmental changes, developing varieties that mature early and developing varieties that are resistant to diseases and pests. Conventional methods like selection and hybridization and advanced methods like mutation breeding, polyploidy breeding and biotechnological breeding are adopted for the above purpose based on various factors.

It is estimated that by the year 2025 it will be necessary to produce about 60% more rice to meet food needs. Great efforts are being made to breed new rice varieties with greater yield potential and to improve crop management levels to enhance average yields. India has estimated to contribute in the areas of diversity analysis, transcriptomics, functional genomics, marker development, quantitative trait loci mapping and molecular breeding for the purpose. Several new varieties have been developed by scientists across the world using the above tools and techniques. Rice is the first food crop the genome sequence of which was completely sequenced. This will make it possible to identify the genes in rice that are responsible for productivity, environmental adaptation and resistance to stress so as to transfer them to new varieties and to augment their functioning under stressed environmental conditions.

Saline rice habitats- an overview with special reference to Kaippad system of rice cultivation

K.T. Chandramohanan
PG Department of Botany, Government Brennen College, Dharmadam, Thalassery, Kerala- 670106, India.

Hunger is a cause of poverty, and thus of hunger. The large size of world population does make it hard to provide a decent standard of living to everyone. Low agricultural productivity, post-harvest loss, and lack of nutritious food are important factors contributing to it. Climate change is increasingly viewed as a current and future ground of hunger and poverty. Escalating drought, flooding and changing climatic patterns make shift in crops and farming practices essential that may not be easily accomplished. One of the major problems faced by agriculture is the loss of agricultural land and as more land is lost, it will become more difficult to produce the quantity of food needed to feed the growing human population. Worldwide, around three million hectares of agricultural land are lost each year because the soil degrades and becomes unusable due to erosion by wind or water leading to the movement of soil components from one location to another. An additional four million hectares are lost each year when agricultural land is converted and used for highways, housing, factories, and other urban needs.

Rice is one of the major cereal food crops of the world. Being grown worldwide, it is the staple food of more than half of the world's population. Rice is being planted now on about 159 million hectares annually and it comes to about 11% of the world's cultivated land. World's rice production was 745 million metric tonnes in 2013. The demand for rice is predicted to increase by 50% by 2050. FAO has predicted that rice production will need to increase from 600 million tonnes annually to 800 million tonnes by 2025. However, average growths in rice yields per hectare have not kept up with population increases and demand, and have in fact decreased substantially over years. Furthermore, rapid urbanization and industrialization has created a situation where this increasing food demand is to be met on decreasing agricultural lands.

The world's annual rice production will have to increase markedly over the next 30 years to keep up with population growth and income induced demand for food. Among low and middle income countries, rice is by far the most important crop worldwide. With the accelerating loss of productive rice land due to rising sea levels, salinization, erosion, and human settlements, the problem becomes one of increasing yields under ever more trying circumstances. From 1965-67 through 1989-91, the improvements in productivity spawned by the Green Revolution spread rapidly. During those years, total rice production almost doubled. Most of this increase came from increased yields and increased cropping intensity, although some resulted from new land brought under cultivation or shift to rice from other crops. Further yield increases have been constrained by diminishing returns and have been increasingly difficult to achieve.

In India, area under rice cultivation was 34.255 million hectares in 1961, 44.712 million hectares in 2000 and 43.771 million hectares in 2007 and rice production was 51.386 million metric tonnes in 1961, 127.465 million metric tonnes in 2000 and 144. 647 million metric tonnes in 2007. Rice yield in India was gradually raised from 1.50 tonnes ha^{-1} in 1961 to 3.30 tonnes ha^{-1} in 2007. In 2012-13, area under cultivation is 42.75 million hectares and production 105.24 million metric tonnes. India is one of the largest rice growing countries accounting for about one-third of the world acreage under the crop. It is grown in almost all the states of India, covering more than 30 per cent of the total cultivated area. Its cultivation is mostly concentrated in river valleys, deltas and low lying coastal areas of northeastern and southern India.

In Kerala, the area under rice cultivation has been getting reduced through the years. In 1961 the rice area in Kerala was 0.753 million hectares and it increased to 0.928 million hectares in 1968. From there it got consistently reduced to 0.348 million hectares in 2000 and 0.229 million hectares in 2007. Rice production in Kerala was 1.481 million metric tonnes in 1961 and 1.630 million metric tonnes in 1990. It got reduced to 1.127 million metric tonnes in 2000 and 0.819 million metric tonnes in 2007. In 2012-13 it has been reported to be 0.508299 million metric tonnes. However, rice yield in Kerala has shown a gradual increase over the years and it reached a value of 3.58 t ha^{-1} in 2007 against the national yield of 3.30 t ha^{-1}. In 2012-13 it has been reported as 2.58 t ha^{-1}. Rice forms the staple food of the people of Kerala and contributes a major share towards its economy. It is grown in a vast range of ecological niches, ranging from regions situated 3 meters below MSL as in Kuttanad to an altitude of 1400 m as in the high ranges. It is cultivated under 3 to 4 meters of depth of water as well as in purely rainfed uplands with no standing water. In Kerala rice crop is cultivated under a diversity of conditions. But Kerala is a deficient state in rice production. The deficit in rice production is increasing year after year due to reduction in rice area arising out of the large scale conversion of paddy lands for raising other crops or for residential purposes.

As far as Kerala is concerned rice is a socially and politically important crop. The wet and humid tropical climate of the region is favourable for the cultivation of rice. Traditionally rice occupied a key position in Kerala's agriculture. But the area under rice has been declining over the years, with a possibility of extinction of rice farming in the state. The livelihood safety of the rural agrarian population spinning around rice farming is at risk. The employment opportunities in this sector, especially for women are declining at a hasty rate. Rice being a labour intensive crop, the rising cost of production is taking away rice farmers from cultivation. Environmental and ecological implications of large scale area conversion from rice farms are disturbing. In 1975, Kerala's rice production was over 50 percent of its consumption requirement. By 2010 the consumption production gap has increased to 84 percent. As rice remains the staple food, food security of the state is at stake and dependency on other States for our staple food is increasing dangerously.

Abiotic stresses are serious in magnitude and widespread in occurrence and thus create major hurdles to attaining higher crop productivity. Tapping the potential of large salt affected areas to increase rice production would contribute to food security and alleviate poverty in unfavorable rice growing environments where the resource poor farmers live. However, this would require the development of salt tolerant varieties and their widespread adoption by farmers. Because of urbanization and water scarcity, the expansion of land use for food production has almost stagnated and has shown a downward trend in the case of many important crops with high input requirements, including rice. The possibilities for rice area expansion in most Asian countries are almost exhausted. The options obtainable to produce more rice include mounting irrigated areas or favourable environments with high productivity, increasing the productivity of rice in unfavorable ecosystems and harnessing unfavourable areas with potential for food production.

Population explosion and declining of the availability of arable land and quality irrigation water are forcing crop production into more and more marginal environments facing abiotic stresses, thus limiting the adaptation and productivity of staple food crops. In future, one cannot wait for a major increase in land area accessible for cropping. At the same time, cultivated area is declining fast in most of the developing countries due to a variety of reasons. It is estimated that half of the world's farms have been damaged by salt.

To tackle these problems, the ability of crops to tolerate such conditions has become a key research issue in the world. Rice is a more amenable crop to marshy soils near sea coast, the unexploited areas where we have to pay more attention to extend the area of rice cultivation in future. This soil is saline due to saline sea water inundation. At this situation, salinity tolerant genetic resources and varieties of rice can play a major role to achieve the goal of food security. Further, some degree of cultivar tolerance for salinity stresses available with certain traditional land races not exploited so far has great significance in crop improvement.

Marginalized saline lands and rice cultivation

Rice production occurs mainly in four agroecological environments: irrigated (mostly lowland), rainfed upland, rainfed lowland and deep water. Deep water areas are spread along riversides and deltas where production is based on annual flooding. Rice is produced in a wide range of locations and under a variety of climatic conditions, from the wettest areas in the world to the driest deserts. Rice adapts readily to production under these varied conditions.

A substantial part of the rice farms are located in ecologically fragile and critical environmental systems extended across Asia and Africa and to some extent in other continents also. Rice farming in these agro ecosystems is highly specific and specialized. Additional land for food crop production will be required to produce food for the ever increasing world population. The tidal lands are an important land resource and they are marginal in the sense that reclamation costs are high, crop yields are low and soil and water management is difficult. The rice varieties grown in the tidal swamps are for the most part traditional photoperiod sensitive varieties requiring more than 200 days from seeding to maturity. The high yielding, wetland irrigated varieties are not adapted to the soils and hydrology of the tidal swamps. However, no other crops can be grown in such areas.

Rice has vast variability for tolerance to most abiotic stresses and it is the only economic crop that can grow well in waterlogged environments tolerating salinity up to a certain extent. The crop can be grown in coastal belts that are always prone to inundation by sea water during high tides, resulting in salinization. Under these conditions, only salt and submergence tolerant crops are the economically viable farming options.

The nearly 30 million hectares of coastal saline soils in South and Southeast Asia offer promise as potential rice lands. Varietal tolerance for salinity and accessory growth limiting factors should be exploited in bringing marginal land under rice. The use of improved, salt tolerant, disease and insect resistant rice varieties, coupled with the correction of nutrient deficiencies will enable farmers to double or triple their present yields on saline soils and also to expand rice growing into surrounding uncultivated lands.

Saline soils vary widely in their chemical, physical, and hydrological properties.The salt source may be seawater, surface or underground saline water or wind. In arid and semiarid areas salts brought by capillary action, surface runoff, or interflow accumulate in the soil profile. In coastal areas salinity is due to direct inundation by salt water or upward or lateral movement of saline groundwater. The salt content of a soil varies vertically, horizontally, and with season. The pH ranges from 2.5 for saline acid sulphate soils to 8.5 for saline alkali soils. Soil salinity in the humid tropics ranges from 1 to 50%, and the nutrient status varies from very low to moderately high. Inland saline soils have a pH >7. They are low in Nitrogen and in available Phosphorus, but are well supplied with Potassium. Hydrology and relief are important in determining the suitability of saline lands for rice production. The vast coastal saline tracts of South and Southeast Asia are in the deltas of big rivers. Most of them have an elevation of 0-10 m above mean sea level. The tracts are subject to flooding by fresh water during the wet season and submergence by salt water during the dry season when the discharge from the river system is low and seawater comes up the creeks and canals. The groundwater of the tracts is 1 to 2 m below the surface and is saline with an EC of 2 mmho cm^{-1} in the wet season and 20 mmho cm^{-1} in the dry season. Coastal saline soils are subjected to tidal flooding. The amplitude of tides in India varies from 0 to 6 m.

Coastal saline soils subjected to tides fall into four main zones: 1. The strip nearest to the sea subjected to daily tides. 2. A strip several kilometers wide subjected to only exceptionally high tides; 3. An area where tides exercise their effect through rivers and creeks; 4. A wide zone not influenced by tides but by the upward thrust of saline water. Zones 3 and 4 are suited for rice production on reclamation without high inputs. Strongly saline soils are barren. Less strongly saline soils in arid areas are characterized by patchy growth of halophytic grasses and shrubs, whereas coastal saline soils of the humid tropics and subtropics are characterized by the presence of mangrove species. Most plants suffer salt injury at EC values exceeding 4 mmho cm^{-1} at 25°C. Many crops can stand much higher concentrations than generally supposed if the solution consists of physiographically balanced salts as in seawater. Crop yield decreases markedly with increase in salt concentration, but the threshold concentration and the rate of yield decrease vary with the species.

Sri Lanka's low lying western coastal floodplain lands still remain unproductive because of impeded drainage and submergence which has created unfavorable soil conditions and as a result rice cultivation is unprofitable and most of the paddies are either not regularly cultivated or cultivated only one season a year. Special characteristics such as seed viability, resistance to storage pests and good cooking quality after a long period of storage have made the traditional varieties popular. Traditional varieties have growth vigour at the seedling stage and their early height helps them withstand flooding and compete well with weeds. The saline soils of the humid region of South and Southeast Asia are economically important because they are located in deltas, estuaries, coastal fringes or river basins that are climatically, physiographically and hydrologically suited to rice; rainfall is adequate for leaching the soil and growing at least one rice crop a year; the lands are close to densely populated areas where labour for and knowhow of rice cultivation are available. Tidal swamp lands in Indonesia include swampy areas directly and indirectly influenced by sea tide, low-lying freshwater swamps and highland rain fed swamps unaffected by sea tides. *Pozas veraneras*, the tidal swamp rice areas of Ecuador, are shallow depressions that fill with fresh water during the January-May rainy season and are transplanted to rice as the water level recedes during the long May-December dry season and it provides about 25% of Ecuador's annual rice production. The tidal swamp rice production of Thailand is mainly in the central plain and along the east coast of the southern peninsula. Salinity of the tidal swamp areas gradually decreases inward from the seashore caused by flooding with seawater during the high tides and ingress of seawater along the estuaries, creeks, drains and rivers, especially in the dry season and it fluctuates depending on the amount of rainfall in the area, tidal movements and discharge of fresh water from the inland area. Salinity ranges from 2 to 6 mmho cm^{-1} in the rainy season, which starts in June or July, and increases sharply to 15-30 mmho cm^{-1} during the dry season. Farmers in tidal swamp areas provide land with high bunds and sluice gates to control the water level in the rice fields and usually grow only one crop per year. Rice varieties grown are tall or intermediate depending on the water level in the rice fields. Rice production in flooded rice fields in the coastal lowlands of Vietnam including the Mekong Delta and the Red River Delta occupy about 12% of the total rice cultivated areas and many farmers have adopted extensive and semi intensive culture methods including integrated rice-shrimp and shrimp monoculture systems. The practice of integrated rice-shrimp farming, which involves a wet season rice crop and a dry season shrimp crop on the same land, has enabled farmers to make significantly higher income than the traditional rice monoculture practice. The Sundarban forest area spans one-third of the southern portion of Bangladesh and is known to be highly saline. In the moderate to highly saline southwest coastal areas, farmers can only grow a single rice crop during the monsoon season when the salinity levels are relatively low. Fish-rice culture is considered as an ideal method of land use since the land is used to produce both rice and fish. Fish-rice culture is now developing rapidly in many countries in Asia. In Bangladesh, rice-fish culture has been gaining popularity at Kuliarchar, Brahambaria, Narail, and Muktagacha sites attached to various river floodplains. Bangladesh is ideally suited for integrating aquaculture with rice farming.

About 4.1 million hectares of land are covered by wetlands of different categories in India. They are predominantly located in the Himalayan Terai, Gangetic and Brahmaputra floodplains, deltaic regions of east coast, forested valley swamps of north eastern India, saline expanses of hot arid regions of Gujarat and Rajasthan, deltaic regions of east and west coast, wet humid zones of the peninsula and the fringing mangrove swamps of Andaman and Nicobar. In the coastal regions of India, a complex and ecologically responsive farming system has evolved over centuries. In this system, rice and fish cultivation alternates through a mechanism of water control. About 0.8 million hectares of coastal land in West Bengal, India is highly saline and therefore relatively uncultivable, especially during winter and summer and here submergence also is a problem. One third of this area has been brought under cultivation by putting earthen bunds along the margins of tidal rivers and estuaries to prevent tidal inundation, but the total production per unit area remains low. The low yields may be due to excessive rainfall during the monsoon, poor drainage, lack of good quality water for irrigation or high soil salinity during rabi cultivation. The coastal area is always subjected to salinity problem. In the coastal land, rice is grown in about 10 lakh hectares during different seasons, which accounts for nearly 17% of the total area under rice in the state. Coastal saline rice is commonly affected by various levels of soil and water salinity and suffers from salinity in different stages of crop growth. The salinity of irrigation water varies between 1.0- 4.0 dS m^{-1} or more depending on the source of irrigation water and the time period within the year. A farm household survey carried out in coastal lands of four districts revealed that about 30% of surveyed lands are non-saline, 55% are moderately saline and 15% are severely saline. Severe salinity during dry season is predominant in deeply flooded lands and moderate salinity is more prominent in shallow lowlands. Due to salinity, yield loss of up to 37% was observed in boro rice. With the increase of irrigation facilities, rainfed lowland and flood prone situation has gradually been converted into irrigated boro ecosystem. The area and contribution of boro rice to the total rice production of the coastal districts has steadily increased over the years. While its contribution to total rice production in these areas in 1980 was only 14%, it has increased to nearly 24% in 2007-08. The yield of paddy in coastal saline soil is poor and the average yield during kharif is about 3.0 tonns ha^{-1} and during rabi about 4.0 tonns ha^{-1}. The coastal saline soils are often affected with deficiency of iron and zinc which causes chlorosis and reduced tillering. The fields with sufficient water retaining capacity for a long period, those are free from heavy flooding are suitable for rice-fish farming system. This system is being followed by the small and marginal farmers in rain fed low lying areas especially in coastal belt and is proved to be a profitable cropping system. Currently, rice-boro rice and rice-aquaculture are the two major farming systems that are being adopted in the coastal region over the last decade. The coastal saline soils in Maharashtra are all along the west coast in the districts of Sindhudurg, Ratnagiri, Thane and Raigad. In spite of the high rainfall to the extent of about 2000 mm and above in these areas, they are suitable only for growing saline resistant rice varieties which is the common crop of the region. These soils are locally known as *khar* or *khajan* (*khazan*) lands. Rice is the predominant food crop of Goa and it occupies an area of 39% of the total cultivated land in the state and the *khazan* lands occupy an area of 17,200 ha. The *khazan* lands have the potential for growing traditional rice cultivars which are salt tolerant during rainy season without supplemental irrigation. In *khazan* land the rice cultivars grown are limited, but specific traditional rice cultivars are grown predominantly. The traditionally cultivated rice cultivars viz. *bello*, *korgut*, *khochro* and *kalo novan* are with good grain quality characteristics. Popular rice varieties grown in this area are *korgut*, *khochro* and *assgo*.

Costal saline ecosystems of Kerala

With a long coastal line of about 580 km, Kerala has several lagoons or backwaters covering a very large area linked to the sea. In most of the coastal land, deltaic areas at river mouths and reclaimed backwaters are either at sea level or 1.0 to 1.5 m below MSL. This leads to incursion of sea water up to a distance of 10 to 20 km upstream during high tides. These periodically saline water inundated lands constitute the major saline soil areas of the state covering an area of 30,000 ha.

The coastal saline soils of South India are highly underutilized because the use of ground waters for normal crop production is not possible due to the poor water quality. At present, the entire coastal area is mostly monocropped with rice being the only crop during the monsoon period. The land remains fallow during the rest of the year due to lack of good quality irrigation water and high soil salinity. Hydromorphic saline soils are common in Kerala and are found near the coastal tracts of the state in the districts of Alappuzha, Ernakulam, Thrissur, Malappuram and Kannur. The network of backwaters and estuaries serve as inlet for tidal waters to flow inland into these areas causing salinity. Only one crop of rice is raised in these areas during August to December using salt resistant varieties. EC of these soils during the growing season ranges from 0.1 to 2 dS m^{-1}. Maximum accumulation of toxic salts is observed during summer (March-April) when the EC may rise to as high as 15.0 dS m^{-1}. Kole soils are a particular soil type in Thrissur and Malapuram covering an area of 11,000 ha and are waterlogged like Kuttanad soils. These are shallow and acid saline due to intrusion of sea water. The soils are hard, brittle and poor in fertility.

The network of backwaters and estuaries serves as an inlet of sea water and causes salinity in the area. There are two kinds of saline soils in the state, (i) normal saline soils and (ii) acid sulphate saline soils. The normal saline soils are generally found in narrow strips along the sea coast and are generally sandy and brownish in colour, but in places they may have heavier texture also. Most of the soils have impeded drainage. The acid soils, called *kari* soils, are mostly present in the mouth of streams and rivers in the low lying areas. They are silty clay in texture and subjected to sea water inundation, black in colour, resembling peat soils. Soils show very low pH due to transformation of SO_4^{2-} to S^{2-} by Sulphur reducing bacteria and are rich in Sulphur compounds. Due to high water table and impeded drainage, soil profiles show a large number of mottlings. The soil pH decreases to about 3.0 after drying. The mineral layer is 25- 50 cm thick or even thicker generally located in marshy places below the sea level and has poor permeability. Soil salinity is very high in summer season but low in monsoon season. Organic layer in the soil consists of partially decomposed upper layer and un-decomposed lower layer. The soils are generally low in N and P but rich in K. The acid sulphate soils show toxicity of Fe, Al, Mn and deficiency of Cu and Zn at times. Rice is usually the only crop grown. In Kerala, the pokkali saline soils manifested acidic properties and it was the main cause of infertility.

When the soil salinity gets washed off due to heavy rains, the inherent acidity of the soil gets regenerated and it exhibits very strong pH values in the range of 3.5 to 5.5. The soil pH of the area has been reported to be slightly acidic (6.3 to 6.5), strongly acidic (3.4 to 4.8) and slightly alkaline (7.0 to 7.5) throughout the depth of the soil profiles taken in Kannur, Calicut and Ernakulam districts, respectively. In general, the coastal saline soils in Kerala have strongly acidic (3.5 to 5.5) soil pH. The saline acid sulphate soils of the Malabar coast of Kerala have high EC values throughout the profile. In general, in the coastal saline soils of the state, the EC of the soil, in summer months, varied from 12.0 to 24.0 dS m^{-1}. However, during rainy season the EC ranged from 6.0 to 8.0 dS m^{-1}.

Kerala State on the south western coast of India in the tropical humid zone has a predominantly agricultural economy, very high population density and therefore high pressure on cultivable land. The close association of agricultural crops, tree crops and animals in the homesteads represents an excellent example of sustainable and productive agroforestry. Rice farming in the conventional farming areas of the state is intensive to a considerable extent and improved varieties are generally used. However, speciality rice farming systems which are habitat specific and cultivar specific are popular throughout the costal belt of Kerala.

The pokkali system of rice cultivation in the acid saline soils of south central Kerala is a unique method of rice production. In this method, a single crop of rice is taken in the low saline phase of the production cycle (June to mid-October) on mounds, followed by prawn farming during the high saline phase (November to April). A noteworthy feature of this traditional rice cultivation method is that neither chemical fertilizers nor plant protection chemicals are applied to the crop. The pokkali fields are also subjected to periodic submergence. The daily tidal inflows and outflows, besides the tremendous microbial activity owing to the presence of large quantities of organic matter (decomposed aquatic weed mass and paddy stubbles), make the pokkali fields particularly fertile. In spite of this, the average rice yield realized by pokkali farmers is only ~2000 kg ha^{-1}, making rice cultivation in this region somewhat unprofitable. VTL5 is a promising 'Mashuri' mutant for cultivation in the coastal saline ecosystems of Kerala, with high yield potential and ability to perform well under the acid saline situations and with the essentiality of little or no external inputs to sustain rice cultivation in the pokkali areas of

Kerala. Kerala Agricultural University has developed five saline tolerant, high yielding rice cultivars suited to the pokkali ecosystem of Kerala. The cultivars are Vyttila-1, Vyttila-2, Vyttila-3, Vyttila-4, and Vyttila-5. Pokkali rice being cultivated in the Districts of Alappuzha, Ernakulam and Thrissur has been granted geographical indication registry by GI Registry office, Chennai

The kole lands which form one of the rice granaries of Kerala are part of the unique vembanad-kole wetland ecosystem, the largest brackish, humid tropical wetland ecosystem in the southwest coast of India comprising of 151250 ha, fed by 10 rivers and exposed to diurnal tidal cycles. Within the vembanad-kole wetland ecosystem, the kole lands cover an area of about 13,632 ha spread over Thrissur and Malappuram districts of Central Kerala. The name kole refers to the peculiar type of cultivation practice carried out on these lands and in the regional language Malayalam *kole* indicates bumper yield or high returns in case floods did not damage the crop. Kole lands extend from the northern bank of Chalakudy River in the south to the southern bank of Bharatapuzha River in the north. The kole lands remain submerged under flood water for about six months in a year and this seasonal alteration gives it both terrestrial and water related properties which determine the ecosystem structure and process which in turn give rise to various provisioning services. Rice is the most important crop cultivated in the kole land. *Virippu* (autumn crop) is usually cultivated in higher rice fields around the kole land where the duration of flood lasts only for a few days. *Mundakan* (winter crop) is cultivated in medium elevation fields around the kole lands where the flood water recedes by August. When the flood water in the kole fields starts subsiding by the end of south west monsoon season, pumping out of water by using *petti and para* which is an indigenous pumping device will be carried out in 10 to 15 days. After this bunds around the fields are raised and strengthened by means of locally available materials and laterite soil to a height of 1 to 1.5 m. Crop is directly sown or transplanted when water is around 10 to 15 cm deep. A few decades back a number of local cultivars of rice were cultivated in the kole fields but nowadays improved varieties like Jyothi, Uma and Jaya are cultivated. Fish farming is usually carried out during March to September.

Kaippad rice farming system

A complex and ecologically responsive rice-fish farming system has evolved in the coastal wetland regions of India over past centuries and it is about 0.7 million hectares. Rice cultivation in these lands takes place either under deep or floating water conditions. The rice varieties cultivated are traditional types with an average yield of about 1.5 to 2 tonnes per hectare. An important characteristic of this farming system is that to facilitate the cultivation of rice during the dry part of the year, the land has to be dewatered for sowing and subsequently protected from saline water intrusion for crop growth; rest of the year it remains under fresh or saline water depending on the ecological setting. For the practicing of this farming, different types of water control, not only for the rice cultivation but also for the culture of fish as well, are required. Variations exist in these farming systems across areas depending on the ecological, technological, institutional and organizational set ups conditioning the wetland resources base.

Kaippad, the indigenous rice-fish farming system of coastal North Kerala in India is a natural system utilizing indigenous knowledge and ensuring efficient utilization of local resources. The proximity to sea and subsequent periodic seawater inundation ensure the uniqueness of the rice varieties cultivated and contribute to the high degree of specialization in the cultural practices followed in the region. The less remunerative rice cultivation compliments a profitable fish culture, making it a unique agro-ecological continuum. The farming system is traditionally organic, as farmers desist from the use of agrochemicals since it hampers the productivity of the succeeding fish crop. This system is similar to the pokkali system of rice cultivation practiced in Central Kerala. Kaippad and pokkali can be seen as efficient alternatives for the *in situ* conservation of indigenous rice varieties and cultivation practices. Kaippad farms are also decreasing in area. In the nineteen seventies about 2500 ha of kaippad rice fields existed in the Kannur District of Kerala, but now it has been restricted to about 600 ha. The major traditional rice cultivars cultivated in the area are *Kuthiru*, *Orkayama*, *Mundon*, *Kandorkutty*, *Orpandy* and *Odiyan*.

The average rice yield of these local cultivars is about 2000 kg ha^{-1}, making rice cultivation in this region unprofitable. Lack of realization of the potential of high yielding rice varieties to this rain fed, shallow lowland is the major reason for the low productivity and shrinkage of *kaippad* fields. The traditional cultivars are susceptible to lodging because of the poor culm strength and excessive culm length and they are with poor grain qualities like awn, long bold nature and heavy shattering. Panicles of these cultivars are long but less in number of grains. However, these cultivars are resistant to all pests and diseases in the natural field conditions of kaippad and the cooked rice is delicious. The high yielding saline resistant pokkali varieties do not perform well in kaippad saline tracts. This may be due to the difference in the physicochemical properties of the soils. The soil pH throughout the depth of soil profiles of kaippad is slightly acidic, whereas that of pokkali is slightly alkaline.

Kaippad agriculture is related to various traditional customs and local indigenous knowledge which are echoed in the beliefs and practices of local people due largely to their proximity to the natural resource bases. The kaippad fields are low lying and submerged in water as they are subjected to tidal invasion. For starting the agricultural operations the land is made dry by controlling this tidal inflow. For this purpose bunds are constructed at the narrow ridges of the kaippad fields near the river using the sticky mud and wild grasses which are available in the river banks. Bunds are about 2-3 m in breadth and 2.5-3 m height, a little over the water level at the time of high tide. The bunds are locally called c*hira* or *kandi*. The flow of water is regulated by wooden sluice gates locally known as *mancha*.

Normally only one crop of rice is raised annually in the area. Cultivation starts in April and ends by October. Agricultural operations are started in mid-April by draining out the saline water completely and allowing the fields to dry for about one month. After drying, small soil mounds are primed by workers who are experts in the task. Using spade like implements, they start the work early in the morning and finish it before the sun starts mighty down. The mounds, locally called *potta* or *kuthiru* are of two kinds: hemispherical mounds with 30-45 cm height and 50-60 cm diameter and long strips with 30 cm width. The mound making operations are completed by the middle of May. The sluices are opened by the beginning of monsoon showers. The salinity of the soil of mounds is washed away in the heavy south west monsoon of early June. The fresh river water tides also help to leach away the salinity. Germinated seeds are sown on the mounds at this time.

Before sowing, the farmers soak the rice seeds in water for one day and the wet seeds are kept for three days in jute bags to germinate. Germinated seeds are sown on the mounds in the low to medium saline phase of the ecosystem. After 30-45 days of vegetative growth, the seedlings on the mounds are dug out along with the root soil with the help of spades and are spread out and planted uniformly. This process usually extends till the end of July. Other than the manual removal of weeds by the middle of August, there are no other cultural operations carried out till harvest. Neither fertilizers nor pesticides are applied. Harvesting is done during September–October months. While harvesting, only the panicles are cut and collected and the rest of the plant parts is left to decay in water, which in turn becomes feed of the prawns and fishes that grow subsequently.

Traditional fish rearing is carried out in kaippad farms during the high saline phase *i.e.*, from November to April. Prawn or fish infiltration in the fields begins after the monsoon. After the retreat of north east monsoon, strengthening of the bunds around the fields is carried out using sticky mud and wild grasses taken from the river side and the wooden sluices are kept open to allow the entry of tidal water from the rivers. The forceful tidal water brings with it the seeds of prawns and fishes in to the fields. Water is kept in the fields for two to three months by closing the sluice gates using filters and it allows the prawns and other small fishes to grow. The growing fishes feed on the leftovers of the harvested crop. Decomposed rice stubbles support the abundant growth of algae which in turn become feed for fish. The rice crop draws nutrients from the excrement and other remnants of these sea creatures. Additionally, diversity of flora and fauna in this area is rich when compared to modern rice farming systems. Fertility of the field is increased due to left over rice stubbles and post-harvest growth of vegetation. Fish is caught during low tide when water is released through the sluices. A net is fixed to the sluices to catch fish and the event of fishing is locally known as *kandi koodal*. Fish catching event is locally known as *aachu*. The daily tidal inflows and outflows, besides the tremendous microbial activity owing to the presence of large quantities of organic matter (decomposed aquatic weed mass and paddy stubbles) make the kaippad fields fertile.

Even when new farming practices become widespread, the peculiar farming practices of such agroecosystems are to be protected and perfected so as to maintain and enrich the link between man and nature.

Crop cultivars/ varieties used

Kaippad system of rice cultivation is an integrated organic farming system in which rice cultivation and aquaculture go together in coastal brackish water marshes which is rich in organic matter. Local salinity tolerant rice cultivars like *Chovverian*, *Kuthiru*, *Kuttusan*, *Orkazhama*, and *Orthadian* have been found to be cultivated in this area. However, the cultivar *Kuthiru* is used more commonly followed by *Orkazhama* and *Kuttusan*. The remaining two cultivars are only very rarely cultivated.

A study by the present author revealed that all the above five rice cultivars are tall and plant height is relatively higher in *Chovverian* with an average of 150.4 cm. Number of tillers at harvest was 10 in *Kuthiru* and 7 in *Orthadian*. Ear bearing tillers were relatively higher in number in *Orkazhama* with an average of 8.4. Panicles of these cultivars were long but less in number of grains and the grains were bold with red kernel. Hundred grain weight was higher in *Orthadian* and the lowest in *Kuttusan*. Yield per plant was higher in *Kuthiru* and the lowest in *Orthadian*. The varieties differ in their morphological and physicochemical characteristics and cooking qualities. Seed to seed duration of *Kuthiru* and *Orthadian* was 110 -120 days, that of *Orkazhama* and *Kuttusan* 135 -140 days and that of *Chovverian* 125-130 days. These saline tolerant traditional land races are low yielders and are susceptible to lodging because of the poor culm strength and excessive culm length, with poor grain qualities like awn on grains and heavy shattering of grains. However, these cultivars are resistant to pests and diseases in natural field conditions of kaippad and the cooked rice is delicious. The above traditional cultivars are locally known to be resistant to the adverse conditions of salinity prevailing in the area. *Kuthiru* is the most popular cultivar in the area followed by *Orkazhama* and *Kuttusan*. The remaining two varieties are only very rarely cultivated now. Improved varieties of the Ezhome series like Ezhome 1 and

Ezhome 2 developed by Kerala Agricultural University are being used for cultivation in this area recently but there is the threat that the native cultivars are abandoned by the farmers resulting in erosion of their unique genes. However, Ezhome 1 and Ezhome 2 are high yielding and non-lodging red rice varieties meant for the salinity prone rice fields of kaippad and are awn less, non-shattering and with favourable cooking qualities. The average yields of Ezhome-1 and Ezhome-2 are 3500 kg ha^{-1} and 3200 $kgha^{-1}$ respectively which is 70 % and 60% more than that of local cultivars. These varieties show lesser duration and are having distinct morphological qualitative traits and different mode of salinity tolerance mechanism imparting varietal diversity to the unique ecosystem of kaippad.

Major challenges to Kaippad rice cultivation

Major challenges confronted by this special habitat in general and indigenous rice cultivation in particular include threat of uncertainty in rainfall upsetting land preparation and cultivation, ambiguous temperature changes affecting yield, decline in the quality of the soil and humus brought to the field by the flow of rainwater, especially the presence of non-biodegradable materials resulting in the decline of water and soil quality of the field, lack of proper drainage system, occurrence of relatively high salinity in water and soil, high labour cost, non-availability of agricultural labourers, change of kaippad land to mangrove areas due to non-cultivation for one or more cultivating seasons and lack of proper modernization in cultivation practices

This system exists as a world acclaimed farming model complementing the natural system, utilizing indigenous knowledge and ensuring efficient utilization of local resources. The proximity to sea and subsequent periodical seawater inundation ensure the uniqueness of the rice varieties cultivated here and contribute to the high degree of specialization in the cultural practices followed in the region. The less remunerative rice cultivation complements a highly profitable prawn culture, making it a unique agro-ecological continuum. The farming system is traditionally organic, as farmers desist from the use of agrochemicals in rice farming which hampers the productivity of the succeeding crop, *i.e.*, the fish culture. But lately, monoculture of fish/ prawn has caught up, which though provides higher net return in short run, it is unsustainable both from ecological and social contexts.

Gregor Mendel Foundation, Calicut University, Kerala, India (2018).

Recent advances in rice biotechnology

T.S. Jishinprakash and A. Yusuf
Plant Biotechnology Division, Department of Botany, University of Calicut, Kerala- 673635, India.

Rice is considered as the 'model monocot' in molecular genomics research with increased output from biotechnology during the mid-1980s and eventually the first food crop whose complete genome has been sequenced. Among the key advantages that rice possesses as a model system are its small genome (~430 Mb), the development and availability of its genome sequences, the rice chromosome 10 sequencing consortium, its diverse germplasm (84,000 accessions at IRRI) and the development of a number of key resources for genomic mapping research. The progress achieved in biotechnology applications for rice improvement is in two major areas- the use of molecular markers for identifying introgressive genes and gene combinations within the rice species and the use of transgenic technologies to incorporate traits for herbicide tolerance, biotic stress resistance, abiotic stress resistance and nutritional value into rice.

Tissue culture

Plant tissue culture plays an important role in the production of agricultural and ornamental plants and in the manipulation of plants for improved agronomic performance. Regenerated plants are expected to have the same genotype as the donor plant; however, in some cases, somaclonal variants have been observed among regenerated plants. In recent years, considerable efforts have been directed towards the improvement of the important agronomic traits of rice through biotechnological techniques. Since the first haploid plants were regenerated from rice anthers the technology has been a routine exercise in laboratories involved in agricultural biotechnology and rapid development. Seed, immature embryo, the anther and the protoplasm were used for successful plant regeneration, with success in anther culture for haploid plant generation methods. Many factors such as genotype, physiological age of donor plant and culture medium affect the development of androgenic callus and plant regeneration.

Though different protocols have been proposed to improve the efficiency of another culture, the plant regeneration frequencies remained low, especially for *indica* rice cultivars (*O. sativa* ssp. *indica*). Rice seeds have more potential for callogenesis as compared to node or shoot tip. Tissue culture of dehusked rice embryo is a novel technique to exploit somaclonal variation and for the improvement of grain quality. The mature embryo in rice is arguably one of the best explants for genetic transformation because of its availability and ease to handle as an explant compared to other tissues, but it has a low frequency of plant regeneration from callus through somatic embryogenesis. Moreover, using mature embryos, little information is available on the improvement of *in vitro* regeneration particularly in *indica* rice than *japonica* type. In addition, a number of economically valuable *indica* varieties are recalcitrant to *in vitro* manipulation due to their poor callus production and regeneration ability. Callus induction and regeneration is still a challenging task in most *indica* rice varieties and therefore, there is a basic need to use mature embryos of *indica* rice to develop an efficient *in vitro* protocol for establishing a highly reproducible regeneration system for molecular transformation and breaking seed dormancy. Even with a sound methodology on rice tissue culture, *in vitro* regeneration of *indica* rice is still a challenge and is genotype dependent.

Carbohydrate, type of explants used, plant growth regulators, basal salts of the culturing medium, culture conditions and most importantly genotype of the explants play an important role in successful tissue culture. Mature embryo, immature embryo and immature inflorescence in eight *indica* rice varieties on MS and N6 media with 2, 4-D showed highest regeneration frequency. Mature caryopses of Asian *indica* rice cultured on MS medium with proper nutrients and IAA, NAA, kinetin (kin) and BAP and ethylene yielded high frequency callus induction. Sucrose (4%W/V) is essential for callus induction and using 0.5 mg/l 2,4-D, sucrose and sorbitol combination is the best for enhancing regeneration. Three month old mature embryos of two *japonica* and two *indica* (IR 2153 and Nano Bolera) varieties of rice grown in different concentrations of ABA, PEG, IAA, proline, tryptophan and also various doses of NaCl, revealed that ABA and PEG showed decrease in regeneration frequency, proline has no effect on regeneration frequency; IAA showed decrease in shoot and increase in root regeneration. Mature seeds of Kusan, Lamsan, Selasi and Siam varieties of rice when grown on MS medium along with 2, 4-D, NAA, kin, BAP showed high regeneration frequency in Lasman and poor in Siam and Kusan. Immature/mature seeds of Pusa Basmati 1, HRR 46 and IR 72 varieties of rice grown in MS basal medium along with NAA showed regeneration frequency of 91.3%, 76.3% and 72.3% respectively. Scutellum of MR 123 and MR 127 varieties of rice cultured on MS medium with 2.5 mg/l 2,4-D showed induction frequency of 70 and 76% respectively. Coleoptiles of Neda and Nemat varieties of rice treated with 2 mg/l kin, 0.5 mg/l NAA and 2 mg/l BAP, 0.5 mg/l kin showed regeneration frequency of 32.30% and 20.95%.

The media constituents and their concentrations of macronutrients, sucrose and phytohormones affect the regeneration potential. Miller's medium was widely used in the late 1960's and early 1970's. Other nutrient media in common use for rice tissue culture include MS, modified MS, LS , modified LS, N6, B5 and modified White's medium. SK medium and Universal medium are recommended as suitable for *indica* genotypes. Providing most of the inorganic nitrogen as ammonium rather than nitrate appears generally favorable for rice tissue culture.

Breeding

Plant breeding, the science of crop improvement, has traditionally developed new varieties through selective breeding. Plant breeders hybridize plants that have been selected for some desired trait. The time tested strategy for selecting crop varieties with higher yield potential comprises of two phases. The first phase involves the creation of variability through hybridization between diverse parents. In the second phase, desirable individuals are selected on the basis of field observations and yield trials. Rice breeding has made significant progress towards higher yield, improved quality, greater disease resistance and other important characters of agricultural importance in the past and even in future. It has been estimated that on the average about 1% increase has occurred per year in the yield potential of rice over a 35 year period since the development of the first improved variety of rice, IR8. The potential to increase the yield of crops has continuously increased and there is no reason why further increases cannot be attained.

The phenomenon termed heterosis or hybrid vigor in the first generation (F1) seeds, by crossing genetically distant breeding lines is well known in crop breeding. Rice being a strictly self-pollinating crop, the identification of cytoplasmic male-sterile (CMS) wild rice germplasm in the 1970s and their subsequent use made significant progress in developing hybrid rice technology based on heterosis.

The rice green revolution

In the 1960s, scientists realized that most tall traditional rice varieties lodged during nitrogen fertilizer application, which is the main constraint to grain yield. IR8, the first high-yielding modern rice cultivar, released by IRRI in 1966 marked the start of 'green revolution' in Asia. IR8 is a semi-dwarf variety having profuse tillering, stiff culms, erect leaves, photoperiod insensitivity, high N responsiveness and high harvest index (HI) compared to traditional cultivars. The semi-dwarf (sd1) IR8 was developed from a combination of the Indonesian variety 'Peta' and 'Dee Geo Woo Gen' from Taiwan. The key factor responsible for the increase in yield potential was the improvement of the harvest index. In the following decades, IRRI developed IR36, which became the most widely planted variety in the 1980s and IR64 was the most used in the 1990s. However, these newer varieties were characterized by disease and insect resistance, they did not contribute significantly to genetic gains for grain yield. Scientists then believed that a new breakthrough in yield potential had to come through a new plant type.

The new plant type (NPT)

In order to develop super high-yielding rice varieties it is essential to increase the biological yield. Searching for a second green revolution, IRRI had been working on a new rice ideotype or new plant type (NPT) with a HI of 0.6 (60% grain: 40% straw weight) and with an increased ability for photosynthesis to increase total biological yield. The components essential for the NPT are: low tillering capacity, few unproductive tillers, 200 to 250 grains per panicle, plant height of 90 to 100 cm, thick and strong stems, vigorous root system and 100 to 130 days of growth cycle. These traits would allow the rice plant to transform more energy into grain production, increasing the yield potential by about 20% but with more input and cost. In 1981, Japan launched a project aiming at combining varieties from *indica* and *japonica* groups to develop a super high-yielding rice cultivar. The development of NPT was based on tropical *japonica* germplasm derived from Indonesia, as the source of low tillering, large panicles, thick stems, vigorous root system and short stature. The process of developing the NPT was more complicated than originally thought. The first generation of breeding lines with the above mentioned traits did not perform as expected. New crosses were made by combining the tropical *japonicas* with elite *indica* breeding lines. The expectation was that lines coming out of these crosses would increase the yield of irrigated lowland rice by about 10%. The development of super high-yielding rice varieties following the concepts has encountered various technical difficulties; however, the basic principles remained the same.

Hybrid rice

The hybrid rice concept dates back to 1964 in China. However, only in 1970, when a wild abortive pollen plant was identified in Southern China, the idea began to materialize and the first article indicating the potential of hybrid rice was published. The proposed strategy relied on the male sterility produced by the abortive pollen identified in the wild species *O. sativa* L. f. *spontanea*. Hybrid rice was produced through a three-line system, where the first line was the genetic cytoplasmic male sterility; the second line responsible for maintaining the sterility, and a third line used as the matching parent for the hybrid with the responsibility of restoring the fertility. The first set of genetic cytoplasmic male sterile lines was produced in 1970, while the first hybrid rice was released in 1974, with the hybrids out classing conventional rice varieties by 20% in yield. In 1999, the area planted with the hybrids was about 15.5 million ha, representing 50% of the total rice area and 60% of the total Chinese rice production. India has released a number of hybrids since 1989; however, the pace of adoption by farmers has been slower than expected with a cultivation of only 200,000 ha. To simplify the hybrid rice production system, the concept of environmental genetic male sterility (EGMS) was introduced. The two environmental factors considered were the photoperiod (PGMS) and the temperature (TGMS) sensitivities, which are controlled by recessive nuclear genes. This technology allows, the use of any genotype with good traits as male parent, to obtain *japonica* hybrids (e.g., it is difficult to identify restorers for this group), and to develop inter-group hybrids such as *indica*/*japonica* (e.g., there is no restriction regarding the restorer–maintainer relationship).

NERICA rice

Upland and low dryland environments are the two most important rice production ecosystems in Africa, where it is a staple food for the sub-Saharan population. WARDA began a program to combine the two cultivated rice species *O. sativa* and *O. glaberrima* in 1991. Embryo rescue technique was employed to obtain viable segregating populations due to their genetic dissimilarity. The newly developed materials were called 'new rice for Africa' and were popularized as NERICA varieties. The main features of these new varieties, when compared to the traditional *O. glaberrima* cultivated by farmers, are their improved ability to compete with weeds, their larger panicles with around 400 grains and a higher yield potential. In addition to reduced shattering, stronger stems to prevent lodging and maturity period of around 30 days earlier than other conventional cultivars, they have greater resistance to the most common biotic and abiotic stresses, as well as improved adaptability to the poor African rice growing soils.

Super rice

Super rice is the rice bred for super-high yield. In 1981, the Ministry of Agriculture, Forestry and Fisheries of Japan launched large scale collaborative research projects to develop super-high-yield rice, along with the improvement of cultivation techniques. This plan focused on breeding high yielding varieties and establishing a system of cultivation to maximize the potential of super-high-yield varieties. Over 15 years, implementation of the plan led to release of some super-high-yield varieties that produced 10 t of brown rice per hectare, an increase of 50% compared to the control varieties. Super rice breeding in China has been very successful. After the establishment of the breeding theory and strategy of generating an ideotype with strong heterosis through inter-subspecies hybridization, by using gene pyramiding to combine elite traits through composite crossing to breed super rice varieties, a series of major breakthroughs have been achieved in both conventional and super hybrid rice breeding. A number of new genetic materials with this ideotype have been created successfully and approved. During the induction of the Super Rice Varieties Program, great attention has also been paid to the integration and demonstration of the rice production technology. Collaboration between industry and university researchers has led to technological innovations and initiation of a demonstration system for super hybrid rice.

The Green Super Rice (GSR) project was launched in 2008 at the International Rice Research Institute (IRRI) headquarters, with the aim of developing rice varieties that retain their stable and sustainable yield potential even when grown with fewer inputs or under unfavorable environmental conditions. Under experimental conditions, new high-yielding GSR cultivars with the tolerance to multiple abiotic stresses have already been developed. The GSR project also released drought tolerant, salinity tolerant and submergence tolerant, and high yielding varieties suitable for irrigated conditions. Overall, the most important finding is the positive and significant effect of GSR varieties on yield and net farm income even with substantial flooding (i.e., the rice being submerged). In fact, non-GSR varieties are the most affected when maximum monthly rainfall exceeds 1000 mm, while the yield of GSR rice varieties is still increasing.

Perennial rice

The principal basis for developing perennial rice is based on a strategy of intercrossing F1 lines, backcrossing to the cultivated rice parent, and rigorous selection for survival and seed set in the field. Development of perennial rice is consequently at the forefront of perennial grain development, and will hopefully act as an incentive to succeed in other species. Despite some success in developing a perennial rice phenotype which may be suitable for more favourable lowland conditions in which abiotic stresses are minimal, significant challenges exist in developing a robust perennial rice for the harsher rainfed lowland and especially upland ecosystems, where perennial rice is really needed. There are five perennial rice (PR) lines, namely PR23, PR57, PR129, PR137 and PR139 that have been bred.

Stress tolerant rice

During the past 30 years, rice breeding efforts have been directed towards incorporation of disease and insect resistance, earlier maturity and improving grain quality. Development of large breeding populations using crosses between drought tolerant landraces and high yielding drought susceptible varieties proved effective in combining high yield potential with drought tolerance. Apart from this, the use of popular varieties as recipient parents in the target environment also provides a chance to develop lines with desired traits related to grain quality, plant type, tolerance for other stresses in a particular region and farmers' preferences, thereby increasing the probability of adoption of the new varieties. It is also advantageous to choose landraces that may have tolerance for other stresses along with drought tolerance to increase the possibility of coming up with lines that can tolerate multiple stresses. It is also important that the parents are selected on the basis of the target ecosystem; the plant types required for upland and lowland conditions are very distinct. The plant types suitable for flooded lowland conditions are high tillering medium to long duration dwarf plant types with drought tolerance. This kind of plants ensure high yield under normal conditions with a minimum threat to lodging. The long maturity duration also allows the plant to attain high biomass and high tillering which in turn leads to an increase in yield under normal conditions. The added tolerance to drought in such lines also ensures yield under drought conditions. The traditional rice varieties have evolved suitable mechanism(s) to survive under stress. Systematic screening of rice germplasm has shown that there are excellent flood tolerant rice types locally available. Breeding efforts at IRRI led to the evolution of tolerant lines with good agronomic traits. The line "IR 49830-7-2-2" combines high tolerance levels with higher yield potential and resistance to diseases and insect pests and it has been extensively used as a donor parent in the breeding programme. "Sudhir" is another variety which has been developed from the "FR13A" × "Biraj" crosses. This variety has been released by the "Central Variety Release Committee, Indian Council of Agricultural Research, Government of India" in 1999. In spite of the above developments, till date, no variety has been developed which combines desirable levels of flooding tolerance with grain yield. Flooding tolerant rice "Goda Heenati" apparently does not have the same submergence tolerance gene. It has been suggested that there are at least three submergence tolerance genes in "FR13A", "Kurkaruppan" and "Goda Heenati". Further, though "FR13A" is considered to be an excellent source of submergence tolerance especially at young seedling stage (10 days), "CN 540 (Suresh)" is found to be more resistant than "FR13A" and "FR43B" and this might result in genotypes with better submergence tolerance.

Major attempts have also been made in breeding for improved submergence tolerance through the use of doubled haploid lines (DHLs), developed using crosses between submergence tolerant and sensitive rice cultivars. Two DHL populations for submergence tolerance have been developed at IRRI using the cross combination of 1) "IR 49830 × CT 6241" and 2) "FR13A × IR 42". Use of DHLs has recently been reported for identification of two restriction fragment length polymorphism (RFLP) markers for submergence tolerance of rice which are mapped to a segment of chromosome 9. This chromosome segment [Sub 1(t)] accounted for 70% of the phenotypic variance in submergence tolerance of this population. It would be rewarding if the Sub 1(t) locus is cloned through map-based cloning technique. A high resolution map has been constructed around the Sub 1(t) locus through the use of RFLP and AFLP (amplified fragment length polymorphism) markers.

Molecular biology

The whole rice genome and annotations

Rice is a well studied model plant whose genome has been decoded, and its transformation technology has been very well developed. The availability of the rice genome, together with the community annotation and other resources added functionality, transformed genetic research and rice breeding. Besides its economic importance, rice has a small genome (430 Mb). RGP has developed whole genome physical maps using YACs, BACs, and PACs, which is the groundwork for the whole genome sequencing using map based strategy. The rice genome database called INE (integrated rice genome explorer) has been developed in order to integrate all the genomic information (http:// www. dna.affrc. go.jp:82/giot/INE.html).

With the advent of functional genomics, after the completion of entire rice genome sequencing and large gene sets prediction, approx. 10000 expressed sequence tags (ESTs) and over 15000 full length cDNAs were analysed. Approximately 66700 unique ESTs have been mapped recently that cover almost 80% of the genome but most were mapped to distal parts of chromosomes. Typical of the redundant sequence families are 18S-25S and 5S ribosomal RNA genes, which are repeated hundreds of times and clustered in certain regions of particular chromosomes. Several gene families, such as ribosomal protein genes and histone genes are scattered over the 12 chromosomes. Numerous protein kinase genes were identified in the whole genome and many disease resistance genes belonging to protein kinase families are clustered on several chromosomes. About 50% of the rice genome, including some parts of open reading frames (ORFs), is made up of repetitive sequences. Precise identification of many kinds of repetitive sequences has been carried out using the full genome draft sequences, revealing that the rice genome is composed of approx. 38 Mb of long and 150 Mb of short repetitive DNA. This showed more than 48000 repetitions of di-, tri- and tetranucleotide simple sequence repeats (SSRs). The shortest repetitions are categorized into microsatellites of SSRs (less than 10 bp units), minisatellites (less than 40 bp units) and satellite DNAs (several hundred bp units). One member of the TOS type of retrotransposon, Tos17, revealed to transpose to various genome positions when cells were subjected to stress condition. Tos17 also proved to be very useful in enabling thousands of insertion mutant lines to be generated. Several genes isolated from the tagged mutants by PCR screening for pooled DNAs of Tos17 transposed lines have been reported. This is a powerful means to construct a functional genomics system to search for many genes by both phenotypic screening and DNA sequence analysis. Distribution and transposition of endogenous retrotransposon sequences may contribute to the organization of genome structure and evolution, but this remains purely speculative.

Characterization of rice CEN5

The characterization of centromere composition and a large centromere isolated clone made it possible to unravel centromere structure in chromosome 5. Contig formation with YAC and BAC clones and analysis of the distribution of major repetitive sequences on the contigs coupled with genetic analysis showed that the centromere of chromosome 5 (CEN5) occupies more than 2 Mb. Several functional genes were also scattered between repetitive sequences and were not found to recombine with each other in meiosis. These genetic and physical characters of CEN5 in rice are similar to those of centromeres of *A. thaliana* and other organisms. The maize centromere was also shown to have a similar constitution, centered on a high copy number block of short tandem repeats being adjacent to moderately repeated transposon like sequences.

The rice CEN5 has been partly analysed, and several YAC clones possessing repeat blocks and multiple copies of retrotransposons in its 380 kb DNA should be promising candidates for examining centromere function. YAC arms with rice telomeres and plant selection markers have been constructed and used for retrofitting the candidate YAC clone. The retrofitted YAC clone, which possesses both centromere and telomere sequences, should function as an artificial chromosome in rice cells. If the introduced artificial chromosome could be transmitted to the next generation, it would provide a valuable opportunity to study genomic organization and interactions between original chromosomes and artificial chromosomes. These might also provide essential knowledge for generating novel plants by the use of artificial chromosomes.

Stress response and functional genes for drought resistance

Responses at the molecular level during adaptation to drought stress regulated by several genes forming response systems to drought were identified. Drought genes were divided into two classes according to their mode of action. The first class is a functional gene which protects against drought and the second a regulatory gene that could regulate functional genes in signal transduction and gene expression.

There were several significant differences between transgenic rice with the gene for GST and CAT1 and normal rice in growth, photosynthesis, reduction extent of RWC (relative water content), accumulation of H_2O_2 and MDA (malondialdehyde), etc. These results implied the GST and CAT1 transgene mitigated oxidative damage from water stress. Excessive expression of the coli trehalose synthesis A (otsA) and coli trehalose synthesis B (otsB) transgenic rice, accumulation of trehalose increased and oxidative damage caused by photo oxidation decreased. The bi-functional fusion of the TPS and TPP (TPSP) transgene enhanced resistance to drought, salt and cold. By activating gene GH3.13 of rice and adapting the content of IAA in leaf, stem and tuber, adaptability to drought was enhanced.

A gene named *osSKIPa*, which has an upstream gene for regulating the other genes of drought resistance, promotes the cell vitality, increased viability in water stress. A rice mutant named drought and salt tolerant (DST) was developed through screening from a mutant library. Further, the gene DST with stress resistance was cloned and DST down regulated the expression of the gene related to the metabolism of H_2O_2, and the ability of H_2O_2 elimination was reduced. This resulted in the accumulation of H_2O_2, and closing of stomata in the guard cells and improved the ability of drought resistance by decreasing evaporation of water.

Gene mapping

Nearly 450 genes have been identified in rice which affect biotic and abiotic stresses, colouration of plant parts and morphological, physiological and biochemical traits. Rice researchers have studied the inheritance of morphological traits of 19 genes controlling anthocyanin pigmentation, 12 for hull and pericarp colour, 28 for spikelet traits, 10 for grain size and shape, 20 for endosperm traits, 22 for panicle traits, 9 for culm traits, 27 for leaf traits, 11 for duration to heading, 30 for reproductive traits, 22 for panicle traits and 9 for chlorophyll deficiency viz., albino, chlorina, fine striped virescent and zebras. Many resistance genes to various diseases have been identified in rice including 18 for bacterial blight, 20 for blast, 2 for *Cercospora*, 2 for stripe viruses and one each for grassy stunt, hojablanca and yellow dwarf viruses. More than 30 genes conferring resistance to various insect pests such as plant hopper, green leafhopper, white backed plant hopper, zigzag leaf hopper and gall midge have been identified. Most of the mutant genes responsible for altered traits have been assigned to linkage groups through genetic and cytological analysis. Rice classical genetic map has been developed using more than 170 morphological markers. Many quantitative trait loci (QTLs) for the various components of drought resistance, submergence tolerance, blast and blight disease resistance, nitrogen use efficiency, heterosis and heading date have been tagged using molecular markers. Excellent genetic maps were developed in rice using various diverse crosses which include BS125/WL02, IR64/Azucena, Nipponbare/Kasalath, AijiaoNante/P16, Milyang23/Gihobyeo, ZhaiYeQing8/JinXi17 and BS125/2/BS125 /WLO2. About 4,897 markers were reported in the *Oryza* database including 2,600 RFLP, 134 RAPD, 235 AFLP, 300 SSR, 75 STS, 116 isozyme and 450 morphological markers (http://ars-genome.cornell.edu/rice). Rice geneticists have developed a classical genetic map of rice for more than 200 phenotypic traits using morphological and isozyme markers. The Rice Genome Research Program (RGP) generated the first high density genetic map by placing 1500 RFLP markers on rice chromosomes and later, a high density rice genetic linkage map was developed with 2275 markers covering 1521 cM using the same 186 F2 individuals derived from the cross between Nipponbare (*japonica*) and Kasalath (*indica*).

Genetic engineering

Though the contribution of conventional breeding methods in enhancing rice production by means of providing better yielding verities with high yield even under stress conditions is remarkable and cannot be denied, the time has come to incorporate the traditional breeding methods with the recent advancements in genetic engineering. It has been almost two decades since the first transgenic rice came into existence. Since then tremendous progress has been achieved by genetic engineers in developing more frequent and routine genetic transformation protocols by means of direct DNA transfer or *Agrobacterium* mediated genetic transformation. Recombinant DNA technology has resulted in the creation of transgenic rice with novel genetic traits and genes for resistance to biotic and abiotic stresses. High throughput transformation protocols for rice, activation tagging and insertional mutagenesis have bearing for enhancing transformation efficiency. This advancement in technologies has facilitated researchers in introducing several agronomically and economically important traits including nutritional improvements, which may not have been possible through conventional breeding.

Agrobacterium mediated gene transfer

Remarkable progress has been made in the development of efficient systems for *Agrobacterium tumefaciens* mediated transformation in rice. Attempts were made to raise and regenerate transgenic calli after *Agrobacterium* mediated transformation. Regeneration of *Agrobacterium* transformed calli from root explants and immature embryos was achieved. Already about 40 different genotypes of *indica, japonica* and *javanica* rice have been transformed using this approach. Several factors were found to have an impact on the efficiency of *A. tumefaciens* mediated transformation, including Ti plasmid type, bacterial strains with broad host range, culture conditions prior to and during inoculation and activation of T-DNA transfer process by exogenously added acetosyringone. Among various explants used, scutellum derived calli are the material of choice for efficient transformation in rice. The successful regeneration of transgenic plants within a month using scutellum from one day precultured seeds as explants, oould avert the risk of somaclonal variations. The strong influence on the transformation frequency is exerted by the plant's genetic background in *indica* rice although the same is not apparent for three different *japonica* cultivars.

Particle gun bombardment

Microprojectile bombardment or biolistics is also an equally successful method as it is considered genotype independent and less labour intensive. It has been associated with some risk due to the arrangement of multiple copies of transgenes, particularly in the form of inverted repeats and the problem of high copy number of the transgene, unlike *Agrobacterium*-mediated transformation. Despite all these constraints, successful integration, expression and segregation of multiple genes were shown in rice using biolistic method. The problem of rearrangement also has been overcome up to a large extent using minimal linear cassette (including promoter, open reading frame and terminator only) to coat microcarriers. Such 'clean gene' technology would be of great importance in avoiding undesirable effects of vector backbone and it also provides an alternative to *Agrobacterium* based method. Rice transformed with five different minimal cassettes showed simple integration pattern coupled with high and stable transgene co-expression over generations. Using a biolistic approach, several transgenes have been introduced into rice calli where they express transiently or get stably integrated and inherited. This approach has been used for investigation on promoters, stress tolerance, nutritional enhancement, gene expression, plant development and grain yield.

Other methods

Rice protoplasts can be transformed with naked DNA by treatment with PEG in the presence of divalent cations such as calcium. Transgenic rices are recovered using PEG technology and thus it is the first technique used in transgenic rice production. Subsequently, this was followed by other workers and they recovered fertile transgenic plants from *indica* rice using PEG. Similarly, fertile transgenic plants were developed using electroporation in *japonica* rice. However, protoplasts are not easy to work with and regeneration of fertile plants is problematic. To improve transformation efficiency, a single cell manipulation supporting robot for high throughput microinjection of rice protoplasts has been developed. Besides the standard and widely used techniques as mentioned above, certain claims of genetic transformation have been made using novel methods, based on pollen tube pathway, LASER, imbibition of embryo or seeds in the presence of DNA and WHISKERSTM. To avoid tissue culture and sterile conditions, *in planta* transformation method has been developed depending on a needle dipped in *Agrobacterium* culture to prick the seed's embryonic portion that subsequently grows into a plant and sets transgenic seeds.

Enhancement of stress tolerance

The response of a plant to environmental stress is determined by many factors like genotype, developmental stage, duration, severity, periodicity as well as additive/synergistic effects of multiple stresses. Stresses trigger a wide range of plant responses, from altered gene expression and cellular metabolism to changes in growth rates and crop yields. Failure to compensate for a severe stress can result in plant death. The transgenic approach can help to generate tolerance to several stresses influencing rice production.

Biotic stress tolerance

Insects attack all parts of the rice plant and not only exert physiological damage to the plant, but also act as vectors for viral diseases. The most important and widely distributed pest species are stem borers, leaf folders, plant hoppers and gall midges. Chemical insecticides provide a simple way to control insect infestation, but the use of agrochemicals without effective biosafety rules may lead to both environmental and health problems. Thus, genetic engineering would provide an effective and safe way to develop insect resistance in rice. Baculoviral insecticides are an effective means of controlling predating insect populations. Increasing the insect's virus susceptibility reduces the amount of virus needed for successful application. By introducing the gene for virus enhancing factor in rice, the effectiveness of baculoviral insecticides against feeding armyworm larvae was enhanced. Transgenic rice resistant to insect storage pests using hydrolase inhibitors was generated. Transgenic rice showed higher tolerance against the rice weevil. Using an alternative approach, rice plants were transformed with spider gene, *SPI*. Lectins, like GNA, provide an alternative way to control the small brown plant hopper. The expression of GNA in rice also conferred resistance against green leaf hopper and white backed plant hopper. Overexpression of *cry* and GNA imparted resistance against yellow stem borer, brown plant hopper, green leaf hopper and the white backed plant hopper and GNA with SBTI in transgenic rice showed varying degrees of resistance against the rice leaf folder *Cnaphalocrocis medainalis* and brown plant hopper *Nilaparvata lugens*.

Bacterial disease resistance

Bacterial blight, caused by *Xanthomonas oryzae pv. oryzae* (*Xoo*), along with blast and sheath blight are the most important diseases of rice and have a worldwide distribution. A total of 30 endogenous genes, conferring host resistance against different *Xoo* strains have been identified and named as *Xa1* to *Xa29*. The transgenic approach using these or other genes provides a reasonable alternative for genetic enhancement towards bacterial resistance. The most promising endogenous rice gene for bacterial blight resistance identified so far is *Xa21*, which conferred complete protection against bacterial blight. Targeting of peptidase sensitive peptides like cecropin to the intracellular spaces by means of signal peptides protects the peptide from degradation. Overexpression of *OSWRKY71* transcription factor in rice also resulted in enhanced resistance to the virulent bacterial pathogen *Xanthomonas oryzae* pv. *oryzae* (*Xoo*) 13751 suggesting its role in rice defense signaling pathways.

Fungal resistance

Fungal resistance genes have been identified from rice. Most promising endogenous resistance (R) gene, *Pi-ta* (cytoplasmic NBS receptor), is responsible for resistance to fungal diseases. Substitution of alanine for serine at position 918 was responsible for susceptibility to *Magnoporthe grisea*, causal organism of rice blast disease. Overexpression of dominant *Pi-ta* allele in a susceptible variety could confer complete resistance against blast disease. A cluster of six tandemly repeated disease resistance like genes from rice, of which one (*Nbs2-Pi9*) encodes a transcription factor and showed broad spectrum resistance against different *Magnoporthe grisea* isolates in transgenic rice. Another gene, *OSDR8*, is involved in thiamine biosynthesis and acts upstream in defense signal transduction pathway.

Pathogenesis related (PR) genes have been used widely to address fungal tolerance in plants and transgenic rice expressing *ChI11*, which showed only partial protection against sheath blight disease. However, significant resistance against *Rhizoctonia solani* has been reported using the same gene. Another chitinase gene (*RC7*) could confer tolerance against *R. solani* (the causal organism of rice sheath blight disease) in transgenic rice. Several other genes encoding antifungal proteins have been introduced in rice for fungal resistance, with variable degrees of success and some are effective against bacterial as well as fungal disease, e.g., cecropins.

Viral resistance

Insect vector mediated viral diseases cause considerable damage to the rice plant and drastically reduce the yield of the plant. Transgenic rice plants were produced against rice stripe virus to demonstrate for the first time that coat protein mediated resistance to virus infection can be extended to cereals and to the viruses transmitted by an insect (plant hopper) vector. To generate virus resistant transgenic rice, *japonica* rice was transformed with a hammerhead ribozyme, a catalytic molecule with sequence specific RNA cleavage activity. The expression of ribozyme confers resistance to infection by rice dwarf virus. However, silencing of the gene had an effect on the degree of viral resistance in some lines. Resistance against RRSV has been introduced in rice by expressing 39 kDa spike protein of RRSV and transformation of susceptible rice cultivar with RHBV nucleocapsid protein gene and moderate to complete resistance was seen in transgenic lines.

Abiotic stress tolerance

In agricultural systems, abiotic stresses are responsible for most of the reduction that differentiates yield potential from harvestable yield. There is a range of external factors that adversely affect the growth and development of crop plants. These include high temperature, chilling, freezing, water deficit (drought and salinity), high light intensity, flooding and exposure to ozone and heavy metals. Most abiotic stresses directly or indirectly lead to the production of free radicals and reactive oxygen species, creating oxidative stress. Thus, it is imperative to develop stress tolerant varieties. Furthermore, with the extension of crop cultivation to environments which are not optimal for the growth of crop plants, development of stress tolerant plants is becoming increasingly important. Transgenic approaches offer new opportunities to improve tolerance to abiotic stresses. Overproduction of various compatible solutes has been tested in rice, e.g.: glycine betaine, trehalose, proline and polyamines, to achieve significant drought, cold and salt tolerance. Late embryogenesis proteins (LEA) are hydrophilic proteins first reported from barely and the overexpression of LEA encoding genes from barley or wheat in rice could enhance drought tolerance. Transgenic plants also performed better than wild type plants under prolonged water deficit conditions. Like compatible solutes, use of membrane transporters holds good promise. Water channel proteins, aquaporins, are members of the major intrinsic protein family which regulate the passive movement of water across membranes. Another promising strategy against salinity stress is the use of Na^+ transporters, which transport cytosolic Na^+ to the vacuole and, thus protect cellular machinery. Na^+/H^+ antiporters from *Artiplex* or *E.coli* confer high salt tolerance in transgenic rice. Overexpression of rice Na^+/H^+ antiporter gene could transport the sodium to the vacuole and provide increased salt tolerance. Genetic engineering for oxidative stress tolerance provides an attractive strategy to achieve tolerance for multiple stresses. Enhanced production of glutathione synthase, an enzyme involved in ROS metabolism, could enhance the salt tolerance in transgenic rice. Similarly, drought tolerance of transgenic rice was improved by overexpressing superoxide dismutase from pea. Transgenic plants expressing protoporphyrinogen oxidase also experienced lesser oxidative stress than control plants

Production of novel compounds

Genetic transformation of rice has been used for producing novel compounds. The plant system provides several advantages over the animal or the prokaryotic system, e.g., more safety for human use, post-translational modification of the expressed protein and less expensive extraction and purification. Endosperm targeted production of recombinant compounds in rice further provides the benefit of storage in the form of seed. Single chain Fv antibody (ScFvT84.66) against a well characterized tumor associated marker antigen, carcino-embryonic antigen, had been produced in rice and was stable in transgenic dry seeds for at least five months at room temperature. Transgenic rice system has been successfully used for the production of industrial valuable enzyme transglutaminase, N(hydroxycinnamoyl) transferase, lupin acid phosphatase, human lysozyme, glycogen-like peptide for type II diabetes treatment, allergen specific T-cell epitope, human granulocyte colony stimulating factor, hG-CSF and linoleic isomers for reducing fat and hypertension in animals. Foods rich in antihypertensive activity might hold the promise of reducing hypertension. Antihypertensive peptide RPLKPW fused with rice glutelin storage protein was expressed in the seeds of transgenic rice plants. Recombinant protein accounted for about 10% of total seed protein in transgenic seeds. Rice cell suspension culture systems also provide an alternative to animal/bacterial cell lines for the production of recombinant compounds for human use as the risk of contamination is very low. Rice calli and cell suspension cultures were transformed using a codon-optimized synthetic gene for human lysozyme. The expression of *Helicobacter pylori* urease subunit B gene in rice has provided a basis for further studies on the potential of transgenic rice for delivery of edible vaccines against *H. pylori*.

Technological innovations

Several technological innovations have been helpful to improve the potential and ease of utilization of transgenic rice. A high level of targeted expression of the transgene(s) within the transgenic plant is highly desirable depending on the requirement. The application of the bacteriophage T7 RNA polymerase - directed gene expression system in transgenic rice was three-to-five-fold better than *CaMV35S* gene promoter. In another approach, MAR from tobacco, TM2, enhanced reporter gene expression in transgenic rice when used with tissue specific or constitutive promoter. Quantification of transgene copy number is an important exercise and a simple real-time quantitative PCR based method to estimate transgene copy number in transgenic rice was developed, which has similar results to Southern hybridisation. Real-time PCR for determination of copy number in transgenic rice has also been used. siRNA mediated post-transcriptional gene silencing (PTGS) has been established as the method of choice for functional analysis to silence the function of the targeted gene in transgenic rice cells.

Biology and cultivation of coconut

K. Samsudeen
ICAR-Central Plantation Crops Research Institute, Kasaragod, Kerala- 671124, India.

Coconut served man through ages. Originated even before continental drift, coconut survived many vagaries of nature outliving all its relatives to develop in to the monotypic genus *Cocos* with the sole species *nucifera*. Place of origin of *Cocos nucifera* L. is an enigma even today. One school of thought is that coconut originated in Central American region while another says it is from South East Asia. Fossil records from New Zealand indicate that small, coconut like plants grew there as long as 15 million years ago. Even older fossils have been uncovered in India. An origin for the whole Cocoeae tribe in western Gondwanaland seems most compatible with the present day distribution. It has been hypothesized that the tribe probably differentiated shortly before the break up of that super continent. With its ability to float the coconut became independent of plate tectonics for its dispersal. The wild type evolved by floating between the volcanic islands and atolls where these fringed the continental plates and not on the lands masses at all. It is further postulated that the coasts and islands of the Tethys Sea could have been the ancestral home of the coconut, from where it dispersed by floating to other islands in the Indian Ocean and from there into Pacific Ocean. Wherever originated, coconut is well adapted to coastal ecosystems of tropical world. Today, coconut is found from tropic of cancer to tropic of capricorn in the cultivated form without any wild relatives.

Cocos nucifera, a monoecious perennial monocotyledon, is placed in Arecaceae family (formerly Palmaceae) and the sub family Cocoideae which includes a total of 27 genera and 600 species. Before 1910 many South American palm genera were classified as *Cocos* but now *Cocos nucifera* is considered monospecific, despite the pantropical distribution of this palm. The coconut palm, *Cocos nucifera*, the most important of all cultivated palms, is essentially an oil crop but is also ranked as an important food crop. The palm not only supplies food, drink and shelter, but also provides raw materials for a number of important industries. The palm is referred to as ‘The Tree of Wealth’ and ‘The Tree of Life, as it provides all the necessities of life.

Coconut is cultivated in 11.93 million hectares in 94 countries producing 60.5 million tons of nuts equivalent of 10 million tons in copra or six million tons in oil. In India, coconut is cultivated in 18 states and three Union Territories under 2.16 million ha for the production of 15.08 million tons. The four southern states, Kerala, Karnataka, Tamil Nadu and Andhra Pradesh account for 90% of area under coconut and 93% of production. Rest of the production comes from Maharashtra, Orissa, Pondicherry, Andaman & Nicobar, Lakshadweep, Gujarat, Goa, West Bengal and non-traditional states like Bihar, Assam, Tripura, Nagaland, Manipur, Meghalaya, Arunachal Pradesh and Chhattisgarh.

Botany

The coconut palm is a tree sans branches, with a single stem topped by a cluster of long pinnate leaves. The palm with indeterminate growth has only one apical meristem that gives rise to leaf and inflorescence primordia. The inflorescences emerge from leaf axils.

Root

The palm being a monocot has an adventitious root system. Roots emerge from the base of the stem (bole). Number of roots in a palm varies with the variety, age of the palm, bole size, and management and ranges from 1500-7000. The main roots form a number of secondary roots that branch into many rootlets, which help the plant absorb nutrients from the soil. The growing root is initially yellowish white in colour and gradually turns light brown and subsequently becomes reddish-brown with age. The tender growing tip of the root is protected from injury by a root cap. The rootlets, however, are short lived and are frequently replaced. From the main roots and rootlets, numerous pneumatophores develop, facilitating gaseous exchange between the roots and the atmosphere.

Stem

The coconut palm has a single, straight stem, greyish in colour, culminating in a crown of leaves. The palm has a single terminal bud that produces a succession of leaves and is well protected by the young unopened leaves. The stem is marked by leaf scars. The thickness of the stem is determined by the environment, in addition to varietal differences. In certain varieties, the base of the stem is swollen and is referred to as the bole. The stem of the coconut palm becomes visible once the bole reaches the full stage of its development. In the initial years, the stem gradually becomes thick and once the maximum size is reached, there is no further appreciable change in the girth of the stem. The length of the stem is determined by the age of the palm, variety, environmental conditions and cultural practices. Dwarf varieties have shorter trunks than tall varieties. Palms under excessive shade and very close planting exhibit rapid stem elongation. In rare instances, branching of coconut palms is observed, due to damage to the terminal bud, and up to five branches have been reported.

The stem of the coconut palm, being more fibrous in nature, combines stiffness with flexibility and hence is capable of withstanding a good amount of lateral strain, even when exposed to severe winds/cyclones.

Leaf

The top of the coconut palm bears a crown of leaves, comprising of opened leaves as well as unopened leaves in various stages of development surrounding the growing terminal bud. The number of leaves in the crown varies with the variety, growing environment and management. An adult palm normally has about 25-35 opened leaves on the crown. Once the leaf emerges, it has an average life span of about 2-3 years.

The leaves are long, measuring about 3-6 m in length depending on the variety, age of the palm, vigour of the tree and environmental and management conditions. In general, tall varieties have longer leaves, while dwarfs have relatively shorter leaves. The individual leaf consists of a strong petiole, extending to form a rachis with numerous leaflets inserted on either sides of the rachis. The petiole accounts for about one-fourth of the total length of the leaf, but varies with the variety. A short and stout petiole is able to better withstand vertical pressure exerted by the developing bunch in its axil. The number of leaflets in a mature leaf ranges from 150 to 250. The first leaflets at the base are short, followed by a gradual increase in length of the subsequent leaflets with the maximum length being achieved at about one-third of the midrib followed by a gradual decline in length towards the top of the leaf.

The midrib of the leaflet is a very strong structure. The stomata are first formed about a year prior to the emergence of the leaf. Stomata are confined to the lower surface of the leaflets, are elliptic with two guard cells containing large starch grains and a small opening. Normally, a leaflet contains about 170-220 stomata/mm^2. Stomatal density is a varietal character and higher density has been reported in dwarfs than in tall varieties.

The young leaves have stipules at their bases, which tend to form a fibrous sheath that more or less encompasses the trunk. As the leaf becomes older, the stipules dry and fall away. In some of the young palms, the stipules tend to persist till the leaf dry and fall.

The progression of leaf development from bud to leaf takes several years, and the average time taken from initiation to final abscission is almost five years. Various workers have studied the stages in development of the leaf and sequence of events in differentiation of leaf primordia into adult leaf. The time taken from differentiation of the leaf primordium to emergence from the leaf sheath is almost 28-32 months. Once the leaf emerges, it has an average life span of about 2-3 years. The season and also soil conditions influence the process of leaf maturing and shedding. The rate of leaf opening appears to be more dependent on the temperature rather than the rainfall. Under favourable growth conditions the leaves remain on the crown for longer period, up to three and a half years after emergence. A higher rate of leaf production, coupled with higher number of leaves on the crown has been observed in heavy bearers. Normally, one year old seedlings have about 7-11 leaves depending on the varieties, with majority of them having eight leaves. Generally, the number of leaves on the crown increases up to 28-38 and an adult tree on an average has got about 30 leaves.

The leaves on the coconut crown are arranged in spirals, running either in the clockwise or anticlockwise direction, or in such a way as to ensure maximum light availability to each leaf. Hence, the 6th leaf is located over the 1st leaf, the 11th leaf over the 6th and so on. The spirality in a palm can either be right-handed (bunches hang towards the right of the petiole), or left but remains the same throughout the life of a particular tree. The two types of spirals are distributed almost equally in a population.

Flowers

The coconut palm is monoecious, with male and female flowers borne on the same inflorescence. The inflorescence emerges from the leaf axils, with one inflorescence produced every month from successive leaf axils, in adult palms under favourable conditions of growth. The age at initial flowering varies with the variety and environmental conditions. The inflorescence is at first visible as an oblong flat structure and is referred to as a 'spadix'. Subsequently, when the spadix is fully mature, the spathe ruptures and exposes the inflorescence.

The length of the inflorescence ranges from 60 cm to 200 cm, depending on the variety, age, nutrient status of the palm and the cultural conditions. The central axis is referred to as peduncle and bears about 30-35 spikelets. The spikelets carry numerous male flowers and a few female flowers (generally 1-2, and occasionally more). The female flowers are borne near the base of the spikelets, while the male flowers are closely set, and borne above the female flowers.

All the flowers are sessile/subsessile. A single inflorescence has about 8,000-10,000 male flowers, while the number of female flowers in an inflorescence varies considerably (0-400) depending on the variety, age of bearing, growing environment and management. However, in the spikeless/spicata type of inflorescence, the central axis is unbranched and male and female flowers (with a preponderance of female flowers) are directly borne on the peduncle.

The male flowers are about 8 mm in length and contain six perianth lobes arranged in two whorls and six stamens arranged in a single whorl. In the centre is a rudimentary/abortive pistil. Anthers are normally yellowish in colour and attain a bluish green tinge on maturity. Flowering commences from the distal end of the spikelets and extends downwards. The flowers open throughout the day, but maximum blooming occurs from 8-10 AM. The interval between the opening of the first male flower and the shedding of the last male flower is termed as the male phase and lasts for 18-22 days, varying with the variety, age of the palm, season and cultural conditions.

The female flowers are larger, globular in structure and bracteolate with a diameter of about 13-25 mm. It contains six rounded, concave, imbricate perianth lobes with a staminodal ring at the base and a short style with three stigmas at the centre. Ovary is tricarpellary, syncarpous with a single anatropous ovule in each carpel. However, only one ovule is fertile. Generally, two small, fertile male flowers called accessory or axillary male flowers accompany each female flower. The female flowers remain receptive for 1-3 days after opening. Generally, the female flowers become receptive two to three weeks after the opening of the spathe.

Since the male and female flowers are separate, transmission of pollen from the male flower to the female flower for fertilization has to take place. In an inflorescence, the male flowers mature earlier than the female flowers and shed the pollen. Pollination in coconut palms is effected either through wind or insects. The possibility of cross as well as self-fertilization exists in coconut. If there is time interval between the opening of the last male flower and the opening of the first female flower, there is greater possibility of cross pollination. When there is no gap there is greater possibility of self-pollination. In majority of the tall coconut varieties, the time interval between the end of the male phase and commencement of the female phase is 2-3 days and hence pollination is effected through pollen from neighbouring trees (cross pollination). However in some trees, especially in Dwarf varieties, there is overlapping of the female and male phases in an inflorescence, thereby resulting in self-pollination. Even in the absence of overlapping of the male and female phases in an inflorescence, self-fertilization can occur through overlapping of the male and female phases of successive inflorescences in a palm. In India, chances of inter spadix pollination is reported to be about 22% of the total spadices opened during the year, with maximum possibility in the summer months of March, April and May. Such inter spadix overlapping during the wet season has been reported in Philippines as well as Sri Lanka.

Fruit

The fruit of the coconut palm is a drupe, commonly referred to as the 'nut'. It contains an internal endosperm referred as kernel with embryo embedded in it and protected externally by a thick pericarp. The pericarp has three distinct regions, the outer exocarp/ epicarp, middle fleshy mesocarp and hard endocarp.

The fruit starts developing upon fertilization of the female flowers. During the course of development, a large number of female flowers shed, leaving only a few on the bunch. The young fruits are initially yellowish in colour, but turn green, yellow or red (depending on the variety) on exposure to light. On reaching complete maturity, the fruits turn brown. The developing fruit attains its maximum size and weight about six months after pollination and remains so for another two months. Subsequently, there is a drastic reduction in fruit weight along with a slight decrease in the size of the fruit, due to loss of water.

The solid endosperm (kernel) begins to develop when the nuts are about six months old, and appears as a thin watery lining on the shell at the basal end, away from the eyes. As the endosperm formation increases, the meat at this end thickens and subsequently hardens. The solid endosperm reaches its maximum thickness when the nuts are around nine months old. The fruits are ready for harvest 10-12 months after pollination, depending on the variety.

The fruit of the coconut palm contains an internal endosperm with embryo embedded in it and protected externally by a thick pericarp. The pericarp has three distinct regions, the exocarp/epicarp, mesocarp and endocarp. The exocarp/epicarp is the outermost layer of the fruit and is a tough fibrous skin, the colour of which varies from green to red to yellow to brown, depending on the variety. The mesocarp is the fleshy portion immediately beneath the epicarp (husk). In the tender fruit, this has an astringent taste but in rare instances, it is sweet and edible. As the fruit matures, this region becomes more fibrous. The thickness of the mesocarp varies from 2 cm to 15 cm, depending on the variety. Immediately below the mesocarp is the endocarp, which develops into a hard shell as the fruit matures. The shell, on its basal side has three pores (eyes) representing the three carpels of the ovary. One of the eyes is soft while the other two are quite hard. The fibre over the soft eye is generally softer and less compact than elsewhere in the fruit. The seed/kernel is present beneath the hard shell and is therefore well protected. The thickness of the endosperm (meat) generally is around 1.3 cm. However, depending on the variety this may vary from 0.8 to 2.0 mm. The embryo is situated below the soft eye. In between the endocarp and the albuminous endosperm is a thin layer of testa/seed coat. The testa is brown in colour and adheres to the endosperm. In the middle of the endosperm is a cavity filled with sweet water and referred to as the liquid endosperm. In the unripe fruit, this central cavity is completely filled with water. However, as the fruit ripens, the quantity of water reduces gradually and gets completely absorbed by the nut on storage for a few months, after harvest. Once the nut water is exhausted, the ability of the fruit to germinate is lost.

Variability

The coconut palm, in spite of being a monotypic species with no known wild relatives, exhibits considerable variability in forms with several distinct populations and ecotypes, widely differing from each other in morphological characters, particularly with respect to plant habit and fruit characters.

Plant habit

Coconut palms are broadly classified into two groups based on plant habit viz., the talls and the dwarfs. Tall palms are the most commonly cultivated in all coconut growing regions of the world. Tall palms grow to a height of 20-30 m, have a sturdy stem, commence flowering 6-10 years after planting and continue bearing up to the age of 80-100 years. Tall palms are normally cross-pollinated and hence highly heterozygous. The fruits are generally medium to large in size and produce good quantity and quality of copra with fairly high oil content. Among the indigenous tall cultivars, West Coast Tall, East Coast Tall, Benaulim Tall, Tiptur Tall, Andaman Ordinary Tall and Laccadive Ordinary Tall are popular. Some popular exotic tall cultivars are Fiji Tall, Philippines Ordinary Tall, Sri Lankan Tall, West African Tall, Panama Tall, Malayan Tall, Jamaican Tall and San Ramon Tall.

Dwarf palms have gained importance in recent times due to tender nut qualities and resistance to certain diseases. They are of shorter stature, 8-10 m high when 20 years old and start bearing about 3-4 years after planting and have a short productive life of about 40-50 years. The dwarf palms are more homozygous than talls, due to a high degree of self pollination. They produce fruits, which are generally small to medium in size. The dwarfs are presumed to have originated from talls either through mutation or by inbreeding or by both. The popular dwarf cultivars grown in India are Chowghat Green Dwarf, Chowghat Orange Dwarf, Kenthali Orange Dwarf and Gangabondam Green Dwarf.

Among the exotic dwarf cultivars, Malayan Yellow Dwarf, Malayan Orange Dwarf and Malayan Green Dwarf have become popular in all coconut growing countries of the world.

The tall and dwarf types have been utilized for development of hybrid varieties, combining the early flowering trait of dwarfs with the hardiness and high yielding character of tall parents and also exploiting hybrid vigour.

Fruit characters

Considerable diversity is observed in the size, shape and colour of fruits of coconut palm. The colour of the fruits varies from yellow, shades of green and brown to red (orange). The variations in shapes of the coconut fruit are broadly classified as round, oblong or elliptic. Further, based on the equatorial view, the shape of coconut fruits can be classified as angled, round or flat based on the curvature of the fruit and the presence of ridges on the fruit. Variations are recorded in shape of the nut inside the fruit and these are broadly categorized as round, oval and oblong.

Grouping of varieties

Plant habit, fruit colour and other fruit characteristics are presently the most convenient for grouping of the varieties. In most cases, the size of the fruit is genetically determined and not solely the effect of environment. However, further refinements of this technique can be undertaken for a more fool proof classification system. Molecular marker studies have classified the present day coconut populations into two major groups: the Pacific group with five sub-groups (Southeast Asia, Melanesia, Micronesia, Polynesia and the Pacific coast of Central and South America) and the Indo-Atlantic group. The Pacific group includes the domesticated coconut while the Indo-Atlantic group, includes NiuKafa (wild) coconut types. However, human intervention through migration and cultivation has brought the different forms together and the resulting opportunity for cross pollination has allowed the development of intermediate forms through introgression.

Harries (1978) put forth a method for classification of coconut varieties as NiuKafa and NiuVai, on the basis of fruit characters and seed-germination traits. NiuKafa and NiuVai types of coconuts were suggested to denote wild and domesticated coconuts, respectively wherein NiuKafa fruits are thick husked, angular and lengthy with smaller inner cavity and late seed germination while NiuVai fruits are round or oblong having large inner cavity and early seed germination. Harries did not include the dwarf varieties under NiuVai and NiuKafa types as these evolved much later and can survive only under cultivation.

In addition to the variation described above, variation in coconut endosperm texture and quality has been reported in natural coconut populations. One such is the Makapuno type from the Philippines where the endosperm is buttery soft and almost fills the nut cavity and is used in delicious preparations. Similar soft endosperm types are reported from other coconut growing areas also. In India these types are called ThayirThengai and have been reported from Andaman Islands. Besides, sweet kernel type called Mohacho Narel and sweet tender husked type called Kaithathali have also been reported from India and are conserved in field gene banks. Another variant is the aromatic coconut, wherein the tender nut water and solid endosperm have a pleasant aroma, similar to the scented rice aroma, as seen in the Klapawangi of Malaysia, Aromatic Dwarf of Philippines, Nam-hom of Thailand, Aromatic Green Dwarf of Philippines, etc. A few other exceptional types are: palms producing thick shelled nuts (Poropol of Sri Lanka, Tutapaen of Philippines, thick shelled types observed in India, China, Indonesia etc.), thin husked fruits (Kelapa Bawang/Onion Coconut of Indonesia, Lupison of Philippines) and pink husked fruits (Ran Thembili of Sri Lanka, Guelle Rose of Mauritius, pinkish mesocarp types observed in India, China, Fijiand Indonesia, etc.). Another oddity in coconut is the persistence of leaf bases and inflorescences, as seen in certain other palm species like Palmyra palm. These types are known to occur in many different coconut populations.

Besides these, a number of abnormalities have been reported from different coconut growing regions. These abnormalities, listed below, are freaks of nature and not distinct varieties, from the botanical point of view. The abnormalities include variations in stem (polyembrony, branching, suckering), vegetative parts (albinism, rosette seedling, chimera, fused leaflets/plicata, forked leaves, twin leaves, fused leaves, multi-leaf type), inflorescence (double spadix, multispathe, partial suppression of spikes, secondary branching of spikes, unbranched spikes, fasciated spikes, foliation of the spadix, terminal inflorescence, vivipary), flower (hermaphrodite flower, variation in number of pistillodes, stamens and perianth) and fruits (horned nuts, double ovary, mono, bi and tetracarpic fruits).

Uses of coconut

Coconut serves humanity by providing each and every part for one or the other uses. It is used as source of food, medicine, nutrition, toiletries and cosmetics. In addition, it provides construction materials, innumerable products from coir and activated carbon from shell. The parts and their contribution to various uses are discussed below.

The root has medicinal properties and can be used to treat gall bladder and urinary infections as well as kidney related diseases. It is useful for treating eczema and fibrosis. It helps melt clotted blood. The roots can also be used to treat heartburns. Coconut trunk is a time tested building material used as timber to make houses, boats, bridges and canoes. The treated coconut wood is used for making furniture. Coconut leaves are used as a thatching material, used to wrap rice for storage, used to make toys, used to make decorative crafts and to make brooms. Toothpicks are made out of the midribs of the leaflets. Coconut leaves are also used to produce good quality paper pulp, hats and mats, fruit trays, fans, lamp shades, bag,and utility roof materials.

Coconut spathe is traditionally used to make caps and handbags. The whole inflorescence is used to prepare decoction that has medicinal properties. Coconut inflorescence is also used to produce neera by incising and tapping. The fermented neera is known as toddy or tuba (Philippines) or tuak (Indonesia and Malaysia). Fermented neera or toddy is distilled to produce arrack. In the Philippines, this alcoholic drink is called lambanog or 'coconut vodka'. The inflorescence sap can be reduced by boiling to create a sweet syrup or candy. It can be reduced further to yield coconut sugar also referred to as palm sugar or palm jaggery.

Coconut fruit has different layers like outer husk, middle shell and inner endosperm that is both liquid and solid. Each one of these layers has various uses to mankind. Coconut liquid endosperm or coconut water can be used as tender coconut water when it is from 6-8 month old coconut fruit. Tender coconut water is a health drink used by man from prehistoric times. It is a good source of sugar, fibre, antioxidants, proteins, vitamins and minerals making it a popular sports drink providing energy, hydration and endurance. It helps restore any electrolyte imbalances caused by diarrhea, vomiting and after exercising. It is the only natural liquid that can be directly administered intravenously due to its ability to mix with blood. It is attributed to have antiseptic, antibacterial, anti-fungal, and anti-viral properties. It is used to replace lost fluids in cases of influenza, typhoid, malaria, and is said to dissolve kidney stones. Mature coconut water is used to produce vinegar. It is also used to make *nata de coco*, a jellylike food.

Mature endosperm is the source of coconut oil, desiccated coconut, coconut milk and coconut chips. In addition to the common use in cooking, coconut oil is used in medicine and cosmetics and as lubricant. Cosmetic uses of coconut oil are as natural skin softener and moisturizer. It reduces fine lines, puffiness and dark circles under the eyes, it prevents skin infections, it has anti-wrinkle properties, it soothes sunburn and treats blisters and burns. It improves skin tone, elasticity and age spots. It conditions hair, prevents split-ends and treats dry flaky scalp including dandruff.

Coconut oil is attributed to have many medicinal uses. It eases acid reflux and gives relief in gall bladder disease, stabilizes blood sugar levels and insulin production, kills viruses causing flu and other infectious diseases, protects against cancers in the colon, breast and digestive tract, protects against intestinal disorders, reduces pain and inflammatory conditions such as arthritis, strengthens liver, protects against Alzheimer's disease, improves calcium and magnesium absorption promoting strong bones, helps stabilize female hormones and prevents hot flushes and vaginal dryness during menopause. Coconut milk is another product from endosperm that has many uses. It is used in a variety of ways in seafood dishes and in baking instead of animal fat. Coconut milk is used regularly, nearly as a staple ingredient in Southeast Asia and forms the base of curries. It is used to make a home brew in Rendell Island (Solomon Islands) where it is fermented with sugar and yeast and left for a week. The milk can be used to produce virgin coconut oil by controlled heating and collection of the oil fraction. The coconut meat or the fresh endosperm is eaten and used fresh. The meat is used in deserts and confectioneries. It is also an essential ingredient for many curries and savory dishes throughout the world.

Other delicacies from coconut include palm cabbage and haustorium. Apical buds of adult plants known as 'palm cabbage' or heart of palm are edible. They are considered a rare delicacy, as harvesting the buds kills the palms. Hearts of palm are eaten in salads, sometimes called 'millionaire's salad'. Coconut haustorium, a spongy absorbent tissue formed from the distal portion of the embryo during coconut germination, is also edible.

Coconut shell is the strongest part in coconut fruit and it covers endosperm. The shell is used to produce various handicrafts. Coconut shells are also used to make charcoal which is used as fuel and is far better than other charcoals. Coconut shell charcoal is widely used to produce activated carbon. Coconut shell charcoal is widely used in purification industry and other industries.

Coconut husk is the source of coir which is the most industrially used part. Coir is the fibre on the husk and is used to make ropes, door mats, potting compost, mattress stuffing, brushes, mats, rugs and sacks and as joint sealer for boats (caulking).

The coconut palm is grown throughout the tropics and defines the landscape of many regions in the world adding value to the environment. It is known all over the world for its many culinary and other uses; virtually every part of the coconut palm can be used in some manner or the other and has significant economic value. Coconuts' versatility is sometimes noted in its naming. In Sanskrit, it is 'kalpavriksha' (the tree which provides all the necessities of life). In the Malay language, it is 'pokokseribuguna' (the tree of a thousand uses). In the Philippines, the coconut is commonly called the 'tree of life'.

Biology and cultivation of arecanut

N.R. Nagaraja[1], K.S. Ananda[1] and M.K. Rajesh[2]
[1]ICAR-Central Plantation Crops Research Institute, Regional Station, Vittal - 574243, Karnataka, India.
[2]ICAR-Central Plantation Crops Research Institute, Kasaragod - 671124, Kerala, India.

Arecanut (*Areca catechu* L.) is one of the important commercial crops of South India, Konkan, Andaman & Nicobar group of Islands and North Eastern Region of India. In the world arecanut is mainly grown in India, China, Myanmar, Bangladesh, Indonesia, Sri Lanka and Thailand. Other countries where arecanut is grown are Bhutan, Nepal, Malaysia, Kenya, Maldives etc. India ranks first in the world both in area and production of arecanut. India is not only the largest producer but also the largest consumer of arecanut and it continues to dominate. India has nearly 50 percent of world arecanut area and contributes more than 56 percent of world production. As per the statistics available, In India arecanut is grown in an area of about 4.72 lakh hectares with production and productivity of 7.35 lakh tonnes and 1558 kg/ha in 2015-16.

In our country arecanut is mainly grown in Karnataka, Kerala, Assam, Meghalaya, West Bengal and Mizoram for its masticatory nuts popularly known as ‘betlenuts’ or ‘supari’. Arecanut is also grown in other states like Andra Pradesh, Goa, Maharashtra, Tamil Nadu, Nagaland, Tripura, Pondicherry etc. Three Indian states namely, Karnataka, Kerala and Assam produce more than 85 percent of our countries’ production. Arecanut plays a prominent role in the religious, social, cultural and economic life of people in India.

Arecanut, along with several other ingredients, is being chewed by many in several countries as it is believed to have numerous medicinal values. It has an important place in the alternate system of medicine such as Ayurveda, Unani and Homeopathy and in clinical practices in certain other countries such as Philippines, China and other South and South East Asian countries. The World Health Organization has listed out as many as 25 beneficial effects of *A. catechu*. It has also been reported that all the alkaloids present in arecanut possess drug like properties. Most of the folk medicinal properties of arecanut are now validated and authenticated with proper scientific data. It has antioxidant, anti-inflammatory, analgesic, anti-diabetic, hypolipidemic, antibacterial, anti-fungal, anti-malerial, anti-viral, anti-HIV and AIDS, anti-aging, memory improvement, wound healing, anti-ulcer, anti-migraine, antihypertensive, anti-depressant, anti-allergic, anthelmintic, aphrodisiac, hepatoprotective and cyto-protective effects. Arecanut plant parts are used for the preparation of household and other articles such as cups, plates, ply boards, hard boards, hats, etc. Arecanut extracts are used for preparation of areca tea, soap, wine, etc. Arecanut leaf sheath is also used as alternate fodder for livestock.

Arecanut (*Areca catechu* L.) is a monocot belonging to the tribe Arecae and subtribe Arecinae in the Arecaceae family. The palm is an unbranched, erect, medium-sized, monoecious tree growing in hot and humid tropical regions of the world and its center of origin is considered to be South East Asia. The Areca palm, which is highly cross-pollinated, is an allotetraploid with chromosome number 2n=32. The genus *Areca* includes 76 species, *A. catechu* being the only cultivated species. It has been observed that there is a wide range of variation existing in plant morphology, size, shape and colour of fruits between the different areca growing regions and between different palms/ accessions of the same region.

Arecanut cultivation is mostly confined to 28º North and South of the equator. It grows well within the temperature range of 14ºC to 36ºC and is adversely affected by temperatures below 10ºC and above 40ºC. It can be cultivated up to an altitude of 1000 m above MSL in deep and well drained soils with low water table. Due to its susceptibility to low temperature, the palms do not come up at an altitude of more than 1000 m above MSL. Arecanut requires abundant and well distributed rainfall. Heavy rainfall and high relative humidity are the major constraints for arecanut cultivation in humid tropics. Heavy rainfall leads to leaching of potassium and calcium, while high relative humidity is congenial for development of pests and diseases. Arecanut is predominantly grown in gravelly laterite soil of red clay type and it can also be grown in fertile clay loam soils with special care of microsite improvement. Laterite, red loam and alluvial soils are more suitable for arecanut cultivation. Sticky clay and sandy, brackish and calcareous soils are not suitable for areca cultivation.

Planting material production

Arecanut is propagated by seeds. Being a perennial and cross pollinated crop, adequate care should be taken in selecting the planting material.

Selection of mother palms

Mother palms should be of more than 12 years age, regular bearers with early bearing nature (36-40 months after planting), with partially drooping or drooping crown with higher number of leaves (>10) and shorter internodes, with high fruit set (>55% set) with around 350-400 fresh nuts/ palm/year, with consistent yield of about 3 kg or more dry kernel (chali)/palm/year, with high recovery of chali from fresh fruit (>25%) and free from pest and diseases incidences. Mother palms are selected based on the requirements for processing, chali or tender nut.

Selection of seed nut

Seed nuts of three different types are preferred for seedling production viz., inter se, hybrid and open pollinated.

Inter se: Seed nuts produced after emasculation and pollination by using the pollen of selected palms of the same cultivar/ variety.

Hybrid: Seed nuts produced after emasculation and pollination between two different desired parents.

Open pollinated: Seed nuts harvested from selected mother palms of the desired cultivar/variety without any artificial emasculation (removal of male flowers) and pollination.

Fully ripened heavy nuts weighing more than 35 g will give better germination than lighter nuts and give more number of quality seedlings. The mature nuts should be harvested when at least a few nuts in the oldest bunch start falling. Normally it takes 11-12 months to become a mature seed nut after pollination. Rope harvest of seed nuts is recommended from trees which are very tall and in places where the ground is hard. The nuts, which float vertically with calyx end pointing upwards in water will produce more vigorous seedlings. Harvested seed nuts can be stored only for about 3 to 6 days since the nuts are recalcitrant, i.e., viability will be lost soon.

Nursery techniques in arecanut

Primary nursery

Sowing the nuts immediately after harvest in soil/sand and watering will result in early and good germination. Selected seed nuts are sown with their stalk end pointing upwards, 5 cm apart in sand beds of 1.5 m width and convenient length. Thick mulching is to be done with straw/ areca leaves. Beds are to be watered daily either by using hose or microsprinklers. Germination of nuts usually commences by 43 days and gets completed by 94 days.

Secondary nursery

For raising the seedlings in secondary nursery, beds of about 1.5 m width and 15cm height are suggested. A spacing of 30-45 cm is considered optimum for planting three months old sprouts in secondary nursery and repotting in poly bags is also preferred. The secondary nursery should be given a basal dose of decomposed farmyard manure or vermicompost @ 5 tonnes per ha. The nursery should be partially shaded to get good seedlings.

Polybag nursery

Seed nuts may be sown directly in poly bags of 6"x9" size and 250 gauge thickness, with holes for drainage. Potting mixture should be of Soil: FYM: Sand in the ratio 7: 3: 2. Well decomposed farm yard manure or vermicompost and sieved sand should be used for potting mixture preparation. Solarization of soil by covering with black polythene sheet and sun drying of potting-mixture for one week may be practiced to avoid any soil borne diseases. Daily watering during rainless period is needed to ensure desired growth.

Selection of seedlings

Seedlings of 1-1.5 years of age having six or more leaves (early leaf splitting), 90 cm height and 26 cm collar girth should be selected. Seedlings having more than 5 nodes after two years are the best seedlings to get better yield. The seedling should have well established root system with 5-8 main fibrous roots intact and active while transplanting. The seedlings have to be uprooted with a ball of earth adhering to roots if they are raised in nursery bed. Seedlings should be free from pests and diseases. Polybag seedlings are preferred for long distance transport. Care should be taken to prevent damage/breakage of seedlings at the collar region during transportation.

An area of 4,000 square meters is required to maintain 50,000 seedlings. Areca sprouts and seedlings are very delicate and do not withstand exposure to direct sunlight. Hence, proper shade should be provided to the nursery. The shade may be either of coconut or arecanut leaves spread over a pandal or by covering with 50-75% shade net (green or black) or by planting some fast growing green manures or banana around the nursery. The nursery should be watered regularly during summer and proper drainage should be provided during rainy season. Periodical weeding and mulching is required. Nursery can be raised in the interspaces of coconut plantation and also in widely spaced arecanut gardens. Sprinkler/micro-jet/hose irrigation systems are well suited to arecanut nursery beds/polybag seedlings.

Crop Improvement

In India, systematic germplasm collection of arecanut from within and outside the country began in 1957 and screening them under uniform conditions was initiated at the ICAR-Central Plantation Crops Research Institute (CPCRI) Regional Station, Vittal. The present germplasm holding at ICAR-CPCRI Regional Station, Vittal is 176 accessions. Out of these 153 are indigenous eco-types of arecanut collected from different parts of India and 23 are exotic accessions introduced from Fiji, Mauritius, China, Sri Lanka, Indonesia, Saigon, Singapore, British Solomon Islands and Australia and the germplasm represents four species viz., *Areca catechu* L. *Areca triandra* Roxb., *Normanbya normanbyii* and *Actinorhytis calapparia*. The indigenous collections are from Gujarat, Maharashtra, Karnataka, Assam, Kerala, West Bengal, Tamil Nadu, Meghalaya and Andaman & Nicobar.

Identification and release of varieties

Increase in arecanut production over decades was not only due to increased area under cultivation but also increased pro¬ductivity contributed by superior varieties, supply of quality planting materials, better agro-techniques and plant protection measures. Evaluation of available arecanut cultivars for their performance under different ecological conditions is a promising method of obtaining genotypes suited for the different regions of India. But arecanut palm is more sensitive to moisture stress than coconut and therefore its cultivation is restricted to areas with well-distributed rainfall or assured irrigation facilities. Based on the comparative yield trials of indigenous and exotic accessions, promising cultivars were selected and released as varieties for commercial cultivation.

The evaluation of exotic accessions and selection for high yield and its attributes, resulted in release of Mangala (introduced from China), Sumangala (introduced from Indonesia), Sreemangala (introduced from Singapore) and Swarnamangala (introduced from Vietnam). Evaluation of indigenous accessions resulted in the release of high yielding varieties like, Mohitnagar, Samrudhi, Sirsi Arecanut Selection-1, Kahikuchi, Madhuramangala, Nalbari and Shatamangala with high yield potential. Two dwarf hybrids namely VTLAH-1 (Vittal Arecanut Hybrid-1) and VTLAH-2 (Vittal Arecanut Hybrid-2) were also released. Most of these varieties/hybrids viz., Mangala, Sumangala, Sreemangala, Swarnamangala, Mohitnagar, Kahikuchi, Madhuramangala, Nalbari, Shatamangala, VTLAH-1 and VTLAH-2 were developed and released by ICAR-Central Plantation Crops Research Institute (CPCRI). Samrudhi was developed and released by ICAR-Central Island Agricultural Research Institute, Port Blair and ICAR-Central Plantation Crops Research Institute. University of Agricultural Sciences, Dharwad was responsible for release of Sirsi Arecanut Selection-1.

Hybridization in arecanut

In arecanut, hybridization starts with removing the portion of rachillae having male flowers (emasculation) soon after emergence of the inflorescence and covering the spadix bearing female flowers with a cloth bag. When the female flowers open, anthers from the desired male parent is rubbed against the stigma or the pollen is dusted on the stigmatic surface, by removing the bag. The bag is replaced over the inflorescence immediately after pollination. The process is repeated daily for about a week till all the female flowers in the spadix open and fruit set can be seen after 20 days. In artificial pollination, fully opened male flowers are collected from the selected palms and are transferred to a reagent bottle containing 0.5 per cent solution of sucrose and the bottle is shaken gently. The pollen grains thereupon get released in the aqueous solution. The solution with the pollen grain in suspension is transferred to an ordinary hand atomizer and sprayed onto newly opened female flowers. The spraying may have to be done three to four times, as all the female flowers do not open at the same time. About 14 per cent increase in fruit set was obtained by this method and the same could be successfully used in commercial hybridization.

Dwarf hybrids of arecanut

Though tall varieties possess high yield potential, they are frequently prone to sun scorching, wind damage and also become difficult to manage. The tall nature of the palm hinders various operations like spraying and harvesting which are quite labour intensive and cumbersome. Arecanut breeding programmes are aimed at development of dwarf arecanut varieties/hybrids in addition to yield improvement. Hirehalli Dwarf (HD) a natural mutant identified in 1963, for its short stature is a good genetic source for arecanut improvement. Dwarf hybrids with high yield potential will directly benefit the growers by way of enhanced returns and reduced cost of various cultural operations like harvesting and spraying. Damages to palms due to sun-scorching and heavy wind will be the minimum. Therefore, the exploitation of dwarfing genes in breeding dwarf varieties with high yield potential was initiated. Hybrids involving Hirehalli Dwarf (HD) and released tall varieties as parents were developed and evaluated for yield performance and dwarfness. Among the hybrids, HD x Sumangala and HD x Mohitnagar were identified as superior for yield with dwarfness and recommended for commercial cultivation as VTLAH-1 (Vittal Arecanut Hybrid-1) and VTLAH-2 (Vittal Arecanut Hybrid-2), respectively.

Biology and cultivation of black pepper, the king of spices

B. Sasikumar

Former Principal Scientist & Head, Crop Improvement & Biotechnology Division, ICAR- Indian Institute of Spices Research, Kozhikode, Kerala- 673012, India.

Black pepper (*Piper nigrum* L.) (Family: *Piperaceae*) is a perennial climbing vine grown for its berries, extensively used as spice and in medicine, often referred to as 'King of Spices' or 'Black Gold'. Black pepper has immensely influenced the geopolitical history of the world as it was a much sought after commodity since very ancient days. An essential condiment in the western and eastern cuisines as food additive and preservative, black pepper was highly priced and frequently used to pay rent, tax and even dowry. Black pepper has been an integral part of the traditional medicines of the orient also.

Origin and distribution

Black pepper is native to the Western Ghats of India, where it still occurs wild in the forests. This area is considered to be the centre of origin of the crop. Center of diversity of the crop is also in this tract as cultivated forms are very high in number here and it is believed that black pepper spread out to other tropical countries from India. The major black pepper growing countries at present are India, Indonesia, Tropical Africa, Malaysia, Thailand, Brazil, Sri Lanka, Vietnam and China. Vietnam is the leading producer currently.

In India black pepper is grown in about 129,000 ha with an annual production of 55,000 MT (2015-16). Kerala, Karnataka and Tamil Nadu and to a limited extent Maharashtra, Assam, Tripura, Arunachal Pradesh, Meghalaya and Andaman Nicobar are the black pepper growing states/regions in India. Kerala and Karnataka account for a major portion (97.7%) of production of black pepper in the country.

Climate and soil

Black pepper prefers humid tropics with high rainfall and humidity. The hot and humid climate of sub mountainous tracts of Western Ghats is ideal for its cultivation. It grows successfully between 20° North and South latitudes, and from sea level up to 1500 m above sea level with temperatures between 10°and 40° C and a well distributed annual rainfall of 1250-2000 mm. Black pepper can be grown in a wide range of soils with a pH of 4.5 to 6.5. In its natural habitat it thrives well in red laterite soils.

In India, black pepper is being grown either as a homestead crop in the plains or as a plantation crop in the midlands and hills (800-1500 m) besides in valleys in the north eastern states of the country.

Varieties and crop improvement

Over 75 cultivars of black pepper are being cultivated in India. The most important cultivars are *Karimunda* (all over Kerala), *Kottanadan* (South Kerala), *Narayakodi* (Central Kerala), *Aimpiriyan* (Wayanad), *Neelamundi* (Idukki), *Kuthiravally* (Kozhikode and Idukki), *Balancotta*, *Kalluvally* (North Kerala), *Malligesara* and *Uddagare* (Karnataka). Self grown seedlings also contribute to cultivar diversity in black pepper. A few important cultivars and their salient features are given below.

Most of the cultivated black pepper varieties are monoecious while in the wild they are dioecious. Cultivated black pepper is predominantly self-pollinated (geitonogamy). Even though protogyny occurs in black pepper, it is ineffective in preventing selfing.

Selections (germplasm, clonal and open pollinated) and hybridisation are the important breeding strategies adopted in improving black pepper. Viable sexual reproduction coupled with excellent mode of vegetative multiplication is a boon in the improvement

Important cultivars of black pepper

Cultivar	Fresh mean yield (kg/vine)	Quality attributes				Features
		Oleoresin (%)	Piperine (%)	Essential oil (%)	Dry recovery (%)	
Aimpirian	4-5	15.7	4.7	2.6	34	Good for higher elevations, good in quality, late maturing
Arakulan munda	2	9.8	4.4	4.7	33	Moderate and regular bearer
Balankotta	1-2	9.3	4.2	5.1	35	Moderate and irregular bearing
Karimunda	2-3	11.0	4.4	4.0	35	Suitable for all pepper growing areas, high yielder, shade tolerant.
Kalluvally	1-2	8.4-11.8	2.5-5.4	3.0	35-38	Good yielder with high dry recovery, drought tolerant
Kottanadan	5	17.8	6.6	2.5	34-35	High yielding, drought tolerant
Kuthiravally	3	15.0	6.0	4.5	35	High yield, good quality
Narayakodi	1-2	11.0	5.4	4.0	36	Moderate yielder with medium quality
Neelamundi	2	13.9	4.6	3.3	33-34	Good yielder, tolerant to *Phytophthora* infection
Vadakkan	3	10.8	4.2	3.2	-	Medium quality and yield

Improved varieties of black pepper

Variety/ Hybrid	Pedigree	Mean yield (dry) (kg/ha)	Dry recovery (%)	Piperine content (%)	Oleoresin content (%)	Essential oil content (%)	Features
Panniyur -1	Hybrid between *Uthirankotta* x *Cheriyakaniakadan*	1242	35.3	5.3	11.8	3.5	Not suited to heavily shaded areas
Panniyur -2	Selection (Col. 141) from cv. *Balancotta*	2570	35.7	6.6	10.9	-	Shade tolerant
Panniyur -3	(KAU) Hybrid (Cul. 331) *Uthirankotta* x *Cheriyakaniakadan*	1953	27.8	5.2	12.7	-	Late maturing
Panniyur -4	Selection from *Kuthiravally*	1277	34.7	-	9.2	-	Stable yielder
Panniyur -5	Open pollinated progeny selection from *Perumkodi*	1098	-	5.5	12.3	3.8	Tolerant to shade
Panniyur -6	Clonal selection from *Karimunda*	2127	32.9	4.9	8.3	1.3	Suited to all black pepper tracts
Panniyur -7	Open pollinated progeny selection from *Kuthiravally*	1410	33.6	5.6	10.6	1.5	Suited to all black pepper tracts
Panniyur -8	Hybrid (HB20052), Panniyur 6 x Panniyur 7	1365	39.0	5.7	12.2	1.2	High yielding, and tolerant to diseases
Panniyur-9	Open Pollinated Progeny Selection	3150	40.0	6.11	12.71	5.0	Suited to Kerala, Karnataka and Andhra Pradesh
Vijay	Panniyur 2 x *Neelamundi*	-	-	-	-	-	Field tolerant to foot rot disease
Subhakara	Selection from *Karimunda* (KS-27)	2352	35.5	3.4	12.4	6.0	Suited to all black pepper tracts

Variety/ Hybrid	**Pedigree**	**Mean yield (dry) (kg/ ha)**	**Dry recovery (%)**	**Piperine content (%)**	**Oleoresin content (%)**	**Essential oil content (%)**	**Features**
Sreekara	Selection from *Karimunda* (KS-14)	2677	35.0	5.3	13.0	7.0	Suited to all black pepper tracts
Panchami	Selection from *Aimpiriyan* (Coll. 856)	2828	34.0	4.7	12.5	3.4	Late maturing
Pournami	Selection from *Ottaplackal* (Coll. 812)	2333	31.0	4.1	13.8	3.4	Tolerant to root knot nematode
PLD -2	Clonal selection from *Kottanadan*	2475	-	3.3	15.5	3.5	Suited to Thiruvana-nthapuram and Kollam districts of Kerala
IISR Shakthi	Open pollinated progeny of *Perambramundi*	2253	43.0	3.3	10.2	3.7	Tolerant to *Phytophthora* foot rot.
IISR Thevam	Clonal selection of *Thevamundi*	2481	32.0	1.65	8.15	3.1	Tolerant to *Phytophthora* foot rot; Suited to high altitudes and plains
IISR Girimunda	Hybrid between *Narayakodi* x *Neelamundi*	2880	32.0	2.2	9.65	3.4	Suited to high altitudes
IISR Malabar Excel	Hybrid between *Cholamundi* x Panniyur-1	1440	32.0	4.95	14.6	4.1	Suited to high altitudes; rich in oleoresin
Arka Coorg Excel	OP seedling selection	3267	37.8	2.1	6.9	1.6	High yielding with long spike.

of black pepper. Barring *Vadakkan* which is a triploid, almost all other black pepper cultivars are diploid (2n=52).

Twenty improved varieties of black pepper have been released for cultivation (Table 2) in India. Panniyur-1 and Panniyur-3 are hybrids evolved at the Pepper Research Station, Panniyur (Kerala) and have *Uthirankotta* and *Cheriyakaniakadan* as their female and male parents, respectively. Vijay is another hybrid developed by the College of Horticulture, Thrissur, India. IISR Girimunda and IISR Malabar Excel are the two hybrids released from the ICAR-Indian Institute of Spices Research, Kozhikode. In the case of Girimunda the female and male parents are *Narayakodi* and *Neelamundi* while *Cholamundi* and Panniyur I are the female and male parents of Malabar Excel.

Propagation

Though seeds are viable, black pepper is mainly propagated using rooted cuttings. Runners and orthotrops (top shots) are used for generating rooted cuttings. Rooted plagiotrops or fruiting branches are bush peppers. Different propagation methods are employed in black pepper.

Traditional method

The runner shoots are separated from the vine during February-March, and after trimming the leaves, cuttings of 2-3 nodes are planted either in nursery beds or in polythene bags filled with potting mixture (Soil, Sand and Cow dung in 1:1:1 ratio).Adequate shade has to be provided and the polythene bags are to be irrigated frequently. The cuttings become ready for planting during May-June. During good rains, direct planting of runner shoots is also done.

Rapid multiplication method

In this method, a trench of 45 cm depth, 30 cm width and convenient length is made. The trench is filled with rooting medium comprising of forest soil, sand and farm yard manure in 1:1:1 ratio. Split halves of bamboo with septa or split halves of PVC pipes of 1.25-1.50 m length and 8-10 cm diameter provided with plastic septa at 30 cm intervals are fixed at 45° angle on a strong support. Rooted cuttings are planted in the trench made earlier at the rate of one cutting for each bamboo split. The lower portions of the bamboo splits are filled with rooting medium (preferably weathered coir dust-farm yard manure mixture in 1:1 ratio) and the growing vine is tied to the bamboo split in such a way as to keep the nodes pressed to the rooting medium. Dried banana leaf sheath fibers or coir fibres are used for tying. The cuttings are irrigated regularly using a rose can. As the cuttings grow on the bamboo splits, the splits are filled with rooting medium and each node is pressed down to the rooting medium and tied. For rapid growth of vines on the bamboo splits, a foliar spray of urea (1 kg), super phosphate (0.75 kg), muriate of potash (0.5 kg) and magnesium sulphate (0.25 kg) in 250 litres of water is to be given @ 0.25 litre per vine at monthly intervals.

When the vine reaches the top of the bamboo splits, (3-4 months after planting of the cutting) the terminal bud is nipped off and the vine is crushed at about three nodes above the base, in order to activate the axillary buds. After about 10 days, the vine is cut at the crushed point and removed from the rooting medium and cut at each node which has striked roots. Each single nodde cutting with the bunch of roots intact is planted in polythene bags filled with fumigated potting mixture. Trichoderma @ 1g and VAM @ 100 cc/kg of soil can be added to the potting mixture. Care should be taken to keep the leaf axil above the soil. The polythene bags should be kept in a cool and humid place and should be covered with thin polythene (200 gauges) sheet to retain humidity. The buds start developing in about three weeks and then the polybags can be removed and kept in shade till main field planting. The advantages of this method of propagation are rapid multiplication rate (1:40), well developed root system, higher field establishment and vigorous growth as a result of better root system.

Trench method

A simple, cheap and efficient technique for propagating black pepper from single nodes of runner shoots taken from field grown vines has been developed at IISR. A pit of 2.0 m x 1.0 m x 0.5 m size is dug under a cool and shaded area. Single nodes of 8-10 cm length with intact leaves are, taken from runner shoots of field grown vines. They are then planted in polythene bags (25 cm x 15 cm, 200 gauge) filled at the lower half with a mixture of sand, soil, coir dust and cow dung in equal proportions. The single nodes are to be planted in the bags in such a way that their leaf axil is exposed above the potting mixture. The polythene bags with the planted single nodes are arranged in the pit in rows. After keeping the bags in the pit, the pit should be covered with a polythene sheet. This sheet may be secured in position by placing weights on the corners. The cuttings should be irrigated at least five times a day with a rose can. Care should be taken to cover the pit with the polythene sheet immediately after each irrigation. The poly bag soil is drenched 2-3 times with copper oxychloride (2g/L).

After 2-3 weeks of planting, the cuttings will start producing roots which are visible through the polythene bags. After the initiation of roots the frequency of irrigation may be reduced to 3-4 times a day. After about 1 month, new shoots start emerging from the leaf axil. At this stage it is advisable to keep the pit open for about one hour per day so that the cuttings would harden and will not dry when they are taken out of the pit. The cuttings can be taken out of the pit after two months of planting and kept in a shaded place and watered twice a day. These cuttings will be ready for field planting after about 2½ months. By this method 80-85% success rate can be obtained. Foliar application of nutrient solution will also enhance the growth of the cuttings.

Serpentine method

Serpentine layering technique can be used for the production of rooted cuttings of black pepper in a cheap and effective manner. In a nursery shed with roofing sheet or shade net, rooted black pepper cuttings are planted in polythene bags holding about 500 g potting mixture, which will serve as mother plants. As the plant grows and produces a few nodes, small polythene bags (20x10 cm^2) filled with potting mixture may be kept horizontally under each node. The node may be kept gently pressed in to the mixture in the bag assuring contact with the potting mixture with the help of a flexible twig such as mid rib of a coconut leaflet. Roots start growing from the nodes and the cuttings keep on growing further. The process of keeping potting mixture filled polythene bags at every node junction to induce rooting at each node is repeated. In three months the first 10 to 12 nodes (from the mother plants) would have rooted profusely and will be ready for harvest. Each node with the ploythene bag is cut just below the rooted node. The cut end is then also buried into the mixture to induce more roots. Polythene bags used are filled with solarized potting mixture fortified with biocontrol agent. The potting mixture is prepared by mixing two parts of fertile topsoil, one part of river sand/granite powder and one part of FYM(2:1:1).The rooted nodes will produce new sprouts in a week time and will be ready for field planting in 2-3 months of time. The growing vines are to be irrigated every day with a rose can. By this method, on an average, 60 cuttings can be harvested per mother plant in a year.

Nursery diseases

Many pests affect the cuttings while in the nursery. Some of the most serious ones are given below.

Phytophthora infection

Phytophthora infection is noticed on leaves, stems and roots of cuttings in the nursery. Dark spots with fimbriate margins appear on the leaves, which spread rapidly resulting in defoliation. The infection on the stem is seen as black lesions which result in blight. The symptoms on the roots appear as rotting of the entire root system. Spraying 1% Bordeaux mixture and drenching with 0.2 % copper oxychloride (2g/L) at monthly intervals prevents the disease. Alternatively, 0.01% metalaxyl (1.25 g/L water) or 0.3% potassium phosphonate could also be used. The potting mixture may be sterilized through solarization.

Anthracnose

The disease is caused by *Colletotrichum gloeosporioides*. The fungus infects the leaves causing yellowish brown to dark brown irregular leaf spots with a chlorotic halo. Spraying 1% Bordeaux mixture alternating with 0.1% Carbendazim (2g/L) is effective against the disease.

Leaf rot and blight

The disease is caused by the fungus *Rhizoctonia solani* and is often serious in nurseries during April-May when warm humid conditions prevail. The fungus infects both leaves and stems. Grey sunken spots and mycelial threads appear on the leaves and the infected leaves are attached to one another with the mycelial threads. On stems, the infection occurs as dark brown lesions which spread upwards and downwards. The new flushes subtending the points of infection gradually droop and dry up. Leaf spots caused by *Colletotrichum* sp. are characterized by yellow halo surrounding the necrotic spots. A prophylactic spray with 1% Bordeaux mixture prevents both the diseases.

Nematode infestation

Root knot nematodes (*Meloidogyne* spp.) and burrowing nematode (*Radopholus similis)* are the two important nematode species infesting rooted cuttings in the nursery. Soil solarization or steam sterilization can be done for sterilizing the nursery mixture. The sterilized nursery mixture may be fortified with biocontrol agents such as *Pochonia chlamydosporia* or *Trichoderma harzianum* @ 1-2 g/kg of soil. A prophylactic application of nematicide may also be needed.

Planting and management of vines

Being a perennial crop, use of healthy rooted cuttings is very important for raising plantations.

Preparation of land and planting standards

In India, planting of wines is done in harmony with the monsoon seasons. With the receipt of the first rain in May-June, primary stem cuttings of shade trees like *Erythrina* sp., *Garuga pinnata* or *Grevillea robusta* or seedlings of *Ailanthus malabarica* are planted in pits of 50 cm x 50 cm x 50 cm size filled with cow dung and top soil. Planting is done at a spacing of 3 m x 3 m which would accommodate about 1110 standards per hectare. The black pepper vines can be trailed on the standards after three years when they attain sufficient height. Homestead plants such as coconut, arecanut, jack, mango, drum stick, etc. can also be used as black pepper standards. Dead standards (dead wood, reinforced concrete columns, earthen pipes, etc.) are also being used as black pepper standards.

Planting

Pits of 50 cm^3 or still bigger, at a distance of 30 cm away from the base, on the northern side of supporting tree are taken with the onset of monsoon. The pits are filled with a mixture of top soil, farmyard manure @ 5 kg/pit and 150 g rock phosphate. Neem cake @ 1 kg, *Trichoderma harzianum* @ 50 g also may be mixed with the mixture at the time of planting. With the onset of monsoon, rooted cuttings of black pepper are planted individually in the pits on the northern side of each standard.

Cultural practices

As the cuttings grow, the shoots are tied to the standards as required. The young vines should be protected from hot sun during summer by providing artificial shade. Regulation of shade by lopping the branches of standards is necessary not only for providing optimum light to the vines but also for enabling the standards to grow straight. Adequate mulch with green leaf or organic matter should be applied towards the end of north east monsoon. The base of the vines should not be disturbed so as to avoid root damage.

During the second year, the same cultural practices are repeated. However, lopping of standards should be done carefully from the fourth year onwards, not only to regulate height of the standards, but also to shade the black pepper vines optimally. Lopping may be done twice (during June and September) in a year. Excessive shading during flowering and fruiting encourages pest infestations. Weed regulation, base cleaning and mulching need to be followed periodically.

Manuring and fertilizer application

Manuring and fertilizer application for pepper vines is to be done for proper establishment and growth of plants. General recommended nutrient dosage for black pepper vines (3 years and above) is NPK 50:50:150 g/vine/year. Only one-third of this dosage should be applied during the first year which is increased to two-thirds in the second year. The full dose is given from the third year onwards. The fertilizers are applied in two split doses, one in May-June and the other in August-September. The fertilizers are applied at a distance of about 30 cm all around the vine and covered with a thick layer of soil. Care should be taken to avoid direct contact of fertilizers with roots of black pepper. Organic manures in the form of cattle manure or compost can be given @ 10 kg/vine during May. Neem cake @ 1 kg/vine can also be applied. Application of lime @ 500 g/vine in April-May during alternate years is also recommended under highly acidic soil condition. When biofertilizer like *Azospirillum* is applied @ 100 g/vine, the recommended nitrogen dose may be reduced by half. In soils that are deficient in zinc or magnesium, foliar application of 0.25% zinc sulphate twice a year (May-June and September-October) and soil application of 150 g/vine magnesium sulphate, respectively is recommended.

Summer irrigation

Irrigating black pepper vines during summer (March II fortnight to May II fortnight) at fortnightly interval enhances productivity by 90 to 100 per cent compared to unirrigated crop. Vines are irrigated at the basin through hose. 50 L per vine is recommended for vines that have crossed 15 years of age while 40 L is enough for vines between 11-15 years age group and 30 L to vines aged between 5-10 years. Spiking will be uniform in irrigated crop and most of the spikes (> 90 %) emerge in July while in rainfed crop, around 60% spikes emerge in July whereas the rest emerge in September. Spike length will be comparatively more in irrigated crop.

Diseases and their control

Black pepper is affected by many diseases. The important ones are listed below:

Foot rot disease

Foot rot (quick wilt disease) caused by *Phytophthora capsici* is the most destructive of all diseases and occurs mainly during the south west monsoon season. All parts of the vine are vulnerable to the disease and the expression of symptoms depends upon the site or plant part infected and the extent of damage. Varieties like Thevam and Sakthi are tolerant to the disease. The disease can be controlled by adopting integrated disease management strategies such as phytosanitation, drainage management, deploying tolerant varieties and spraying any of the appropriate fungicides as suggested below:

(1) After the receipt of a few monsoon showers (May-June), all the vines are to be drenched at a radius of 45-50 cm with 0.2% Copper oxychloride @ 5-10 litres/vine. A foliar spray with Bordeaux mixture 1% is also to be given. Drenching and spraying are

to be repeated once again during August-September. A third round of drenching may be given during October if the monsoon is prolonged.

(2) After the receipt of a few monsoon showers, all the vines are to be drenched with 0.3% Potassium phosphonate @ 5-10 litres/vine. A foliar spray with 0.3% Potassium phosphonate is also to be given. A second drenching and spraying with 0.3% potassium phosphonate is to be repeated during August-September. If the monsoon is prolonged, a third round of drenching may also be given during October.

(3) After the receipt of a few monsoon showers, all the vines are to be drenched with 0.125% Metalaxyl mancozeb @ 5-10 litres/vine. A foliar spray with 0.125% Metalaxyl mancozeb may also be given.

(4) At the onset of monsoon (May-June), apply *Trichoderma* around the base of the vine @ 50g/vine. (This quantity is recommended for a substrate containing *Trichoderma* @ 10^{10} cfu). A foliar spray with 0.3% potassium phosphonate or 1% Bordeaux mixture is also to be given. A second application of *Trichoderma* and foliar spray of 1% Bordeaux mixture or 0.3% potassium phosphonate is to be given during August-September.

Pollu disease (Anthracnose)

This disease is caused by *Colletotrichum gloeosporioides*. It can be distinguished from the pollu (hollow berry) caused by beetles by the presence of characteristic cracks on the infected berries. The disease appears towards the end of the monsoon. The disease can be controlled by spraying 1% Bordeaux mixture.

Viral diseases

The affected vines exhibit shortening of internodes to varying degrees (stunting). The leaves become small and narrow with varying degrees of deformation and appear leathery, puckered and crinkled. Chlorotic spots and streaks also appear on the leaves occasionally. The yield of the affected vines decreases gradually. Two viruses namely *Cucumber mosaic virus* and a *Badna virus* are associated with the diseases in black pepper. Virus diseases can be managed by using virus free healthy planting material, regular inspection and removal of infected plants and burning or deep burying of the removed plants, spraying insecticides such as 0.05% Dimethoate or Monocrotophos to control the vectors and providing adequate nutrients including micronutrients to the vines.

Slow decline (slow wilt)

Slow decline is a debilitating disease of black pepper. Foliar yellowing, defoliation and dieback are the aerial symptoms of this disease. The affected vines exhibit varying degrees of root degeneration due to infestation by plant parasitic nematodes. The root system of diseased vines show varying degrees of necrosis and presence of root galls due to infestation by plant parasitic nematodes such as *Radopholus similis* and *Meloidogyne incognita* leading to rotting of feeder roots. The damage to feeder roots is caused by these nematodes and *P. capsici* either independently or together. It is necessary to adopt a combination of fungicide and nematicide application for the management of the disease.

Insect pests and their control

Major insect pests of black pepper are pollu beetles, top shoot borer, leaf gall thrips and scale insects.

Pollu beetle

The *pollu* beetle (*Longitarsus nigripennis = Lanka ramakrishnai* Prathapan & Viraktamat) is the most destructive pest of black pepper and is more serious in plains and at altitudes below 300 m. The adult beetles feed on tender leaves and spikes. The females lay eggs on tender spikes and berries. The grubs bore into and feed on the internal tissues and the infested spikes turn black and decay. The infested berries also turn black and crumble when pressed. The term *pollu* denotes the hollow nature of the infested berries in the vernacular language of Kerala State of India, Malayalam. The pest infestation is more serious in shaded areas in plantations. The pest populations are higher during September-October in the field. Regulation of shade in plantations reduces the populations of the pest in the field. Spraying Quinalphos (0.05%) during June-July and September-October or Quinalphos (0.05%) during July and Neemgold (neem based insecticide) (0.6%) during August, September and October is effective for the management of the pest.

Top shoot borer

The top shoot borer (*Cydia hemidoxa*) is a serious pest in younger plantations in all black pepper areas. The larvae bore into tender terminal shoots and feed on internal tissues resulting in blackening and decaying of affected shoots. Fully grown larvae are greyish green and measure 12-15 mm in length. When successive new shoots are attacked, the growth of the vine is affected. The infestation is higher during July to October when numerous succulent shoots are available in the vines. Spray Quinalphos (0.05%) on tender terminal shoots; repeat spraying at monthly intervals (during July-October) to protect emerging new shoots.

Leaf gall thrips

Infestation by leaf gall thrips (*Liothrips karnyi*) is more serious at higher altitudes especially in younger vines and also in nurseries in the plains. In severe cases of infestation, the growth of younger vines and cuttings in the nursery is affected. Spray Dimethoate (0.05%) during emergence of new flushes in young vines in the field and cuttings in the nursery.

Scale insects

Among the various scale insects recorded on black pepper, mussel scale (*Lepidosaphes piperis*) and coconut scale (*Aspidiotus destructor*) cause serious damage to black pepper vines at higher altitudes and also to older cuttings in nurseries in the plains. The infestation is more severe during the post monsoon and summer periods. Clip off and destroy severely infested branches. Spray Dimethoate (0.1%) on affected vines; repeat spraying after 21 days to control the infestation completely. Initiate control measures during early stages of pest infestation. In nurseries spraying neem oil (0.3%) or Neemgold (0.3%) or fish oil rosin (3%) is also effective in controlling the pest infestation.

Bush pepper

Rooted lateral branches grown as bushes are known as bush pepper. Bush pepper can be raised as potted bushes or field grown bushes. Bush pepper yields green pepper throughout the year and the fresh yield per bush can be up to 1 kg after 3 years of planting.

Organic black pepper production

For certified organic production of black pepper, at least 18 months the crop should be under organic management. In new plantations the first crop of pepper can be sold as organic, as the yielding starts from third year. To convert an existing plantation to organic, a conversion period of 36 months is set for perennial crops. The conversion period may be relaxed if the organic farm is being established on a land where chemicals were not previously used, provided sufficient proof of history of the area is available. It is desirable that organic method of production is followed in the entire farm; but in the case of large extent of area, the transition can be done in a phased manner for which a conversion plan has to be prepared.

The entire pepper holding can be converted to organic production when pepper is grown as sole crop. When grown in a mixed cultivation system, it is essential that all the crops in the field are also subjected to organic methods of production. Black pepper as a best component crop in agri-horti and silvi-horti systems, recycling of farm waste can be effectively done when grown with coconut, arecanut, coffee, rubber etc.

As a mixed crop it can also be intercropped with green manure/ legume crops enabling effective nutrient built up.

In order to avoid contamination of organically cultivated plots from neighboring non-organic farms, a suitable buffer zone with definite border is to be maintained. In smallholder groups, where the pepper holdings are contiguous, the isolation belt is needed at the outer periphery of the entire group of holdings. Pepper grown on this isolation belt cannot be treated as organic. In sloppy lands adequate precaution should be taken to avoid the entry of runoff water and chemical drift from the neighboring farms.

Management practices

For organic production, traditional varieties adapted to the local soil and climatic conditions that are resistant or tolerant to diseases, pests and nematode infection should be used. All crop residues and farm wastes like green loppings, crop residues, grasses, cow dung slurry, poultry droppings etc. available on the farm can be recycled through composting, including vermicomposting so that soil fertility is maintained at high level. No synthetic chemical fertilizers, pesticides or fungicides are allowed under organic system. Farmyard manure may be applied @ 5-10 kg/vine along with vermi/leaf compost @ 5-10 kg/vine based on the age of the vine. Based on soil test, application of lime/dolomite, rock phosphate/bone meal and wood ash may be done to get required quantity of phosphorus and potassium supplementation. When the deficient conditions of trace elements become yield limiting, restricted use of mineral/chemical sources of micronutrients and magnesium sulphate are allowed as per the limits of standard setting or certifying organizations. Further, supplementation of oil cakes like neem cake (1 kg/vine), composted coir pith (2.5 kg/vine) or composted coffee pulp rich in potassium and suitable microbial cultures of *Azospirillum* and phosphate solubilizing bacteria will improve fertility.

Use of biopesticides, biocontrol agents, cultural and phytosanitary measures for the management of insect pests and diseases forms the main strategy under organic system. Management of pollu beetle by Neemgold (0.6%) spray at 21 day intervals during July-October, shade regulation and management of scale insects by removing severely infected branches and spraying Neemgold (0.6%) or fish oil rosin (3%) are recommended.

Application of biocontrol agents like *Trichoderma* or *Pseudomonas* multiplied in suitable carrier media such as coffee husk or coir pith compost, well rotten cow dung or quality neem cake may be done regularly to keep foot rot disease in check. To control fungal pollu and other foliar diseases spraying of 1% Bordeaux mixture may be done restricting the quantity to 8 kg copper per hectare per annum. Application of quality neem cake mentioned earlier along with the bioagent *Pochonia chlamydosporia* will be useful to check the nematode population and thereby slow decline of the disease.

Certification

Certification and labeling is usually done by an independent body to provide a guarantee that the production standards are met. Govt. of India has taken steps to have indigenous certification system to help small and marginal growers and to issue valid organic certificates through certifying agencies accredited by APEDA and Spices Board. The inspectors appointed by the certification agencies will carry out inspection of the farm operations through records maintained and by periodic site inspections. The grower has to document all the details with respect to field map, field history sheet, activity register, input record, output record, harvest record, storage record, pest control records, movement record, equipment cleaning record, labeling records, etc. Documentation of farm activities is must for acquiring certification especially when both conventional and organic crops are raised. Group certification programmes are also available for organized groups of producers and processors with similar production systems located in geographical proximity.

Harvest and post-harvest management

Harvesting

Black pepper takes about 7-8 months after flowering to reach full maturity. In India the crop is harvested during December-January in plains and January-April in the high ranges of Western Ghats. Harvest starts when one or two berries turn yellow. The spikes are nipped off by hand and collected in bags. Normally, single pole bamboo ladder is used as a support for harvesting.

Recent advances in product diversification have necessitated harvesting of the berries at different stages of maturity. The level of maturity required at harvest for processing into different pepper products is given below:

Product	Stage of maturity at harvest
Canned pepper	4-5months
Dehydrated green pepper	10-15 days before maturity
Oleoresin and essential oil	15-20 days before maturity
Black pepper	Fully mature and 1-2 berries start turning from yellow to red in each spike
Pepper powder	Fully mature with maximum starch
White pepper	Fully ripe

Post-harvest processing

Post-harvest processing operations followed for black pepper involve threshing, blanching, drying, cleaning, grading and packaging. During processing care should be taken to maintain quality during each step of operation. Though manual threshing is more common, mechanical threshers with capacities varying from 50 kg/h to 2500 kg/h are available which can thresh quickly and provide cleaner products.

The quality of the black pepper can be improved by a simple treatment of dipping the mature berries taken in a perforated vessel in boiling water for a minute before drying. This processing technique imparts uniform colour, reduces the microbial load and helps to dry the product within 3-4 days as against 5-6 days required when following the traditional practice and removes extraneous impurities like dust from the berries.

Pepper has a moisture content of 65 to 70 per cent at the time of harvest, which should be brought to safer levels of 10 per cent by adequate drying. The green colour of matured pepper is due to the presence of chlorophyll pigment. During drying, enzymatic browning sets in and the phenolic compounds are oxidized by atmospheric oxygen under the catalytic influence of the enzyme phenolase and eventually the product turn black.

Sun drying is the conventional method followed for drying of black pepper. The despiked berries are spread on concrete floor and dried under sun for 3-5 days to bring the moisture content below 10 per cent. Dried black pepper with high moisture content (>12 %) is susceptible to fungal attacks. Mycotoxins produced by fungal attack render the product unfit for human consumption. In order to get quality dry product, pepper berries are spread on clean dry concrete floor, bamboo mats or PVC sheets and dried in the sun for a period of 4-6 days. Average dry recovery varies between 33-37 per cent depending on the varieties and cultivars.

The threshed and dried black pepper has extraneous matter like spent spikes, pinheads, stones, soil particles, etc. mixed with it. Cleaning and grading are basic operations that enhance the value of the produce and help to get higher returns. Cleaning on a small scale is done by winnowing and hand picking which removes most of the impurities.

Packaging

Organically grown black pepper should be packaged separately and labeled. Mixing different types of pepper is not good from a commercial point of view. Ecofriendly packaging materials such as clean gunny bags or paper bags may be adopted and the use of polythene bags may be minimized. Recyclable/reusable packaging materials shall be used wherever possible.

Storage

Black pepper absorbs moisture from air during rainy season when there is high humidity and may result in mould and insect infestation. Before storage it is to be dried to less than 10 per cent moisture. The graded produce is bulk packed separately in multi-layered paper bags or woven polypropylene bags provided with food grade liners or in jute bags. The bags are arranged one over the other on wooden pallets after laying polypropylene sheets on the floor.

Uses

Black pepper is traded as whole dried corns, white pepper, powder, extracts, spice blends and mixtures. Apart from its use as a spice and flavouring agent, black pepper has antimicrobial, antioxidant, anti-inflammatory and antitoxic properties. It also has carminative, digestive, antioxidant and antidepressant properties. Black pepper is also a remedy for skin diseases, flu and congestion, cough and cold, dental problems, vitiligo, dandruff and even cancer. Besides, it is diuretic and diaphoretic. Black pepper is one of the most common spices used in different cuisines around the world. It is used in both the whole and grounded form.

Biology and cultivation of cardamom, the queen of spices

V.V. Radhakrishnan
Genetics and Plant Breeding Division, Department of Botany, University of Calicut, Kerala – 673635, India.

Cardamom (*Elettaria cardamomum* Maton) is a large, perennial, herbaceous rhizomatous monocot, belonging to the family Zingiberaceae. It is a native of the moist evergreen forests of the Western Ghats of southern India. The cardamom of commerce is the dried ripe fruit (capsules) of cardamom plant. This is often referred as the 'queen of spices' because of its very pleasant aroma and taste, and is highly valued from ancient times. It is grown extensively in the hilly regions of South India at elevations of 800-1300 m as an undercrop in forest lands. Cardamom grows luxuriantly in forest loam soils, which are generally acidic in nature with a pH range of 5.5 - 6.5. The crop thrives well in regions which receive well distributed annual rainfall of 1500 - 2500 mm with a mean temperature of 15°C to 30°C and relative humidity of 75 - 90%. Cardamom prefers well drained soils rich in organic matter and it does not tolerate water logging.

Cardamom is one among the major spice crops originated in India. Earlier, cardamom was a minor forest produce and there was no organized cultivation. The system of cardamom collection from naturally growing plants continued till 1803 at least, but in later years the demand became too large, and large scale organized cultivation started in India as a secondary crop in coffee plantations. But its cultivation spread rapidly in the hilly terrains of Western Ghats and the portion south of the Palakkad gap came to be known as Cardamom Hills. The cultivation of cardamom in India was actively taken up by the erstwhile Travancore Government in 1823 AD. During 19th century, the Britishers established cardamom plantations and started its systematic cultivation. Cardamom is cultivated in Kerala, Karnataka and Tamil Nadu states of India. Most of the cardamom growing areas in Kerala are located in the districts of Idukki, Wayanad and Palakkad. In Karnataka, cardamom is grown in Coorg, Chikmagalur and Hassan districts and to a lesser extent in North Kanara district. In Tamil Nadu, cardamom cultivation is located in certain localities in Pulney and Kodai hills. Kerala has 57% of area and contributes 88% of production; Karnataka 36% of area and 7% of production, while Tamil Nadu has 7% of area and 5% of production. In India the area under cardamom has come down drastically over the last three decades from 1,05,000 ha during 1987-88 to 70,080 ha during 2016-17, while production has gone up from 3,200 tons during 1987-88 to 19,625 tons in 2016-17. During the period, the productivity has increased from 47 kg/ha to 254 kg/ha.

Habit

The cardamom plant is a 2-4 m tall herbaceous perennial with branched subterranean rhizomes from which several leafy shoots arise, forming a clump. Leafy shoots have a limited life span; the first year is mainly for vegetative growth, the second year for reproductive growth (flowers and fruits), and the third year a senescence and death stage. New buds are formed from the base of the old shoots in the first and second yearG and thus in a clump, old shoots, young shoots and buds can be seen in varying numbers. Flowers are borne on erect, prostrate or semi-erect (flexuous) inflorescences depending on the variety.

The leaves are lanceolate in shape and lamina tapers into a sharp tip and are 25-90 cm long and 5-15 cm wide. Leaves are dark green and shiny on the upper surface and pale green on the lower surface. The lower surface of the leaf could be smooth (glabrous) or pubescent (hairy) depending on the variety. The inflorescence arises from the base of the leafy shoots and is 45-120 cm long. Flowers are borne in racemes, they are hermaphrodite, zygomorphic and about 4 cm long and 1.5 cm wide. The calyx is tubular green and shortly three toothed and persistent. The corolla tube is as long as the calyx tube, with narrow spreading pale green lobes.

Flowers have an attractive petalloid labellum which is made of modified stamens, about 1.8 cm long with an undulating edge. The labellum is white in colour with violet streaks radiating from the centre. There is only one functional stamen which has a short, flat, broad filament with a longer anther and connected with a short crest. The inferior ovary consists of three united carpels with numerous ovules in axile placentation and a slender style with a small capitates stigma which sits on the top to the anther along the crest. Flower initiation takes place in india along with the onset of south west monsoon during the month of May. From initiation to full bloom it takes 25-35 days, and from bloom to maturity, 110 to 140 days. The fruit is a trilocular capsule, ovate-globose, dark green to pale green in colour. On ripening the capsule turns yellow in colour; it contains 15-30 seeds which are dark brown, angled, aromatic and about 3 mm long with a thin mucilaginous aril.

Types/cultivars

Based on the nature of panicles and shape and size of capsules, three natural cultivars have been observed in cardamom namely Malabar, Mysore and Vazhukka. The cultivar Malabar having prostrate panicles (panicles spreading on ground) is widely grown in Karnataka, while the cultivar Mysore, characterized with erect panicles is extensively cultivated in Kerala and parts of Tamil Nadu. The cultivar Vazhukka, a natural hybrid between Malabar and Mysore types with distinct semi-erect (pendent) panicles, is the most popular cultivar in Kerala.

Propagation

Production of planting material

Propagation by vegetative means through suckers is the most preferred method. Production of planting materials from seeds and through tissue culture is also practiced. Seedling propagated plants may not be true to its parent type due to the presence of cross pollination in the crop. In Kerala, suckers are used for raising cardamom plantations. Sucker multiplication is taken up from the first week of March to the first fortnight of October. The site is selected in open, gently sloping well drained areas near a water source. Trenches of 45 cm width, 45 cm depth and convenient length are taken across the slope or along the contour at 1.8 m apart. They are filled with equal quantity of humus rich top soil, sand and cattle manure. Mother clumps identified for planting material production are uprooted partially, leaving some part in the field itself for future perennation. The roots are trimmed and the suckers separated so that the minimum planting unit consists of one grown up tiller and a growing young shoot. They are planted at a spacing of 1.8 m x 0.6 m in filled up trenches. Sufficient mulch is provided. Overhead shade and sufficient irrigation are provided during summer months and the shading material is removed with the onset of monsoon rains. Application of DAP and MOP enables better establishment and growth. On an average 20 to 30 suckers per initial planting unit can be produced within one year of planting. Care should be taken to identify and collect mother clumps only from areas totally free from viral diseases.

Field planting and management

Before taking up planting, field should be made ready. For planting in a new area, ground should be cleared and if it is a replanting area, old plants should be removed. Shade regulation, terracing and preparation of pits should be done during summer months. Shade regulation is one of the important practices in cardamom plantations. It should be carried out during summer (March-April) in the new planting areas and during May-June after the receipt of summer showers in the existing plantations. If there is thick shade due to dense branches and bigger leaves, chopping off of branches should be done to provide filtered light up to 40 to 60 percent. Cutting braches from all the sides ensures a balanced canopy. South-western slopes should be provided with more shade than north-eastern slopes. Shade trees should have small leaves and tap root system and in summer they should not shed leaves.

In areas having medium and steep slopes, soil preparation is different from that of gentle slopes. In sloppy areas soil loss due to erosion should be prevented for which planting should be done in terraces. Terraces should be made across the slope at required distances depending on the spacing adopted. Pits of 90 cm x 90 cm x 45 cm are prepared before the commencement of monsoon and about one third of the pit is filled with top soil and one third with 1:3 mixture of organic manure and top soil. Suitable planting materials are selected and planted in the already prepared and filled pits and plants should be protected from wind by staking. For Mysore and Vazhukka cultivars plant to plant distance can be 3 m x 3 m or 2.4 m x 2.4 m when planted in high rainfall and irrigated areas. A spacing of 1.8 cm x 1.8 cm is suitable for Karnataka state of India. Immediately after planting, the plant base should be mulched well with available dried leaves to protect soil from erosion and conservation of soil moisture. Weeds are potential competitors in the consumption of water and nutrients which will depress the growth of cardamom. Two to three rounds of hand weeding at the plant base during May, September and December/ January and slash weeding in other areas are advisable. The weeded material can be used for mulching.

Judicious irrigation during summer months ensures increase in yield by at least 50%. Irrigation is required generally from February to April but at times from January to May depending upon the availability of rainfall. In cardamom growing areas of Tamil Nadu, where the South-West monsoon is not very effective, irrigation during March-August is advisable. This is the period during which development of young tillers and panicles takes place and if plant suffers during this stage, yield will be reduced drastically. Irrigation can be done through different methods such as hose irrigation, sprinkler irrigation and drip irrigation depending upon the facilities available in the plantation. Hose irrigation can be done at weekly intervals at the rate of 20-30 L per clump depending on the clump size. In the case of sprinkler, irrigation equivalent to 35-45 mm rain at fortnightly interval is recommended whereas in drip irrigation water at the rate of 4-6 L per day can be given.

Forking the plant base to a distance of 90 cm and to depth of 9-12 cm is found to enhance root proliferation and better growth of plants. As far as possible, the entire plantation and particularly the plant base are to be kept under mulch to reduce the ill effects of drought. Removal of old tillers and dry leaves, known as trashing, is to be carried out once in a year after completion of final round of harvest and these materials can also be used as mulch. Earthing up is not required in a normal plantation, but due to soil erosion or mismanagement, at times it is noticed that the top soil covering the plant base is washed away and the rhizomes and roots are exposed and in such situations, earthing up of the plant base with top soil is recommended during December-January.

Crop improvement

In spite of its prominence in world trade from time immemorial, systematic research on cardamom was initiated in India only in 1944. Much information on scientific management of cardamom cultivation has been generated by now. Primary mandates of cardamom research in India are crop improvement, development of agrotechniques, development of strategies for integrated nutrient, pest and disease management and development of post harvest techniques. As many as six research organizations are at present engaged in research on improvement of cardamom in India. Over the last thirty years, there has been a drastic reduction to the tune of 30% in the area under cardamom in India due to various reasons but the production has gone up many folds owing to the large scale cultivation of improved varieties suited to different agroclimatic situations coupled with adoption of high production technology.

Use of genetically superior planting material and cultivation adopting improved agrotechniques is the most accepted means to enhance crop productivity. Since cardamom is amenable to both sexual and vegetative propagation, methods such as selection, hybridization, mutation breeding, polyploidy breeding and tissue culture are used as measures for genetic upgradation of the planting materials. Cardamom is cross pollinated, and large variability exists in seedling progenies. The chromosome number of cardamom is 2n=48. Selections and hybrids have mainly been made for yield improvement and resistance to pests and diseases. Plants with medium stature and prostrate panicles are more suited for closer planting (3000 plants per hectare) whereas robust plants with semi-erect panicles are suited for low density planting and intensive management practices (1000 plats per hectare).

Selection

Clonal selection is generally practiced in cardamom and it is based on both qualitative and quantitative characters. Initial selection in cardamom for desirable traits is made from the planters' field and wild habitats. Selection is made based on some passport characters identified in the descriptor for the crop. In order to isolate promising clones, germplasm collections are subjected to initial evaluation studies. Selection in cardamom for high yield and superior quality capsule was initiated a few decades ago. Though some cultures were isolated earlier they did not become popular among the planting community. Systematic evaluation of germplasm accessions carried out after 1980s has resulted in the identification and release of a few elite clones having high yield potential and good quality capsules.

Hybridization

The most popular cardamom cultivar namely *'Vazhukka'* is presumed to have evolved as a result of natural cross between cv. *Malabar* and cv. *Mysore*. Breeding in cardamom is aimed at evolving recombinants which are superior with regard to yield and quality of capsules. In cardamom, both intergeneric and intervarietal hybridizations were carried out but the results of the former were not encouraging. Intervarietal hybridization was successfully carried out using different varieties/cultivars of cardamom for producing high yielding heterotic recombinants. Evaluation of these hybrids enabled in the isolation of over half a dozen high yielding heterotic recombinants with a yield of above 1000 kg/ha.

High yielding varieties and selections

Various research institutions working on the crop improvement aspects of cardamom have released a number of elite, location specific and high yielding clones having a yield potential of above 450 kg/ha (rain fed) and superior capsule characters. Prominent among them are detailed in the table given below.

In addition to this, there are several high yielding clones selected by cardamom farmers. The most popular and widely cultivated among them is *'Njallani green gold'* which has very high yield potential and good quality characters. Other prominent farmer selections are *Palakkudi, Panikulangara, Vali green bold, Elarani, PNS Vaigai, Vander cardamom, Kalarickal bold, Pulari, Pappalu, Arjun*, etc. Even though fourteen improved and location specific varieties of cardamom have been developed and made available to farmers by various research institutes working on the crop, many farmers still depend on promising landraces for cultivation.

Harvesting and processing

Cardamom plants start bearing two or three years after planting suckers or seedlings respectively. The capsules ripen within a period of 120-135 days after its formation. Harvesting period commences from June-July and continues till January-February in Kerala and Tamil Nadu. In Karnataka, harvesting begins in August and prolongs till December-January. Usually harvesting is done at an interval of 30-40 days. The capsules are harvested when they attain physiological maturity, which is indicated by dark green colour of rind and black coloured seeds. Harvesting of ripened capsules is avoided as it leads to the loss of green colour and also causes splitting of capsules during curing process. Immature capsules on processing yield uneven sized, shriveled and undesirably coloured produce. Freshly harvested capsules are washed in water to remove the soil particles and other dirt adhering to it and to get good quality commodity. Storage of capsules after harvest for longer duration adversely affects quality of the end product.

Curing of cardamom is the process by which moisture of freshly harvested capsules is reduced from 80 to 10-12% through indirect heating. Maturity of capsules and the curing temperature influence the colour and quality of processed cardamom. During curing, a temperature range of 40-45°C is maintained during all the stages of drying which helps in good retention of green colour. Gradual increase of drying temperature to 50-60°C in the last two hours of curing enables easy removal of floral remnants during polishing. During curing, if temperature exceeds the threshold levels, capsules develop brownish streaks due to heat injury. An increase in drying temperature also results in loss of oil from the seeds. A traditional firewood based curing house consists of a furnace for burning the wood, flue pipes for conveying the hot air and drying racks for stacking the trays. The capsules are evenly spread as a single layer on the trays. After stacking the trays on the racks in the drying chamber, the curing room is closed. Hot air generated by burning firewood in the furnace is circulated through the flue pipes, which are placed a few centimeters above the floor. This process enhances the room temperature to 45-55°C, which is maintained for a period of 3-4 hours. During this period, capsules sweat and give off the moisture. The drying process is facilitated by opening the ventilators for sweeping out the water vapour generated from the drying capsules. Exhaust fans are also used for the speedy removal of moisture. After complete removal of water vapour, the ventilators are closed and temperature inside the chamber is again maintained at 45-55°C for a period of 18-24 hours. In the final stage of curing process, the temperature is further raised to 60-65°C. The temperature is raised to hasten the cleaning process by which debris like stalks attached to the capsules can be removed easily. Temperature inside the curing chamber is maintained around 65°C to avoid splitting of the capsules and also to prevent the loss of volatile oil. Under these conditions, it is possible to obtain high quality green cardamom in about 24-30 hours.

Efficient and highly automated cardamom driers have been developed and are

Major varieties of cardamom developed in India

Sl. No.	Selection/ Variety	Cultivar	Special distinguishing characteristics	Area of adaptability	Source	Yield potential (kg/ha)
1	ICRI - 1	Malabar	An early maturing profusely flowering variety, medium sized panicle with globose, extra bold, dark green coloured capsules	South Idukki zone of Kerala, where the rainfall is well distributed	ICRI (Spices Board), Myladumpara, Idukki, Kerala- 685553, India	660
2	ICRI - 2	Mysore	Performs well under irrigated conditions. Suitable for higher altitude. It has medium long and parrot green capsules.	Vandanmedu and Nelliampathy of Kerala and Anamalai and Meghamalai of Tami Nadu	ICRI (Spices Board), Myladumpara, Idukki, Kerala- 685553, India	760
3	ICRI - 3	Malabar	Early maturing type, non-pubescent leaves, oblong bold, parrot green capsules.	Cardamom growing tract of Karnataka	Regional Station, ICRI (Spices Board), Saklespur Karnataka, India	600
4	ICRI - 4 (TDK- 4)	Malabar	An early maturing variety adaptable to low rainfall area. Medium size panicle, globose bold parrot green capsules. Non pubescent leaves.	Adapted to Lower Pulney hills of Tamil Nadu. Suitable for low rainfall area (1500 mm) and having similar agroecological conditions.	Regional Station, ICRI (Spice Board), Thadiankudisai, Tamil Nadu- 624 212, India	460
5	ICRI - 5	Malabar	Hybrid variety, early bearing, high yield, high oil content deep green a bold capsule, moderately talent to rot disease.	Kerala and parts of Tamil Nadu	ICRI (Spices Board), Myladumpara, Idukki, Kerala – 685553, India	2000

Sl. No.	Selection/ Variety	Cultivar	Special distinguishing characteristics	Area of adaptability	Source	Yield potential (kg/ha)
6	ICRI - 6	Malabar	Regular yielder, high oil content, deep green long bold capsule, moderately tolerant to rot pathogens trips, borer and drought.	Kerala and parts of Tamil Nadu	ICRI (Spices Board), Myladumpara, Idukki, Kerala- 685553, India	1900
7	ICRI - 7	Malabar	Hybrid variety, early bearing, high yield, high oil content deep green a bold capsule.	Cardamom growing areas of Wayanad District of Kerala	ICRI (Spices Board), Myladumpara, Idukki, Kerala-685553, India	1400
8	PV - 1	Malabar	An early maturing variety with slightly ribbed light green capsules. Short panicle, close racemes, ellipsoid to elongate capsules	All cardamom growing tracts in Kerala and parts of Tamil Nadu	Cardamom Res. Station (Kerala Agri. University), Pampadumpara, Kerala-685556, India	500
9	PV - 2	Vazhukka	High yielder, deep green long bold capsule, high dry recovery percent.	Kerala	Cardamom Res. Station (Kerala Agri. University), Pampadumpara, Kerala-685556, India	1200

Sl. No.	Selection/ Variety	Cultivar	Special distinguishing characteristics	Area of adaptability	Source	Yield potential (kg/ha)
10	Mudigere - 1	Malabar	Compact plant, suitable for high density planting. Tolerant to hairy caterpillars and white grubs. Short panicle, oval bold, pale green capsules. Tolerant to thrips and shoot borer.	Traditional cardamom growing Malanad areas of Karnataka	Zonal Hort. Res. Station (University of Hort. Sciences), Mudigere, Karnataka- 577 132, India	275
11	Mudigere - 2	Malabar	Suited for cultivation in valleys in Karnataka	Suited for Karnataka (Valley areas)	Zonal Agri. Res. Station, UAS, Mudigere	475
12	IISR, Suvasini (CCS- 1)	Malabar	An early maturing variety suitable for high density planting long panicle, oblong bold, parrot green capsules	All cardamom growing tracts of Karnataka and Wayanad of Kerala	India Institute of Spices, Research, Cardamom Research Centre, Appangala, Karnataka- 571201, India	400
13	IISR Avinash (RR- 1)	Malabar	Resistant to rhizome rot disease, Suited for hot spots of rhizome rot and leaf blight diseases. High quality elongated capsules	Kodagu, North Wayanad, Hassan and Chikmagalur	IISR Cardamom Research Centre, Appangala, Karnataka- 571201, India	850
14	IISR Vijetha (NKE - 12)	Malabar	Tolerant to Katte disease	Kodagu, North Wayanad, Hassan and Chikmagalur	IISR Cardamom Research Centre, Appangala, Karnataka- 571201, India	650

being widely used with alternative sources of fuels such as kerosene, Liquid Petroleum Gas, diesel or with combination of fuels. Such improved systems have the advantage of retaining high quality of produce with respect to colour and duration of curing is also substantially reduced to 16-18 hours.

Dried capsules are polished either manually or with the help of machines. Polishing is carried out by rubbing the dried capsules in hot state against a hard surface. The polished produce is subsequently graded based on quality parameters such as colour, weight per volume, size and percentage of empty, malformed, shriveled and immature capsules. After grading, cardamom capsules are stored. The capsules are stored at a moisture content of less than 10 percent to retain the original parrot green colour and to prevent mould growth. Use of 300 gauge black polythene lined gunny bags improves efficiency of storage. It is advisable to store the dried cardamom in wooden boxes at room temperature, preferably in the curing houses.

Uses

The major use of cardamom on a worldwide basis is for culinary purposes in the form of capsules or in the ground form. In Asia, cardamom plays an important role in the preparation of a variety of spiced rice, vegetable and meat dishes. Cardamom can add a lingering sparkle to many dishes, both traditional and modern. International trade in cardamom is dependent on the demand created by specialized applications that have evolved in two distinct markets namely the Arab countries of the Middle East and in Scandinavia. Cardamom gives a warm, comforting feeling and it is responsible for the peculiar and exotic flavour of Bedouin coffee. In the Middle East, religious ceremonies, social functions and celebrations are not complete without serving *Gahwa* or Arab coffee (cardamom flavoured coffee). It is believed that this drink cools down body heat in a country where extreme heat is a regular feature of daily life. It is also believed to aid in digestion and is said to be an aphrodisiac. Indian cardamom is low in fat, high in protein, iron and vitamins B and C. In India it is used as a masticatory and also in flavouring culinary preparations. Cardamom seeds are chewed after meals to ward off foul smell and as a mouth freshener. Recently, in India, a variety of cardamom flavoured products have come to market such as biscuits, chocolates, health drinks, milk, cheese and so on. It is also used for making garlands in India and Arab countries for special occasions.

Conclusion

Till now world demand for cardamom has been increasing commensurate with the growth in production and due to this there has been no slump in world market and entire production is consumed in the same year without much left over. In the last fifteen years world production of cardamom has increased almost three times and similarly consumption also. Cardamom economy in the Western Ghat region of India supports a sizeable proportion of small farm sector and agricultural labour and there is an urgent need to improve and sustain the production and productivity of the crop. There should be concerted attempts to achieve a quantum jump in productivity not only through high yielding varieties but also through the process of constraint alleviation mainly in respect of drought, pest and diseases. There is immense potential and technological feasibility to increase cardamom yield in India and as the global requirements are growing, the future seems to be bright for India.

Biology and cultivation of vanilla, the prince of spices

V.V. Radhakrishnan
Genetics and Plant Breeding Division, Department of Botany, University of Calicut, Kerala – 673635, India.

Vanilla is a tropical orchid cultivated to extract its pleasant flavouring principle. It belongs to the family Orchidaceae. Though over 110 species have been described, only three are important as source of the flavouring agent vanillin. They are *Vanilla planifolia* Andrews, *Vanilla pompona* Schiede and *Vanilla tahitensis* J.W. Moore. Of these, *Vanilla planifolia* is the most preferred commercially and hence widely cultivated. Vanilla is a native of Mexico and Central America. Congenial conditions for the growth of vanilla were available in several parts of the world, but introduction of this plant as a plantation crop was not possible because of the absence of specific agents for pollination. It was Edmond Albius, a former slave, who found out a practical method for artificial pollination which is still being practiced. This discovery of the method of artificial pollination of flowers and amenability of the crop to vegetative propagation paved the way for commercial cultivation of vanilla in many countries. The major vanilla growing countries are Indonesia, Madagascar, Mexico, Tahiti, Comoro Islands and Reunion. Uganda, Tongo, French Polynesia and India grow vanilla on a limited scale. The history of introduction of vanilla into India appears to be obscure since no authentic information on this subject is available. According to the record available with the Fruit Research Station at Kallar/Burliar in the Nilgiris, vanilla has been under cultivation there since 1945. Late in 1960, preliminary investigations on the cultivation aspects of vanilla were initiated at the Research Station at Ambalavayal in Wayanad District of Kerala. Highly impressed by the results, a few enthusiastic planters of Wayanad District took up the cultivation of this unique crop. The Government of Kerala also initiated a small scheme at Cheengeri at Ambalavayal for settlement of tribals through cultivating vanilla over an area of two hectares. However, these initial attempts did not succeed due to various reasons like lack of proper care, continued technical support and proper marketing arrangements for the produce. Nevertheless, these plantations served as source of planting material for vanilla development programmes initiated by various agencies in the recent past.

Climate and soil

Vanilla needs a warm and wet tropical climate. It grows well on a variety of soils ranging from sandy loam to laterites provided the soil is loose and friable with high organic matter. It flourishes well in partial shade of about 50%. It can be grown from sea level to over 1500 m above mean sea level in a temperature range of 25 to 32^{o}C. Moderate slope and good drainage help its easy establishment. The ideal growing condition for vanilla is moderate rainfall evenly distributed throughout ten months of the year, with dry spells during flowering and harvesting period.

Habit

Vanilla is a herbaceous perennial vine, climbing up trees or other supports to a height of 10-15 m by means of adventitious roots. In cultivation it is trained to a height which will facilitate hand pollination and harvesting. Long, whitish, aerial adventitious roots, about 2 mm in diameter, are produced singly opposite the leaves and adhere firmly to the support plant. The roots at the base ramify in the humus or mulch layer. The stem is long, cylindrical, succulent and branched. It is 1-2 cm in diameter and is dark green and photosynthetic with stomata. The internodes are 5-15 cm in length. Leaves are large, flat, fleshy, sub sessile, alternate and oblong-elliptic to lanceolate. They are 8-25 cm long and 2-8 cm broad. The tip is acute to acuminate and the base somewhat rounded. Venation is parallel and the veins are distinct. The petiole is thick, short and canalized above.

The stout racemose inflorescences are axillary, usually simple but rarely branched. They are usually borne towards the top of vine and are 5-8 cm long with usually 10-26 flowers opening from the base upwards. The rachis is stout and 4-10 mm in diameter. The bracts are rigid, concave and persistent. Flowers are large, waxy, pale greenish yellow, bisexual and zygomorphic. The sepals and petals look alike and they are commonly called perianth lobes or tapels. The lower petal is short, broad and it is modified into a labellum. The lower part of the labellum envelops a central 'column' (gynostemium). The tip of the column bears a single stamen with two pollen masses (pollinia) covered by a cap or hood like structure called 'rostellum', which prevents natural pollination. The slender stalk like portion is the ovary, which is 4-5 cm in length. A cross section of the ovary of an opened flower shows three carpels, three pairs of fibrovascular bundles, and three pairs of placentae. The placentae extend throughout the length of the ovarian cavity.

Support plants/standards

Being a climber, vanilla requires a support or standard for climbing. Low branching trees with rough bark and small leaves are preferred as support trees. If the support tree selected is a leguminous one it can add nitrogen to the soil. A few of the common support trees suitable are *Glyricidia maculata*, *Plumeria alba* and *Erythrina lithosperma*. Support trees are planted at least six months prior to planting of vanilla for successful establishment. Cuttings of 1.5 to 2 m length with 4 to 5 cm diameter are used for planting in filled pits of about 30 cm x 30 cm x 30 cm size at a spacing of 2.5 m between rows and 2 m within a row. About 1600 to 2000 plants are accommodated in one hectare area as a pure crop. However, in optimally spaced coconut or arecanut gardens, the number of plants will be lower than this. It can be cultivated as an intercrop in coconut, arecanut and other similar farms.

Propagation and planting

Vanilla is propagated mainly by shoot cuttings, as seed propagation is very difficult. The length of cuttings is to be adjusted depending upon availability of planting material. However, cuttings with less than 30 cm length should not be used for planting directly in the main field. If longer cuttings are planted, they will grow faster and usually come to flower in the third year after planting. Strong, healthy and actively growing vines are to be selected as planting material. They should be cut into pieces of about one metre length with the bottom three or four leaves removed and kept in a shady place for a week to loose water content. The portion of a vine which has once given yield is not useable for planting. The cuttings are planted close to the base of the support tree by laying the 3-4 basal nodes from where leaves have been removed on the soil surface and gently pressing these nodes to the soil or putting sufficient soil to cover the nodes. While planting, the basal cut end portion of the cutting is kept just above the soil surface to avoid chances of decay. The top end of the cutting is to be tied to the base of the support tree gently so that the new sprout produced from it will eventually climb on them. The ideal time for planting is when the weather is neither too rainy nor too dry. Under South Indian conditions planting can be done between August and October.

After care

Vanilla loves organic matter and decomposed mulch as they are the main source of nutrients for the plants. Easily decomposable organic matter is applied around the plant base three or four times in a year. Spraying one percent 17:17:17 NPK complex on the foliage and stem has been found to be beneficial to enhance the growth of vines. Irrigation at the rate of two to three litres of water per plant in the initial years of growth is necessary. Any operation done in the plantation should not disturb the roots, which are mainly confined to the mulch and surface layer of soil.

The support tree should be allowed to form branches to different directions to have an umbrella shaped appearance about 150 cm above the ground. From the time of initial planting, the vines attached to the support are to be allowed to grow upward. However, if they are permitted to grow up on the support tree itself, it will rarely blossom so long as it is growing upward. Moreover hand pollination will also be very difficult to be carried out. Therefore, the vines are allowed to grow up to a height of 1.2 to 1.5 metres and allowed to hang down on the branches. Such vines should be brought back to the ground and a portion of it placed under the mulch. Later it is coiled again on the same support tree. Thus the vine should be looped up and down adjusting the height in such a way that it is not more than the shoulder height of workers. This makes operations such as pollination, harvest and pruning easy and will make the crop more productive. Vanilla vines can be trained from one support tree to the other within the same row by planting additional supports in between or on horizontal bars connecting two main support trees. Trailing or coiling is an important cultural operation as it induces flowering.

Flowering and pollination

Depending upon the altitude of the cultivated area, flowering occurs from December to May and it takes 45-60 days from the initiation of inflorescence to flowering. If longer cuttings are used for planting, flowering commences in the third year after planting. Generally one flowering occurs in a year. Removal of growing shoot tips one or two months prior to flowering season induces profuse flower production. Inflorescences are formed in the axils of leaves on stems of the previous year's growth. Twenty or more flowers are found in an inflorescence. The stigma is physically prevented from coming in contact with the anther by a flap like structure known as rostellum as mentioned earlier. This makes artificial hand pollination a must for production of beans. In Mexico and Central America where vanilla is indigenous, to a lesser extent the flowers are pollinated by *Melipona* bees and humming birds. Elsewhere, hand pollination is unavoidable for fruit set. Hand pollination can be easily resorted to with pointed bamboo splinter or tooth pick. With it, the rostellum is lifted up and the overhanging anther is pressed against the stigma with the thumb which ensures smearing of the pollen over the stigma. The ideal time for pollination is between 6 a.m. and 1 p.m. The fruit setting percentage is found to be the maximum when pollination is carried out at 8 a.m. and thereafter it shows a decreasing trend as pollination is delayed. Stigma receptivity is reported to be for 24 hours. Each flower lasts for a day only and so pollination should be carried out on the same day. The flowers, which are not fertilized, fall off within a day or two. It is reported that the size of the beans has a direct positive correlation with the amount of pollen deposited on the stigma. Normally eight to ten flowers located on the lower side of the inflorescence and not more than 10 to 12 inflorescences in a vine are pollinated in a plant. The remaining flower buds are nipped off to reduce strain on the vine. If this restriction is not practised, definitely the beans will be smaller in size. Once fertilization takes place, the ovary elongates rapidly for 45 days and full length and girth of the bean is attained within 75 days. Depending upon the elevation of the cultivated area, the bean takes nine to ten months to reach full maturity. The fruit (pod) is a capsule and in trade it is known as a bean. The bean is pendulous, narrowly cylindrical, obscurely three angled, 10-25 cm long and 5-15 mm in diameter. It becomes aromatic on processing. The vanilla bean contains thousands of seeds which are very minute, black in colour and globose in shape. Around 50 to 65 mature beans of 15 cm or more length can make one kilogram of fresh beans. The recovery of dry bean is about 20% of fresh weight.

Harvesting and processing

The fresh vanilla beans do not have any flavour or aroma because vanillin and other chemical substances responsible for imparting the peculiar fragrance and flavour are not present in free form at the time of harvesting. During the process of curing, free vanillin is developed in the beans as a result of a series of enzymatic actions on several glucosides. Simultaneously, various aldehydes, aromatic esters, protocatechic acid, benzoic acid, vanillic acid and anisic alcohol are also formed and all these compounds together give the fragrance of natural vanilla well distinguishable from synthetic vanillin. Immature beans are dark green in colour. When the beans are ready for harvest, they will have a pale yellow tinge at the distal end. Fully matured beans are harvested for curing or processing. Though different methods of processing vanilla beans are followed in vanilla growing countries, the Bourbon method, practised in Madagascar gives the best quality beans. This method is simple and consists of four stages.

Killing or wilting

The beans after cleaning are dipped in hot water (63 to 65^{o}C) for three minutes to stop the vegetative phase of mature beans and or the initiation of enzymatic reactions responsible for the development of aroma. Killing is indicated by the development of brown colouration by the bean.

Sweating

It is done to further raise the temperature of the beans. The beans are made to sweat by exposing to hot sun light for about one and a half hours once in a day on a raised platform erected at about 75cm to 100 cm above the ground. This is to be followed immediately after killing. After keeping in sunlight the beans are wrapped in a woolen blanket and stored in wooden boxes. Keeping in sunlight and the other steps are to be repeated for 8 to 10 days depending upon local climatic conditions. During this operation, the beans acquire a deeper brown colouration and become quite supple, and the development of an aroma becomes perceptible. At the end of the sweating period, the weight of the beans will be around half of the initial weight.

Slow drying

It is done by spreading beans on wooden racks in a room at ambient temperature. The period of slow drying can be 20 to 25 days wherein the beans will further loose moisture very slowly and become more pliable and capable of being twisted onto the fingers. While slow drying, the relative humidity of the room should be kept at more than 70% by hanging moistened cloths or keeping water in trays below the racks. When the beans are ready for conditioning after slow drying, their weight will be around one third of the original weight.

Conditioning

The beans are sorted out depending on length and bundled into 50 or 100 and tied at both ends. They are packed in butter paper, cellophane paper or polypropylene bags and stored in airtight containers to allow full development of aroma and flavour. The vanillin content of properly cured beans would be around 2.5 to 3% with moisture content of 20 to 25%.

Yield

The yield of vanilla varies depending on the age of vines and the method of cultivation. Under reasonable level of management, the average yield of a middle aged plantation would be about 250 kg of cured beans per hectare. The yield may decline after 12 or 13 years of planting and so replanting is to be done at this stage.

Uses

Vanilla is one of the expensive spices traded in global market. The substance chiefly responsible for the fragrance, flavour and pleasant aroma of the vanilla beans is vanillin ($C_8H_8O_3$). Vanilla essence is largely used in the preparation of ice creams, chocolates, bakery products, puddings, pharmaceuticals, liquors, perfumes, soaps, etc. With the advent of chemical technology to produce vanillin, various types of vanillin such as ethyl vanillin, synthetic vanillin, other natural flavours and secondary metabolites have taken over the use of natural vanillin. Nevertheless, natural vanillin is still the most preferred as a spice for flavouring food owing to its delicate aroma with pleasant taste. World over, there is an increasing trend for use of natural products and therefore the share of natural vanillin is likely to increase to a great extent.

Constraints

In view of rising demand for natural products, the prospects of vanilla cultivation are wide. But the production of vanilla in India is very less. Vanilla cultivation has the problems of availability of improved varieties, restricted adaptability to high humid area, poor seed germination, hindered self pollination, etc. By evolving suitable varieties and introducing cultivation in coconut and arecanut gardens, production of vanilla can be increased in the country.

Prospects of Indian vanilla

Of late vanilla cultivation is gaining importance in our country mainly due to the R & D efforts of the Spices Board, an autonomous organization under Ministry of Commerce & Industry, Government of India. Considering the good demand for natural vanillin extracted from vanilla beans in the international market, the Spices Board has initiated programmes for its development. The area under cultivation has steadily increased since 1990. The area which was only a few hectares has increased to over 1000 hectares by now. There is a big market for vanilla essence in India but today almost entire vanilla essence used is synthetic. Considering the growing international market and the possibility to use natural vanillin in our country, there is a bright future for vanilla cultivation in India in the years to come.

Biology and cultivation of grain amaranths

V. Prajitha and J.E. Thoppil
Cell and Molecular Biology Division, Department of Botany, University of Calicut, Kerala-673635, India.

"Amaranth - thou art immortal and dost never fade, but bloomest for ever in renewed youth" were the words of rose to amaranth according to Aesop, the Greek story teller.

Amaranth has always been in the limelight as a crop for farmers and as a topic of interest for researchers. The plant gets its name from the Greek word *amaranthon* meaning 'unfading' or 'immortal'. Interestingly, this plant has been a favourite of poets too. The beauty of its unfading flowers was even referred to by famous poets like John Milton, Francis Thompson, Samuel Taylor Coleridge and John Keats. In the poem 'The Hound of Heaven' (1893), Francis Thompson even goes a step further to compare God's love to "an amaranthine weed". No words can express the beauty and popularity of this leafy and grain crop than those mentioned above.

The question why this crop has attained global attention, points to its peculiar properties, mysterious origins and current agricultural development. And, it is increasingly popular with gardeners who find it fascinating for its ease of cultivation, colourful appearance and diverse uses in the kitchen. Owing to its wider adaptability, low production cost and high nutritional value, it played a major role in wiping out malnutrition and hunger amongst the poorest populations in Africa in the past 20 years. It serves as a poor man's vegetable. There are evidences for this plant being grown from prehistoric times. A plant grown as a food crop 1000 years ago could be one of the answers to coming dry seasons. It can definitely ensure global health and food security in future. Hence this plant can rightly be considered as a food from the past for the future.

The word 'amaranth' in Greek means 'everlasting' and in fact, the crop has endured. To assure a small annual supply of this crop, traditional farmers have continued to grow small plots of the grain each year. Furthermore, the distinctly beautiful appearance of amaranth has helped to prevent the crop from slipping into obscurity.

The small seed size of amaranth might have been a partial cause for the reduction of amaranth cultivation in some areas. As a small seeded crop, it requires greater attention in the early parts of the growing season when compared to a larger seeded crop like maize. The cultivation of grain amaranth is now in the process of expanding in a number of countries. Grain amaranth research at Rodale Research Center (RRC, Pennsylvania, USA) focuses on three areas: germplasm preservation and utilization, the development of improved lines and outreach and information dispersal. Over the past ten years, RRC has sent seeds of segregating accessions and improved lines of grain amaranth to researchers of over 70 countries. Many of those countries now have internally funded amaranth projects of their own. The American Amaranth Institute (AAI), which has been organized to promote research and development in amaranths, is working closely with many other research institutions to develop standards for amaranth seed certification.

Farmers are developing innovative techniques to find ways to produce grain amaranth economically. As a result of their ingenuity, the supply of commercially available amaranth has increased to the point where several food companies are producing amaranth products which can be purchased in many stores in the USA. The rising demand for amaranth food products will require a substantial increase in amaranth production during the coming years.

There are reports from collaborating researchers that there are substantial plantings of grain amaranth in Mexico, Kenya and China to produce grain for export, as well as for domestic use. Even though several advancements are being made in the development of grain amaranth species, it is important to stress that many research questions and developmental opportunities still exist for those who wish to make an impact on the expansion of this crop.

Origin and distribution

Amaranth is a very old cultivated crop believed to have originated in the American continent. It has been a staple food in Mesoamerica for thousands of years, first collected as a wild food and then domesticated at least as early as 4000 BC. About 60 species are native to the Americas, whereas less numerous are the species originally from Europe, Africa and Asia. The most widespread species are native to North, Central and South America and these are *Amaranthus cruentus, A. caudatus* and *A. hypochondriacus.* The species *A. cruentus* and *A. hypochondriacus* are native of Mexico and Guatemala and *A. caudatus* is widely distributed both in South America and India. This species developed as one of the staple foods for the ancient inhabitants of the Andean region. The Aztecs, Incas and Mayas considered amaranth as their staple food together with maize and beans. It is one of the traditional food plants in Africa used to wipe out malnutrition within poor segments of the population. It was one of the most important crops of America before Spanish colonialists conquered it and further cultivation of the crop was banned. Amaranth was first introduced as an ornamental plant to Europe in the 16th century. Different species of Amaranth spread throughout the world during 17th, 18th and 19th century. In India, China and even under the harsh conditions of Himalayas this plant became an important grain and/or vegetable crop. After the arrival of the Spanish Conquistadors in Mexico in the early 1500s, amaranth almost disappeared in the Americas as a crop until research began on it in the U.S. in the 1970s. In the meantime, amaranth had spread around the world and became established for food use of the grain or leaves in places such as Africa, India and Nepal. In the past two decades, amaranth has reiterated to be grown by a much larger number of farmers around the world in China, Russia, parts of Eastern Europe and South America and is re-emerging as a crop in Mexico. Amaranth was grown as a grain crop in the U.S. in the late 1970s. The valuable characteristics of amaranth grain, combined with its adaptation to a wide range of growing areas, make it a very promising crop for the future. At present amaranth is grown in the USA, South America, Africa, India, China and Russia. The Czech Republic is the most important grower in Europe (approx. 250 ha). The largest area of the grain-type amaranth is in China, where 150,000 ha are reportedly grown for forage use. *Amaranthus* is the most popular leafy vegetable in india, mostly cultivated in Kerala, Tamil Nadu, Karnataka, Maharashtra, Andhra Prasesh and Telangana.

Botany

The genus *Amaranthus* belongs to the monoclamydous family Amaranthaceae and consists of 60–70 species, 40 of which are considered native to the Americas. Over 400 varieties within these species are found throughout the world in both temperate and tropical climates. The three grain amaranth species *viz*. *Amaranthus caudatus* L., *Amaranthus cruentus* L. and *Amaranthus hypochondriacus* L. are cultivated in Mexico, Central America and the Andean highlands of Southern America for several thousand years. The species have gained high popularity in the Indian subcontinent as well. These amaranth grains are highly rich in protein and the essential amino acid lysine. In recent years these have received global attention, being a quality protein crop that can stand remarkably well against abiotic stress under marginal management practices. One motivating factor for the initiation of the amaranth research evolves from the perceived need to broaden the food base by the utilization of underutilized food materials. Amaranth is one of the 23 tropical plants recommended for studies aimed to enhance food quality in the tropics.

Grain amaranths are herbaceous annuals with upright determinate growth habit. They are tall (0.5–2 m) and moderately branched from a main stem or unbranched and develop dense panicles at the tip of the stem. They are characterized by large to moderately large complex inflorescences comprising of aggregates of cymes. Most amaranth species are monoecious and a few are dioecious. The flowers can be terminal or axial, but are always organized into glomerules within the inflorescence. Within the glomerules the first flower is generally staminate and the later flowers are pistillate.

The flowers show 5 tepal lobes, 5 stamens and unilocular superior ovary. The seeds show variable seed coat colour. Vegetable amaranths can be easily distinguished from grain amaranths by inflorescence features like mostly or exclusively axillary glomerules or short spikes, origin of flower bud from leaf axil, 3 tepal lobes, 3 stamens, brownish black seeds and indeterminate growth habit. They form flowers and seeds along the stems and set seeds at a smaller size during short days. Grain types may produce yields comparable to rice or maize [2,500 kg/ha].

Amaranth is a quantitative short day plant, which is an advantage in the subtropics where the generative stage is delayed during summer. Amaranths like fertile, well drained alkaline soils (pH > 6) with a loose structure. The mineral uptake is very high. Flowering of *Amaranthus* species can start 4–8 weeks after sowing. However, the growth and development patterns are highly variable from one species/cultivar to the other and may also depend on photoperiodism, altitude and cultivation practices. Overall, the three grain species have a longer growth period than weedy species.

In the *Amaranthus* genus, several species are weeds, a few are ornamentals, some are leafy vegetables and some are having forage use potential. Grain amaranths are 2 to 8 feet tall, but the most commonly grown variety 'Plainsman' (a hybrid of *A. hypochondriacus* x *A. hybridus*) is usually 5 to 6 feet tall. Plainsman has a single unbranched stem, with a large mass of tiny maroon flowers clustered in an inflorescence at the top of the plant. Grain heads of 'Plainsman' range from 4 to 12 inches in length and 2 to 8 inches in width. Grain amaranths vary in flower, leaf and stem colour, but maroon or crimson colour is common in these plant parts. Some varieties have green flowers and others are golden. Some of the deep crimson varieties can be very striking when in full bloom. A few small clusters of flowers may occur at the first few leaf axils below the head.

The grain, vegetable, ornamental and weedy types do have some distinct variations. The leaves and grains of all types are edible and equally nutritious. The seed or grain of the grain type is of a pale colour, varying from off-white to pale pink. The seeds of the vegetable, ornamental and weedy types are black and shiny. Both types are edible and may be used as flour sources, but if the black seed types are mixed in the pale types, it is often considered as adulteration. The grain amaranths are characterized by having discoid grains with well differentiated folded flange region and seed coat colour other than black or brownish black. So the seed character is very useful in demarcating vegetable, grain and weed amaranths.

Amaranth has a 'C-4' photosynthetic pathway as in the case of other cereals, which enables it to be uniquely efficient in utilizing sunlight and nutrients at high temperatures. It is more drought resistant than maize and thrives in 30–35°C temperatures and tolerates poor fertility also. Amaranth can be cultivated in some areas where farmers have limited options, especially in those areas with limited rainfall. The drought tolerant characteristics of amaranth make it a prospective dry land crop for farmers in semi-arid areas. Amaranths as C4 plants, grow rapidly under a variety of unfavorable abiotic conditions, including drought stress, heat stress, high salinity, etc., making them uniquely suited for subsistence agriculture.

In botanical terms, grain amaranth is not a true cereal because it is a dicotyledonous plant. Hence they are referred to as 'pseudocereals', as their seeds resemble in function and composition those of the true cereals. Amaranth seeds are small (1-1.5 mm diameter), lenticular in shape and weight per seed is 0.6-1.3 mg. The grain structure of amaranth differs significantly from that of cereals such as maize and wheat. In amaranth seeds, the embryo or germ, which is circular in shape, surrounded by the starch rich perisperm and together with the seed coat represents the bran fraction, which is relatively rich in fat, protein, vitamins and minerals. Seed production in grain amaranth varies with growing conditions. Seed production per plant could be estimated from plant height and basal stem diameter. The size and weight of the seeds vary between the populations of the same species, between the individuals of the same populations and even between seeds on the same plant. Seed dispersal is accomplished by wind, water, birds and animals and also by human activities. *Amaranthus* seeds are light weight, but not otherwise adapted for wind dispersal.

Several investigations are going on to gather phylogenetic relations among the three species of grain amaranth to provide information for breeding experiments, germplasm conservation efforts and decision on evolutionary patterns in the grain types. Hybrid development programmes from crosses between these species have been carried out to find out the genetic relationship between them. Interspecific crosses have been made and it has been found that that *A. cruentus* is closer to *A. hypochondriacus* than *to A. caudatus. A. caudatus* is also closer to *A. hypochondriacus* than to *A. cruentus*.

Cytogenetics

The genus *Amaranthus* is characterized by small sized chromosomes with indistinguishable secondary constriction, satellites, etc. and this fact has restricted the cytogenetical studies of this crop. The taxonomy of the genus *Amaranthus* has also been confusing due to the extreme range of phenotypic plasticity among the species and the possible introgression and hybridization involving weedy and crop species.

Karyomorphological studies in *Amaranthus* are scarce, probably due to higher number of small sized chromosomes. Updated data have indicated that there are two basic chromosome numbers such as x=8 and 9 in the family Amaranthaceae. The genus *Amaranthus* is tribasic, because three gametic numbers *viz*., n = 14, 16, and 17 were reported previously. The gametic number n=17 seems to be originated from n=16 through primary trisomy. In some cases both 16 and 17 can occur in the same species. Based on cytogenetic analysis of interspecific hybrids, it has been proposed that the species with 2n=32 are polyploids (basic number x=8) and that x_2=16 is a derived basic number. The basic number x_2=17 would have appeared later by primary trisomy. A study pertaining to the karyological details of the three grain amaranths *viz*., *A. caudatus*, *A. cruentus* and

A. hypochondriacus has revealed the diploid chromosome number as 2n=32, 34 and 32.

Crop improvement

Grain amaranths are pseudocereals that played an important role as human food in the ancient civilizations of America. Current interest in amaranths resides in the fact that they exhibit high nutritional value, C_4 photosynthetic pathway, great amount of genetic diversity and phenotypic plasticity. Amaranths are predominantly self-pollinated with varying amounts of outcrossing. By growing amaranths in isolation, it is possible to control the amount of outcrossing for the development of true to type lines from segregating accessions within a few generations of selection. Many selections have been made from the segregating accessions in an effort to create uniform lines. Seeds from the amaranth accessions have been distributed to thousands of researchers and farmers around the world. The germplasm collections at various institutes such as RRC, AAI, CAAS, INIFAP, UNSAAC/CICA, NBPGR, etc. are the backbones of varietal improvement programmes aimed at developing agronomically acceptable lines using classical plant breeding and selection methods. *Amaranthus*is well suited to *ex-situ* conservation because the seeds are long lived and small.

Identification and preservation of germplasm are necessary for maintaining genetic diversity, studying local genetic material in order to choose ecotypes having high nutritional interest in their place of origin, and initiating breeding programmes. RRC has got approximately 1,400 accessions mostly represented by *A. cruentus*, *A. hypochondriacus*, *A. caudatus*, *A. tricolor* and *A. dubius*. The *Amaranthus* germplasm collection of the Plant Introduction Station (USDA, USA) includes approximately 3,000 accessions. The National Botanical Research Institute (NBRI, India) has one of the best collections of amaranth germplasm in the world with over 2,500 accessions referable to 20 species. The World Vegetable Center (AVRDC, Taiwan) holds a collection of about 520 accessions of 18 amaranth species.

The breeding objectives of grain amaranths include raising yield, increasing harvestability and developing properties like lodging resistance, reduced seed shattering, seedling vigour, uniform maturity, synchronous drydown of the plant and seedhead, reduced leafiness in the green head area, reduced plant height, pest resistance/ tolerance, tolerance to damping off, larger seeds, good nutritional profile of seed (high seed protein), tolerance to cold, etc.

Four grain amaranth varieties registered in Crop Science are 'Montana 3' ('MT 3'), 'Montana 5' ('MT 5'), 'Amont' and 'Plainsman'. Several lines have been developed by RRC, NU-World Amaranth and AAI, and have been widely distributed and tested. All of the registered cultivars trace to materials developed by the RRC. The cooperative amaranth breeding programme between the RRC and the University of Nebraska started in 1992 resulted in the release of the variety 'Plainsman'. Breeding objectives for 'Plainsman' development included early maturity, light seed colour and short plant height. 'Plainsman' matures in 110 days after planting in some of the planting areas. Evaluation tests in Nebraska, Colorado, Missouri, Minnesota and South Dakota indicated that 'Plainsman' was one of the most promising amaranth cultivars for the United States. It became popular due to its relatively high yield potential, lodging resistance, limited seed shattering, seed colour and early maturity.

In India, a grain amaranth variety named 'Annapurna', a cultivar of *A. hypochondriacus* has been developed through selection in India. Annapurna's average grain yield is 22.3q/ ha. The whitish creamy seeds of Annapurna contain about 14.5% protein and it shows excellent popping quality. It shows the following plant and yield characters: plant height: 220-225cm; flowering: 75 days; maturity: 140-145 days; stem: stout, generally unbranched, ridged; foliage: leaves broad, dark green, lanceolate (24 cm x 12 cm); inflorescence: long (70 cm), green, compact with terminal and lateral spikelets; test weight: 0.8-0.9 g/1000 seeds; seed colour: cream white.

Other varieties developed are 'Pastevnyi 1', 'Turkestan' and 'Ural' of Russia; *A. cruentus* variety 'Anden' of South America and 'Noel Vietmeyer', 'Oscar Blanco' and 'Alan Garcia', released from selection programmes in Peru.

The cultivated species of grain amaranth are monoecious. Conventional and modern methods of hybridization have been used to improve grain amaranths. Recently the potential for the development of hybrids has been advanced by the identification of gene markers. Markers can be used to identify and discard self-pollinated plants in the F1 generation. In addition, markers allow breeders to avoid the process of emasculation when making crosses. The identification of three sources of cytoplasmic male sterility paved the way for additional hybridization techniques. Genetic investigations have been conducted in India to learn more about the traits which control yield, including harvest index, yield per plant and weight per 1000 seeds. There have also been some unique investigations to identify the mode of inheritance of traits that affect the nutritional characteristics of the grain.

Uses and economic importance

The demand for food is increasing, not only to meet food security for growing populations, but also to provide more nutritious food, rich in good quality proteins and nutraceutical compounds. Amaranth is a valuable nutritious foodstuff with high production potential. The edible parts are the seeds, leaves and tender stems. They are non-grass, broad-leaved plants that produce small seeds on a sorghum like head. The grain is a pseudo cereal consumed in various parts of the world due to its higher dietary benefits.

The amaranth species as a group is used for a wide variety of purposes. Leaves and stems are interesting vegetables suitable for soups, salads and other dishes, used across Africa, Asia and the Americas. *A. dubius, A. cruentus* and *A. tricolor* are adapted for growth as leafy vegetables in areas with hot climate, especially in the hot humid tropics. The leaves are a good source of carotene, iron, calcium, ascorbic acid, vitamins and proteins. In Africa and the Caribbean, amaranth is commonly eaten as a pot herb, with individual leaves picked off the plants periodically. The leaves of both the grain and vegetable types may be eaten raw or cooked. Amaranths grown principally for vegetable use have better tasting leaves than the grain types. A dark seeded strain of *A. cruentus* L. is commonly cultivated as a vegetable in West Africa.

The food value of grain amaranth was recognized by the people of Mexico, Peru and Nepal long before any nutritional analyses had been conducted. Because it is easy to digest, amaranth is traditionally given to those who are recovering from illness or a fasting period. Amaranth is used as an ingredient primarily in bread, pasta, baby foods, instant drinks, etc. For such purposes seeds have to undergo processing through boiling, swelling, flaking, extrusion, puffing, roasting, grinding, sprouting, etc. The most common product is flour and whole amaranth seeds in breads, musli bars, porridges, pastas, biscuits, cookies, etc. In Mexico, grain amaranth is popped and mixed with sugar solution to make a confection called 'alegria' (happiness). A traditional Mexican drink called 'atole' is made from milled and roasted amaranth seeds. In India, *A. hypochondriacus* is known as 'rajgeera' (the King's grain) and is often popped to be used in confections called 'laddoos' which are very similar to Mexican 'alegria'. In Nepal, amaranth seeds are eaten as a gruel called 'sattoo' or milled into a flour to make chapattis.

Grain amaranth species are cultivated exclusively for seed production in the U.S. and other regions of the world. The attraction of the crop to both earlier civilizations and modern consumers is the highly nutritious golden seed. The most studied nutritional aspect concerning the food value of grain amaranth is the identification of the limiting amino acids of the protein component. The crude protein content of selected light seeded grain amaranths has been reported to range from 12.5 to 17.6%. The grain is reported to have high levels of lysine, a nutritionally critical amino acid, ranging from 0.73 to 0.84% of the total protein content. Lysine is an amino acid which is deficient in other grains. Its high lysine content makes it particularly attractive for use as a blending food source to increase the biological value of processed foods. The high protein content, the well balanced amino acid profile, high content of fat, fibre and minerals all make the grain amaranths candidates for a renewed major role as world food source. Grain species of *Amaranthus* are not only richer in protein content than other cereals but also their properties for human diet are closer to nutritional perfection.

Amaranth is valued for the positive chemical composition of seeds that does not contain gluten/prolamin, a composite of storage proteins, stored together with starch in the endosperm of various grass related grains. Consumption of gluten rich grains will cause celiac disease in sensitive individuals. The individuals, who are allergic to wheat, use substantial quantities of amaranth grain and find that they can substitute amaranth for wheat without an allergic reaction, since amaranth is gluten free.

Starch is the major part of carbohydrate in grain amaranth and starch granules are small (1-3 mm), polygonal in shape, with high swelling power and is easily degradable by alpha-amylase. Amaranth starch is highly stable during freezing and highly resistant to mechanical stress. There is a distinctive gel characteristic to the starch and both waxy and non-waxy starch granules have been identified. Interest has been expressed in specialized food and industrial applications for amaranth starch as a result of its distinctive characteristics. The most intriguing is the microcrystalline starch in amaranth seed, which is about one-tenth the size of corn starch particles. The small size of the starch could be of value in both food and industrial uses.

Amaranth grain contains 6 to 10% oil, which is found mostly within the germ. The lipids are rich in tocotrienols and squalene, which are natural organic compounds positively involved in lowering low density lipoprotein blood cholesterol. Amaranth lipids are characterized by a high degree of unsaturation, which is desirable from a nutritional point of view. Linoleic acid is the most abundant fatty acid followed by oleic acid and palmitic acid. Another interesting component of amaranth oil is squalene, a terpenoid compound ubiquitous in the unsaponifiable fraction of cereal grains, used in medicines and cosmetic industry. Amaranth seed oil contains approximately 6% of squalene a considerably higher amount than usually found in oils from other cereal grains. Its importance as a food constituent resides in its ability to lower cholesterol levels by inhibiting its synthesis in the liver. Plant sterols (phytosterols) are another group of biologically active components present in pseudocereal lipids. Phytosterols, which cannot be absorbed in the human intestine, have very similar structure to cholesterol and they inhibit intestinal cholesterol absorption, thereby lowering plasma total and low-density lipoprotein (LDL) cholesterol levels. Total sterols in amaranth lipids can represent approximately 20% of the unsaponifiable fraction with the predominant sterol present being chondrillasterol.

Amaranth which produces a large amount of biomass in a short period of time can be used as a forage crop for domestic animals. Several cuttings can be made per growing season. The forage use of amaranth is established in both the tropic and temperate zones. In many tropical areas, where amaranth is consumed as a vegetable, amaranth stover is fed to livestock after several harvests.

Amaranth forage has succeeded as an animal feed in the temperate zone of China. In Peru, stover is grazed or milled for use as a feed supplement after the seed heads have been hand harvested. In the U.S., animals always used to eat wild amaranth, but not as a deliberately managed forage.

Many amaranths have become popular ornamental plants and are found worldwide. Examples include brightly coloured *A. tricolor* ‘bedding plants’ and *A. caudatus* ‘love lies bleeding’ plants with beautiful drooping rope like inflorescences. The enchanting beauty of the vividly coloured leaves, stems and seed heads in an amaranth field is a sight which evokes emotions that other crops cannot give.

Studies have shown that as pseudocereals, amaranths represent good sources of minerals, vitamins, dietary fibre and natural dyes. Contents of minerals depend on species and growing conditions. Amount of calcium and magnesium are higher than amounts in other cereals. The anthocyanin (reddish) pigments in amaranth flours and vegetable appear to have great potential for competing with sugar beets as a source of natural, non-toxic red dyes. Seeds are good source of vitamins mainly Vitamin B and E. Polyphenol compounds have been extensively researched in the last decade for health promoting properties such as their role in the prevention of degenerative diseases which include cancer and cardiovascular diseases. The main phenolic compounds found in amaranth seeds are caffeic acid, p-hydroxybenzoic acid and ferulic acid.

In addition to nutritional properties, grain amaranths are already known for their high medicinal value. Several studies have shown that amaranth seeds or oil may benefit those with hypertension and cardiovascular diseases, regular consumption reduces blood pressure and cholesterol levels, while improving antioxidant status and some immune parameters. In Ethiopia, *A. cruentus* is used as a tapeworm expellant. In Sudan the ash from the stems is used as a wound dressing and in Gabon heated leaves are used on tumours.

Some types of amaranths accumulate toxic levels of oxalate and nitrate when grown under conditions of stress. The occurrence of phenolics, saponins, tannins and phytic acid (a well-known inhibitor of iron absorption and other minerals), in the whole grain has also been reported. Some studies suggested that thermal processing of amaranth, particularly in moist environment, prior to its preparation in food and human consumption may be a promising way to reduce the adverse effects of amaranth’s antinutritional and toxic factors.

Future prospect of grain amaranth

Amaranth is a versatile crop with a long history of domestication and use. To date only a modest amount of research and plant breeding have been done with this plant, mostly with the grain types. Amaranth is an important plant to diverse human populations around the world, but its use could be greatly enhanced through further breeding and research. With the diverse collection of germplasm available, rapid progress could be made with a minor investment in screening and breeding projects. Investigations by amaranth researchers and farmers around the world have provided a solid foundation for further development of this valuable crop plant. Additional research is needed to better define the feeding values, potential toxicity problems and possible cultivation strategies of both utilized and underutilized grain amaranth species.

Biology and cultivation of coffee

V.B. Sureshkumar
Regional Coffee Research Station, Narasipatnam, Andhra Pradesh-531116, India.

Coffee is the most popular beverage and a very important commodity. Among the traded commodities in the global market, oil is the first, coffee the second, natural gas the third and gold the fourth in position. Coffee is cultivated from 25° North to 25° South of the equator in Africa, South East Asia and Central and South America. Global production of coffee is around 96.32 lakh tonnes presently. Brazil is the major producer, sharing one third of global production. Out of the total global production, more than 90% is produced in developing countries. Nevertheless, major quantity is being consumed in developed counties.

In India coffee is cultivated mainly in the hilly tracts of Karnataka, Kerala and Tamil Nadu. Coffee based farming systems with suitable intercrops is now widely being popularised in Andhra Pradesh, Odisha and north-eastern states to check deforestation and sustain the livelihood of the tribal people of these regions, as these areas are found suitable for coffee. In India, presently coffee is cultivated in an area of around 4.5 lakh hectares with average annual production above 3 lakh tonnes.

Production of coffee in major producing countries (MT)

Countries	Arabica	Robusta	Total
Brazil	2736000	630000	3366000
Vietnam	66000	1536000	1602000
Columbia	876000	0	876000
Indonesia	78000	558000	636000
Honduras	444000	0	444000
Ethiopia	391200	0	391200
India	94980	217020	312000
Others	1363320	641340	2004660
Total	6049500	3582360	9631860

India exports around two third of its production. Major quantity is exported to Italy, Belgium, Turkey and Russian Federation. India's coffee exports generated revenue of Rs.5600 crores during 2016-17.

Botany

Coffee belongs to the family Rubiaceae. Coffee is the most economically important genus of the family. There are about 100 species of coffee. But *Coffea arabica* (Arabica coffee) and *C. canephora* (Robusta coffee) are the two economically important species and are cultivated on large scale. *C. liberica* (tree coffee) is also cultivated to a small extent in some regions. *Coffea arabica* is tetraploid (2n=44) and it is the major variety cultivated. If untopped, Arabica grows like a small tree to a height of over 30' (9m) but on regulation through training/pruning it looks like a small bush. *Coffea canephora* is diploid (2n = 22) and the second largest cultivated species. It is robust in growth compared to Arabica. Without training/pruning it also becomes a

Area and production of coffee in different states of India

State	Area under coffee (Hectares)			Production of coffee (Metric tonnes)		
	Arabica	Robusta	Total	Arabica	Robusta	Total
Karnataka	108845	135940	244785	70510	151235	221745
Kerala	4228	81642	85870	2140	61125	63265
Tamil Nadu	29513	6094	35607	11850	4485	16335
Andhra & Odisha	75327	267	75594	10400	50	10450
NE States	5903	1598	7501	100	105	205
Total	223816	225541	449357	95000	217000	312000

tree. Due to cross-pollination, wide ranging variation within the population is observed.

Both Arabica and Robusta are perennial evergreens. They have prominent vertical stems with horizontal branches in pairs opposite to each other, known as primaries. The upright shoots, arising from the stem is known as 'suckers' or 'water sprouts'. These grow more profusely when the plant is topped. These orthotropic suckers are used in vegetative propagation. The shape of coffee leaf is usually elliptical. The length and breadth of coffee leaf vary considerably depending on the species, shade intensity and cultivation practices.

Flower buds appear at the leaf axils of mature wood and sometimes on green wood as inflorescence. Four to six inflorescences are produced per axil, each inflorescence containing up to 5 to 6 flowers depending on various influencing factors. Under South Indian conditions the mature buds blossom in the dry months of February to April, seven to ten days after receipt of the first summer showers or irrigation. Arabica is predominantly self pollinated with different degrees of natural cross pollination in contrast to Robusta, which is strictly cross pollinated. Pollination occurs within 6 hours after flowering under bright light. Wind, gravity and bees help pollination. The process of fertilization is completed within 24 to 48 hours of pollination. In Arabica, period of development from flower to ripe fruit is about 6 to 8 months, whereas in Robusta it is about 9 to 11 months.

Coffee fruit is a drupe with fleshy pericarp (fruit skin) having deep red colour in general. Below the fruit skin lies the mucilaginous layer surrounding the hard parchment cover containing the coffee bean of commerce. Normally each fruit contains 2 beans, elliptical or egg shaped, with the seed coat known as silver skin. Sometimes abortion of one ovule due to non-fertilization leads to the formation of a single seed, the 'pea-berry'. Occasionally 3 or more seeds may be seen due to the presence of more than one ovule per locule.

Coffee consists of a stout central root growing 0.5 m to 1 m depth with 4 to 8 axial roots. The lateral roots grow more or less parallel to the soil surface to a distance of 1.2 m to 1.8 m from the trunk. The feeder roots are seen in larger numbers in the surface soil. The concentration of the feeding roots increases from the centre towards the periphery. In Arabica feeder roots are the highest at the 30-60 cm layer and in Robusta they are concentrated in the first 30 cm layer.

Climatic factors suitable for coffee cultivation

For successful establishment and economic production of coffee a variety of factors, climatic as well as edaphic, must be optimal. As coffee is a perennial crop and economic life span of a plantation ranges from 40 to 70 years depending upon variety. Selection of a proper site is imperative to make it productive and profitable.The optimum altitude for Arabica coffee is 1000-1500m (3250-5000 feet) and for Robusta coffee is 500-1000 m (1600-3520 feet).

The term aspect is used to describe the slope of the land in relation to the direction of the position of the sun in the morning hours.

In general, north, east and north-east aspects are ideal for both Arabica and Robusta. However, the desirable aspect depends on the altitude. Absence of adequate shade and direct exposure to sunlight in the afternoons can destroy the chlorophyll, resulting in leaf yellowing and berry blotch particularly in the presence of a heavy crop. A block with gentle slope lesser than 15% is ideal for coffee.

For Arabica, the optimum temperature range is 15°C to 25C. For Robusta, a higher temperature range of 20°C to 30°C is ideal. Though it can withstand an occasional fall of temperature up to 7°C, long periods of even 15°C interfere with the physiological processes. Frost damage is caused by a fall in the temperature of the coffee tissues below the lethal limit of 3°C. Compared to Arabica Robusta is more susceptible to low temperature.

Since coffee is, by and large, a rainfed crop, rainfall is of fundamental importance for cultivation of all the species of coffee. For Arabica, a rainfall of 1500-2000 mm (60-100 inches) and for Robusta, 1000-2000 mm (40-80 inches) is required. More than the quantum of the rainfall, equitable distribution is very essential. Blossom showers of 25-50 mm (1-2 inches) and backing showers of 50-75 mm (2-3 inches) for Arabica in March-April and almost the same quanta of rainfall for Robusta during February-March are indispensable for successful blossom and fruit set. Early showers without backing showers or very late showers cause physiological disorders. Failure of these summer showers results in crop loss unless irrigation is provided. Apart from timely summer showers, a well distributed rainfall during the developmental and ripening stages of the berries, i.e., from June onwards till October-November is necessary for a good crop. The optimum relative humidity for Arabica is 70-80% and Robusta is 80-90%. It is ideal to plant coffee under shade so as to get 50% of day light for Arabica and 70% of day light for Robusta.

Coffee prefers deep, well drained, loamy soil with plenty of humus and exchangeable bases. A deep soil provides a larger volume for root proliferation to explore water and nutrients. Coffee soils in India belong to the red and lateritic soil groups. The organic matter status and soil pH as prevailing in most of the hilly and forest soils of South India are favourable for coffee. Slightly acidic soil (pH 5.8 to 6.0) is the most favourable for root growth.

Propagation of coffee

Though coffee could be propagated through seed as well as vegetative parts, seed propagation is common and easy. But in the case of cross-pollinated Robusta and hybrid Arabica, seed progenies tend to be highly segregating unlike in self-pollinated Arabica.

Seed propagation

Selection of mother trees, collection of fruits and preparation of seeds

The selected mother plants must be healthy, free from diseases and good yielders with lesser number of defective beans, pea berries and floats. The block where the mother plants are identified should be free from 'off-type' plants. To get seeds of Arabica true to type and to avoid cross pollination advance blossom irrigation is given to the selected plants/blocks. Ripe but not over ripe fruits, perfect, free from disease are picked from the selected plants, washed with clean water and floats are removed. The same day, the berries are carefully pulped using a hand pulper. After removing the remaining cherry skins, the slimy beans are again stirred in clean water and any left-over floats are removed. All damaged, deformed, small and discoloured beans are discarded. The beans are then mixed with finely sieved wood ash, evenly spread to a thickness of about 5 cm and allowed to dry slowly in shade. They are stirred twice or thrice a day to facilitate uniform drying. After drying for 5 days, excess ash is rubbed off and packed. It is desirable to treat the seed evenly with a fungicide like Bavistin 50 WP (1 g/kg) or Vitavax 75 WP (0.66 g/kg) to protect the seeds from fungal infection. Dried seeds should be sown at the earliest possible as the coffee seed looses viability on storage.

Nursery site and artificial shade

The site selected for nursery should be either a flat land or a gentle slope with a good water source nearby. Coir mats or synthetic nursery mats capable of providing varying intensity of shade from 50% to 75% shade cover can be used for shade. Precaution should be taken to roll up the mats during continuous rain to ward off diseases.

Primary bed

The primary nursery bed is just a raised platform of sieved loamy soil with enough organic matter or jungle soil free from nematodes, stones, clods or plant debris. Sand could be mixed to improve drainage. The bed should be free draining. The primary bed could be of 1 m width, 15 cm height and length of any convenient size. Seeds are sown immediately on receipt as germination gradually decreases. The seeds are placed about 2.5 cm apart and 1 cm deep, facing flat side downwards, by gently pressing with the thumb. Deep sowing is avoided. After lightly covering the seeds with soil, the entire bed is covered with paddy straw to conserve moisture and warmth. Watering, preferably using a water can, is done once a day. Germinating coffee seeds are sensitive to extremes of soil moisture. If the soil dries out after germination, the seeds die and if the soil becomes too wet then the seeds may rot. After sprouting, the straw is removed and when the seedlings reach 'topi' or 'soldier' stage, they are ready for transplanting.

Secondary polybag bed

In the secondary bed, polybags filled with soil media are arranged for transplanting the seedlings. For this, polybags of 6"x9" (23 cm x 15 cm) size and150 gauge thickness are used. Holes are provided on lower half of the polybags for adequate drainage and aeration. Soil mixture of sieved jungle soil, FYM and sand in the ratio of 6:2:1 is used. The soil used should be free from nematodes. The bags are arranged in rows of 10 and the number of rows could be multiples of 10. The bags are secured firmly without crumpling using binding wires or long bamboo splits with suitable props driven into soil.

Transplanting

While transplanting to the poly bags adequate care should be taken not to damage or bend the roots. Before lifting the seedlings from the germinating bed it is watered to loosen the soil. The seedlings are gently lifted using a sharp wooden splinter. Using the same splinter a small hole of 2 cm width and enough depth to accommodate the root is made in the centre of the bag and the seedling is placed in the hole with the collar region at the same level as found in the primary bed. Deep planting results in collar rot. The transplanted seedlings are gently pressed with the thumb and fore-finger and watered immediately. The seedlings will be ready with 5 to 6 pairs of leaves in about 4 or 5 months after transplanting.

After care

The young seedlings in the polybags may die due to 'damping off' if the soil is too wet, especially in areas of heavy rainfall. Also the seedlings should not be allowed to wilt. The frequency of watering depends upon the climatic conditions. In addition to 'damping off' disease, water stagnation or tight packing may induce iron deficiency, which is easily identified by the interveinal chlorosis (reticulation) or whitening of the emerging leaves. Making additional holes in the bag to improve drainage helps reduce the symptoms.

The seedlings must be hardened off by progressive removal of the shade over a period of weeks as sudden exposure to sun will cause leaf loss and delay the development. The seedlings should not be kept in the polythene bags for more than 6-7 months as the roots get bent or twisted.

If the growth of seedlings is not satisfactory, application of supernatant liquid of cow dung slurry is recommended to enhance growth. Alternatively, urea solution of 0.5% concentration (50g urea in 10 litres of water) could be applied two months after transplanting, once in a month. About 4 litres of the urea solution will suffice 1sq.m. area. To boost up the seedlings in case of delayed transplanting, spraying of 50 ml of Planofix/ Agrona or 60 ml of Cytozyme plus in 200 litres of water with 1 kg of urea may be taken up when the seedlings put forth 4 to 5 pairs of leaves or one month before field planting.

Vegetative propagation

Vegetative propagation assumes greater importance in cross pollinated species like Robusta or hybrids as there is no guarantee that the seedlings raised from the seeds are true to the mother plants. In coffee, clones are raised mainly from shoot.

Propagation by cuttings

In coffee, only the vertical shoots i.e., suckers (orthotropic growth) are used for vegetative propagation as the horizontal branches (plagiotropic) are unsuitable. Selection of mother plants to take cuttings is similar to that of seed propagation. Three types of cuttings are used for vegetative propagation viz., (i) single node cutting, (ii) terminal cutting and (iii) mallet cutting.

i) Single node cuttings

Three to six month old suckers (preferably pencil thickness of 1cm) are selected from the selected mother plants and single node semi-hardwood cuttings of 10 cm length are cut from each sucker with a basal slant cut and top horizontal cut at internodal region. A pair of leaves, cut to half their size, is retained at each node.

ii) Terminal cuttings

The terminal portion of the sucker after taking the single node cuttings is collected and a slant cut is given at the base to use as terminal cuttings.

iii) Mallet cuttings

Mallet cutting is 45-60 day old sucker detached from the mother plant with a piece of woody bark, using a sharp knife.

Pre-treatment of the cuttings

Before planting in the propagation trenches, the cuttings are immersed in 0.2% Bavistin solution (1g of Bavistin in 250 ml of water) for a minute to avoid any fungal contamination followed by dipping the bases of the cuttings in IBA (Indole Butyric Acid) solution for 5-10 seconds. For single node cutting 5000 ppm IBA (500 mg IBA dissolved in 50 ml. alcohol and made up to 100 ml. with water) is used for basal dipping whereas for terminal cuttings and mallet cuttings 1000 ppm IBA (100 mg of IBA dissolved in 50 ml alcohol and made up to 100 ml with water) is used.

Planting of cuttings and arranging in propagation trenches

The treated cuttings are planted in polybags, individually, containing soil mixture (6 parts sieved jungle soil, 3 parts sand and 1 part FYM). The bags are arranged in propagation trenches of 1 m width, 0.5 m depth and of convenient length. The trenches are covered with transparent polythene sheet (500 gauge) over a supporting frame in a semi-circular hood shape allowing enough space above the cuttings. As in the case of seedling nursery, the propagation trenches are arranged under overhead artificial shade. To drain off rain water narrow drainage channels are provided around the trenches. Adequate moisture level/humidity is maintained by watering once or twice a day. After rooting in about 3 months, the polythene sheet is removed and the rooted cuttings are allowed to harden under the nursery shade before planting out. The cuttings could be collected and planted during the rainy season (June-August). In the case of Robusta, rooted cuttings of different mother plants should be mixed for effective pollination and fruit set. Rooted Robusta clones give uniform yield as well as quality compared to seedling progenies. Further, they generally come to bearing earlier than seedlings.

Common nursery diseases

Damping off (collar rot)

This disease caused by *Rhizoctonia solani* is aggravated by excessive moisture in the soil. Providing proper drainage and timely transplanting reduce the incidence. In case of severe incidence, spray Carbendazim at 0.05% *a.i.*(1g/1L) or Captan or Dithane at 0.4% *a.i.* (5 g/L).

Brown eye spot

With *Cercospora coffeicola* as the causative agent, this disease becomes acute under inadequate shade. Providing adequate shade followed by spraying of Captan or Dithane or Ferbam at 0.4% *a.i.* (5 g/l of water) or carbendazim at 0.05% *a.i.* (1g/lL of water) once in 30 days helps reduce the incidence.

Stem necrosis

It is caused by *Myrothecium roridum* and is seen in seedlings during monsoon season. Disease infects both stem and leaf. Infection causes brown discolouration on the stem and necrotic spots on the leaves. Seedlings start wilting and gradually die. Judicious irrigation, removal and destroying of affected seedlings and spraying propiconazole at 0.02% (Tilt at 0.8 ml/1 L of water) at monthly intervals from May to August are recommended to control the disease.

Stem-wasting disorder (Kondli)

This is a non-parasitic disorder resulting from toxicity of copper fungicides sprayed on young plants in the nursery during inclement weather. Affected plants show constrictions at the first or second node from the base. The plants become lean and lanky and easily snap off at the constriction. Use of organic fungicide instead of copper fungicides, to control nursery diseases avoids this disorder.

Common nursery pests

Nematodes *(Pratylenchus coffeae)*

The soil for the nursery should be thoroughly checked for nematodes before use and only nematode-free soil should be used. If presence of nematodes is suspected, the sieved soil should be thoroughly dried under sun, before use.

Cockchafers (white grubs)

Use of thoroughly dried and sieved soil and cattle manure prevents cockchafers which affect the root system. It can also be prevented by installing traps during first summer showers to kill the trapped adults.

Cut worms, wire worm, crickets, aphids, loopers and caterpillars

As weeds harbour many of these pests which feed on coffee seedlings, the nursery should be kept weed free. In case of severe infestation, spraying o fEkalux 25 EC @ 2 ml or Metacid 50 EC @ 1 ml in one litre of water gives good protection.

Field planting

Once the area is selected for planting coffee, clearing of land is attended to with simultaneous arrangements for raising nursery.

Clearing of land

Generally it is recommended that some of the big, standing trees are retained during clearing of land to provide initial shade to the newly planted young plants. After extracting the remaining undesirable trees, a thorough cover-digging to a depth of 1’ (30cm) is given and all the roots and stones are removed followed by incorporation of the underground vegetation. Adequate ‘fire-path’ is maintained all around the estate during dry months to prevent spread of forest fire. After clearing the land, the next important work to be attended to is soil conservation measures as soil erosion is a serious problem in the high rainfall areas of coffee growing hilly tracts. Contour bunding and terracing are effective in slopes.

Planting in the field

Tall selections like Sln.3, Sln.4, Sln.5, Sln.6, Sln.8 and Sln.9 should be planted at 7’ x 7’ (2.1 m x 2.1 m) and semi-dwarf selections like Chandragiri should be planted at 6’ x 6’ (1.8 m x 1.8 m). Spacing recommended for Robusta selection Sln.1R (S.274) is 10’ x 10’ (3 m x 3 m) and for SIn.3R (CxR) is 8’ x 8’ (2.4 m x 2.4 m). In south-west monsoon area, where planting is done in June, pits could be taken in March-April after the summer showers and kept open for weathering. In north-east monsoon area where planting is taken up during September, pits are taken in June at the onset of South-West monsoon rains. A pit of 45 cm x 45 cm x 45 cm is recommended. The back-fill in the planting pit should be a mixture of top soil, well decomposed, dried and cockchafer free FYM along with 30 g of rock phosphate one month prior to planting for the filled up soil to settle down. As adequate soil moisture is essential for initial establishment, planting is taken up as soon as the monsoon starts. In south west monsoon zone, planting is done in August, whereas in the north east monsoon zone, it is just after the first showers of the north east monsoon in September.

Disease free and healthy seedlings are planted in the marked and already closed pits. The bottom most portion of the nursery bag (1 cm) containing the seedlings is chopped off and the polythene bag should be removed invariably. After placing the seedling in the hole made to accommodate the bag just before planting, it is firmed up using the feet. Care is taken to plant the seedlings a little above the soil surface to give allowance for possible sinking and to avoid collar rot in case of water stagnation. Hot sunny days, very wet days and windy days are not desirable for planting. Planting in sticky soils is to be avoided.

Aftercare

As swaying of seedlings in windswept areas delays establishment, two stakes are inserted criss-cross against the wind direction with the plant in the cross junction. Mulching with dry leaves is done around the plant to a distance of 1’ (30 cm) from the stem to prevent washing off of the soil around the plant. Immediately after the cessation of rain, the plants are protected from hot sun and cold night with small huts of coconut thatches or loosely knit open bamboo baskets. The huts are fixed with stakes in such a way that it could be slowly raised to accommodate the growing young plants. Along with coffee seedlings, both permanent and temporary shade trees are planted. Once the temporary shade is able to give adequate protection, the huts are removed and additional mulch is placed. Care is taken to see that the huts do not suppress the seedlings. If the shade is inadequate and plants are exposed to hot sun, the young plants may succumb to leaf spot disease caused by *Cercospora coffeicola*. It is always advisable to fill up the gaps caused by the death of young plants in the initial or gestation period itself, otherwise it will be very difficult to fill up the gaps later as supply plants have to struggle to survive under the established plants or shade trees, due to root competition.

Replanting and rejuvenation grafting

The economic productivity of Arabica (tall cultivars) starts declining around the age of 25 years and that of Robusta around 60 years. But there are instances where Arabica over 30 years and Robusta over 50-60 years doing well under proper crop husbandry. When it is felt that bringing back the productivity of older coffee by improved farming practices is not possible, replanting with the same cultivar or improved strain is thought of. Conversion of an old block into a new block is brought about by replanting, interplanting or interlining.

Replanting

This process consists of complete uprooting of old coffee and replanting with improved cultivars, after fresh line marking in conformity with spacing for the new cultivar. This is the best method to convert an old block into a new one. The newly planted young plants will not have any competition from established coffee. Moreover, being in a block of young materials, the plants are likely to get better attention. Young shade trees are retained while old shade trees, which have grown unwieldy, are removed as young coffee struggles to come up under huge shade trees.

Interplanting

This method involves planting of seedlings of selected plant material in between rows of existing old coffee. Only the spacing of old coffee or its multiple can be adopted for the new material as the old stand is not disturbed. A few branches of the existing old coffee covering the seedlings are clipped off to allow more light and air. The growth of coffee will be extremely slow and the branches tend to be elongated without enough secondary and tertiary development due to severe competition from existing old coffee. The old coffee is removed gradually. As the grower continues to get some income from the old coffee without any gestation period this method is popular in many small holdings.

Interlining

In this method alternate rows of old coffee are eliminated and new plants are planted in the old rows. The spacing within the row is flexible but not between the rows. When the young coffee has grown sufficiently, the middle row of old coffee is uprooted and replanted with the new material. By following this method the planter gets some income from half of the area, while the other half gets rejuvenated.

In case of interplanting or interlining, it is always advisable to take pits early enough to allow weathering for at least 2 or 3 months before filling in and planting. By doing so the cut ends of the roots of the surrounding old coffee will all dry up and so will not extend into the pit for at least some time enabling the young plants to get a chance to establish and grow. Secondly, the pit should be deeper and bigger than the usual pits, at least with 2½' (75 cm) diameter and 2½' (75 cm) depth. Thirdly, while filling the pits, well decomposed cattle manure should be added.

Interplanting with rejuvenation

Here, the old plants are collar-pruned and two to three suckers are allowed. New plants are planted simultaneously between the rows as in the case of interplanting. The suckers will yield from second year onwards and the crop on the suckers will always be heavier than the exhausted old coffee. By the time three or four crops are taken from the suckers, the young coffee would have developed fully and started bearing some crop. Now the old plants with suckers are completely uprooted.

Rejuvenation grafting

Whenever a plant becomes less productive due to mechanical damage or serious disease, it is removed and replaced by new material. Sometimes, the 'off-type'/'passenger' plants are also replaced to increase productivity of unit area. Removing the unproductive plants and planting new material are costly and time consuming. Moreover, there will be a gestation period of 4 to 5 years resulting in less income. To overcome these problems, rejuvenation of the unproductive plants through grafting is advocated. The rejuvenated plant comes to bearing at least 2 years earlier than conventional replanting. But grafting should not be attempted on very old plants or plants whose productivity has been reduced due to root damage.

The unproductive plants are collar pruned at 1' (30 cm) above the ground level during March/April, after the summer showers. Suckers come out in 1 to 1½ months and among them, 2 to 3 healthy suckers are retained removing the rest. During the monsoon rains in June, suckers of the same age and thickness, allowed in desirable plants, are collected and single noded scions are prepared. A vertical slit (cleft) of 1.5 to 2.0 cm is made in the stock suckers arising from the collar pruned plant after cutting off the suckers at 5 to 8 cm height. The single noded scion sucker is fashioned into wedge shape of 1.5 to 2 cm and inserted into the stock. The graft portion is tied with a polythene strip. The grafts are covered with polythene bags to prevent rotting. When union takes place in 1 to 2 months, the polythene strips are removed. As the grafting success is only 65 to 70%, 2 to 3 suckers are grafted to be on the safer side.

Shade trees and shade management

Shade trees

In India shade is inevitable for economic production except in some Robusta plantations where the soils are deep and fertile with assured irrigation facilities. Many parts of the coffee regions in the world, such as Brazil, Hawaii, Indonesia, Kenya, Vietnam, etc., grow coffee without shade on commercial basis. But in India majority of the plantations are under rain-fed conditions and hence coffee is recommended to be planted under shade. The recommended spacing for permanent shade trees is 40' x 40' (12 m x 12 m). In new clearing, for every two coffee plants one temporary shade tree (dadap) is planted. Shade trees must provide 50% shade in Arabica and 30% shade in Robusta, as only 50% and 70% of day light is considered optimum for Arabica and Robusta coffee respectively.

Shade reduces light intensity, helps to overcome physiological problems like die-back and floral malformations, narrows down diurnal variation, and enhances photosynthetic activity and net assimilation rate. It also protects the plants from hot sun, strong wind, hailstone, cold temperature and frost damage and decreases incidence of diseases and pests in coffee. Planting shade trees in coffee helps better root growth by reducing soil temperature, supplies enough quantities of major and minor nutrient elements to sustain average crops, adds nitrogen to the soil through the root nodules of leguminous shade trees. Further, shade also suppresses weed growth, especially perennial grasses, increases soil biomass through leaf shedding/shade-lopping and addition of mulch preserves soil organic matter by inhibiting rapid decomposition of organic residues and brings down soil erosion by protecting the soil from lashing rains. It indirectly affects the quality of beans and increases longevity of coffee plants by reducing overbearing.

An ideal shade tree should have long life as that of coffee and it should not be brittle leading to breakages of branches during heavy winds. It should have a spreading habit and bear feathery leaves to give a filtered shade and not casting too dense a shade, branches may spread at a height several feet above coffee. It should not be a host for any of the serious pests and diseases of coffee and should not compete with coffee for moisture and nutrients. The leaves should provide good mulch and it should give valuable timber. Shallow rooted shade trees compete with coffee for soil moisture. Since no single species of tree has all the desired qualities, a mixed shade consisting of different long standing permanent trees and temporary shade trees is advocated for coffee. The shade trees in coffee plantations are grouped into two categories *viz*., temporary and permanent based on their size, nature of growth and longevity.

The temporary shade trees are planted to provide immediate shade for the young plants. Dadap (*Erythrina lithosperma)* is a popular and widely used temporary shade. Calliandra *(Calliandra calothyrsis),* Castor *(Ricinus communis*), *Sesbania* sp., *Gliricidia* sp., etc., could also be used to provide shade initially to the young plants and to supplement nitrogen. *Solanum* sp. is also being used as a temporary shade in some of the areas.

Ficus species (*F. virens, F. racemosa*, *F. microcarpa*, *F. nervosa*, *F. retusa*, *F. tsjahela), Artocarpus integrifolia* (jack tree) and *Albizzia* species, are popular permanent shade trees commonly maintained in coffee plantations. Trees like *Cedrela toona*, *Dalbergia latifolia*, *Pterocarpus marsupium*, *Syzigium jambolana*, etc. are also recommended for coffee plantations. In majority of the plantations in South India, silver oak (*Grevillea robusta*) is the predominant shade tree. In strict sense, silver oak is not an ideal shade tree, as its leaves do not easily get decomposed and the dry leaves create a potential fire hazard in low rainfall areas. As the spine like leaves get stuck on to the plants, black rot may get accentuated in high rainfall areas. Further, the branches of silver oak are not spreading in nature. In spite of these demerits, silver oak is popular among the small growers for its quick growth, timber value and its suitability as standard for training pepper. African shade tree (*Maesopsis eminii)* is another fast growing shade tree seen in coffee plantation in India. It is a soft-wood tree and the large branches cannot withstand heavy wind and hence is not recommended for planting in coffee plantations.

Time and mode of shade regulation

Shade trees require regular pruning and thinning to prevent shade becoming excessive. Shade regulation is preferably done immediately after harvest but before pruning of coffee plants to enable removal of broken/damaged branches of coffee as a result of falling of shade tree branches during lopping. If dry weather prevails during the post-harvest period, shade regulation is commonly taken up just before the onset of south west monsoon. In young clearing the shade canopy is maintained at a low level of about 4 to 5 m above the ground. In established plantations, lower canopy branches are removed and upper canopy of the permanent trees is maintained at a height of 10 m to 14 m height. Removal of lower canopy branches prior to monsoon facilitates air circulation, reducing atmospheric humidity. Reduced atmospheric humidity discourages build-up of disease causing pathogens.

Bush management

A strong frame work with healthy cropping branches is a pre-requisite to obtain profitable crop year after year in a perennial fruit bearing crop like coffee. Maintaining a proper balance between vegetative and reproductive phases without impairing the health of the plant is achieved by proper bush management which involves training, pruning and handling.

Training basically refers to allowing the plant to have a single stem or multiple stems. In India, it is most common to find single-stemmed coffee mainly to reduce the menace of white stem borer in Arabica and to have an easy bush management in Robusta. In single stem training system, the vertically growing main stem is allowed to reach a certain height and the apical growth is clipped (known as topping or capping) just 2" (5 cm) above the node of the recommended height. One of the top most primaries is also removed to prevent possible splitting of the main stem due to heavy crop load. Topping is done to reduce the apical dominance and to encourage strong lateral growth of the primaries. The first topping forms the first tier. After 4 to 5 crops, when the plants start closing in, one healthy sucker from the main stem, just below the top most primary pair is allowed to grow. One healthy sucker is allowed and when this sucker reaches $4^1/_2$ feet (1.35 m) in tall Arabica and $5^1/_2$ feet (1.65 m) in Robusta, the apical portion is clipped to develop formation of the second tier. In the case of semi-dwarfs, toping is recommended at 3' to 5' (0.9 m to 1.5 m). Suckers arising from the main stem are removed periodically.

Multiple stem system is common in many of the African and Latin American countries. Various methods such as cutting, bending (agobiada), angle planting and multiple planting are available to have multiple-stem coffee. But cutting the main stem to produce multiple stem is common. After 3 or 4 crops, when the main stem attains good girth, it is stumped (collar-pruned) at about 1' (30 cm) from the ground level giving a smooth slanting cut. After a few weeks when suckers sprout, 3 healthy suckers at different heights around the stem are selected and retained removing the others. When the suckers bear 4 to 5 crops, the exhausted suckers are removed one at a time in a year with simultaneous allowing of new sucker.

In coffee, pruning is generally means removal of excess vegetative growth. Main objectives of pruning are to minimise biennial bearing tendency and consequent risk of die-back during over-bearing, to remove unwanted dead, diseased and over-aged branches and to provide a micro environment within the plant for maximum crop production but minimum spread of diseases/ pests. The process of pruning involves removal of criss-cross branches and branches growing vertically upwards or towards the main stem, removal of exhausted, lean and lanky branches having a few cleft of leaves at the end, broken and dead wood, removal of suckers and secondary laterals arising from the first nodes on the primary adjacent to the main stem and removal of whippy branches touching the ground. Remove all vertical growth arising from the primaries/ secondaries; otherwise, these growths are converted into special branches known as 'gourmandisers', being in an advantageous position of getting good sunlight and aeration, yielding a good crop at the cost of the adjacent growth below. Cut the whippy secondary branches close to the primary so that no stub is left to interfere with the development of replacement. Excessive pruning or excessive removal of foliage is detrimental and reduces the crop production. Removal of all non-bearing branches is not advisable as every bearing branch should be supported by non-bearing branches. There is a close relationship between the number of flower buds and number of leaves in a bearing branch. Generally pruning is taken up immediately after the harvest to remove the exhausted and undesirable wood. When a plant is in a state of die-back it needs all the available foliage and it should never be pruned other than removing the dead wood. While pruning is essentially a knife work, handling involves no cutting but just breaking and removal of the dead/diseased wood and suckers by bare hand. Handling and desuckering are carried out 3 or 4 times a year.

Nutrient management

In any perennial crop, the health of the plant is very important to produce crop year after year. At the same time, the health of the soil, which anchors plant and supports its life, is also equally important. Hence, an integrated nutrient management involving chemical fertilizers, organic manures, foliar feeding, bio-fertilizers and vermi-compost comes a long way for efficient nutrient management. Since organic manures have negligible N, P and K contents, application of chemical fertilizers is inevitable in intensive economic farming systems. But equal importance should be given for organic manures to save the dying soils of the tropics and to sustain higher productivity. While chemical fertilizers supply the needed nutrients, organic manures, serving as soil amendments, add life and make the soil more conducive for plant growth.

Availability of adequate essential nutrients in balanced proportions throughout the life of coffee is essential for economic production. Inadequacy of any one of the major fertilizer elements (N, P & K) or the secondary nutrients (Ca, Mg & S) or unavailability of any micro nutrient/trace element (Fe, Mn, Zn, Cu, B, Cl and Mo) adversely affects plant growth. Recycling of the entire shade tree litter, coffee leaf, pulp etc., contributes 84-95 kg N , 40-42 P_2O_5 and 108-123 kg K_2O per ha., which may sustain a shade-grown low crop, it may not be sufficient to support a higher crop under lesser shade canopy. Nutrients brought in by the leaf fall are essentially the nutrients recycled from the soil and, hence, addition of nutrients to soil is essential to compensate the crop removal of atleast the major nutrients.

Fertiliser recommendation for bearing coffee

Based on experiments on crop removal (35 kg. N, 5-7 kg P_2O_5 and 37-45 kg K_2O for every tonne of clean coffee), plant bio-mass requirement, fertiliser use efficiency and release of nutrients from soil sources, the general basic recommendation is 10 kg N, 5 kg P_2O_5 and 10 kg K_2O for every 100 kg of clean coffee harvested up to an yield level of 500 kg clean coffee per acre (1250 kg/

ha). Soil testing or soil fertility evaluation in scientific farming needs little emphasis. Fertilizer recommendation supported by soil test values avoids ion-antagonism (suppression of uptake of one nutrient element due to the presence of other element(s) in excess) and helps economising fertilizer dose. In coffee, the basic recommendation is subject to 10-25 % increase or decrease based on soil test values.

Fertilizer recommendation for young coffee

Unlike bearing coffee, young coffee requires more P in readily available form for profuse rooting and hence P is recommended on par with N and K in 1:1:1 ratio in water-soluble granular form. Complex fertilisers like 17:17:17 or 19:19:19 @ 60 g in one split during 1st year, 120 g in two splits during second year, 180 g in three splits during 3rd year and 240 g in four splits during 4th year is recommended for young Arabica coffee. For Robusta twice the dosage of Arabica is recommended.

Time of fertiliser application

It is advisable to apply fertilizers when there is sufficient moisture in soil. Keeping in view of the peak demand periods of coffee, 4 split applications are recommended. Under Indian conditions, the first application in March coincides with flowering/fruit set, the 2nd split in June feeds the developing berries, the 3rd split in September helps maturation of berries and makes up the leaching losses and the 4th split in November compensates the mobility of nutrients from foliage to matured crop and also prepares the plants to overcome the ensuing drought period after harvest. In the case of 3 splits, the fertilizers could be applied in March, June and September. When only two splits are envisaged as in the case of low yield, the 1st split could be in March and the 2nd split in September. If rock phosphate is included in the schedule it should be broadcast and forked in one single application in March along with the 1st split of N and K.

Method of fertilizer application

The root system of bearing coffee extends to more than 3' (90 cm) in all sides from the stem and the entire field is matted with roots in an established plantation. Hence, the most effective method is to apply fertiliser in broad circular band, but 1' (30 cm) away from the stem. After application, the mulch is disturbed to make the fertilizers come in contact with the soil. The soil moisture dissolves the water-soluble fertilizers and the dissolved nutrients percolate down due to gravity. Foliar feeding is recommended to supplement soil application of nutrients to meet the higher nutritional requirement of a bumper crop, to rectify nutritional disorders, to supplement micro-nutrient demand and to help plants in the event of root damage due to disease (root rot) or pests (nematodes/root mealy bugs). When the yield exceeds 1250 kg/ha in Arabica and 2 tonnes/ha in Robusta, 2 foliar sprays, one during late April and another in October-November help overcome the crop strain.

Organic manures

In coffee the importance of organic matter in soil hardly needs any emphasis. Organic manure improves soil structure facilitating gaseous exchange and drainage, increases the water holding capacity and CEC, enabling the soil to retain more soil moisture and the applied nutrients, binds the soil particles thus reducing the soil erosion and fulfils the entire requirement of the micronutrients and creates a favourable environment for the microbial activity which is essential for conversion of many of the nutrients into available form.1 to $1^1/_2$ tonne of dried, cockchafer free FYM should be applied any time in a year when there is sufficient moisture in the soil and when the soil conditions are suitable for forking in the manure.

Soil acidity and liming

Under South Indian conditions coffee is known to come up well in soils of pH around 6.0. Liming is recommended when soil pH goes below 6.0. Application of lime should be carried out based on evaluation of soil samples, as excess lime application causes reduced availability of phosphorus and micronutrients. Higher calcium content in the soil due to excessive application of lime may also hinder the uptake of potassium and magnesium due to ion-antagonism. Generally the quantity of agricultural lime ($CaCO_3$) recommended varies from 0.5 to 2 tonnes per acre. Whenever magnesium deficiency is suspected, equivalent amounts of finely powdered dolomite ($(CaMgCO_3)_2$) may be applied. Generally liming is done after harvest. Since moisture is essential for most of the chemical and biological reactions, lime is applied when adequate moisture is present in the soil. However, at least a month's gap between fertilizer application and liming is desirable to prevent the possible interaction between the fertilizers and liming materials. Lime is to be broadcasted throughout the planted area and thoroughly incorporated for proper contact and reaction with the soil matrix.

Weed management

In a fully established coffee plantation under shade, where no gaps are generally seen consequent to full coverage of the canopies, or in fields fully covered by mulch, weed growth is not a problem. However, in new/young clearings or in poorly established estates without adequate shade, where more of open patches are commonly seen, weed growth does pose problems. Slash weeding, clean weeding by scraping the soil using farm implements and chemical weeding are commonly practiced to control weeds. Glyphosate is generally recommended for coffee plantations. Spraying of gramoxone @ 500 ml per barrel of 500 litres has been found to be effective to control the dicots and glycel @ 1200 ml per barrel of 200 litres controls all types of weeds. With addition of urea @ 2 kg per barrel, the quantity of weedicide could be reduced to half.

Soil conservation measures

Soil cultivation such as scuffling and digging is generally done (i) to control weeds (ii) to break up any hard pans, which might restrict the entry of water into the soil and (iii) to open up the soil for gaseous exchange and penetration of water deep into the root zone. But soil cultivation is not advocated in coffee plantations excepting the cover digging done in the new clearing before planting to loosen the compact soil and to remove the weeds to facilitate faster growth of the young plants. The advantages of organic mulching are many. It protects the soil surface from the impact of rain, increases infiltration of rainfall and reduces run off, conserves soil moisture and surface soil, suppresses weed growth and it protects the soil from hot sun and cold nights thus maintaining optimal soil temperature for continued microbial activity and root growth. Additionally, mulching improves soil structure, avoids formation of 'cap' and facilitates rain water acceptance, adds organic manure on decomposition and provides most of the needed micronutrients, spreads rain water and avoids gully formation, increases soil nitrates, reduces soil acidity and helps reduce chlorosis. For young coffee seedlings, mulching should be provided immediately after planting. Mulching takes care of soil erosion and weed growth.

Another soil conservation measure is to grow a cover crop. It helps to conserve soil, smother out weeds and enhance biomass in soil. In high rainfall area particularly in Robusta where spacing is large, cover crop helps to a greater extent. Sometimes food crops like ginger are cultivated till the coffee canopies close in. But any crop which involves soil cultivation is not preferable in coffee. An ideal cover crop or inter crop should not compete with coffee for nutrients, water or light. Nor should they interfere with the cultural operation.

In order to prevent soil erosion in sloppy areas it is recommended to dig cradle pits of 30 cm width, 45 cm depth and 150 cm length across the slope in staggered manner. By the end of monsoon cradle pits get filled with fallen leaves and weed slashing and act as compost pits and helps in conserving the soil moisture. Cradle pits can be cleared by the end of monsoon once in two or three years.

Intercrops

Growing compatible perennial crops in a mixed farming system, particularly in the small grower sector, is quite common in coffee. Almost all the coffee tracts in India have pepper as a mixed crop trained on the shade trees. Silver oak is an ideal live standard for pepper. But pepper is also trained on temporary dadaps as well as huge permanent jack trees. In addition to pepper, orange and banana are also being cultivated as an intercrop by the planters of Pulneys in Tamilnadu. Annuals like ginger, turmeric and elephant foot yam etc., are cultivated in young coffee plantations in Kerala. This helps in controlling the weed growth. Intercrops bring in additional income in the gestation period of coffee, in addition to smothering of weed growth. Any intercrop involving soil cultivation is not preferred as it leads to soil erosion in hilly terrains. Sinceover 98% of the growers are in the small grower sector, without adequate finance for intensive cultivation, a diversified cropping system with coffee as the base crop is always advisable as an insurance against price fluctuations.

Physiology of coffee

For successful management of the plantation the knowledge on influence of environmental factors and cultural practices on yield is essential. Although coffee grows continuously, the growth is slow during summer and winter months. During heavy rainfall also growth is retarded. Immediately after summer rains or the heavy monsoon rains growth is rapid. Production of new flushes and extension of growth in terms of number of nodes and leaves are important to serve as cropping wood for the succeeding years.

Generally, coffee in India seems to come to 'floral phase' by September. Flower buds in Arabica usually develop in succession during September to February/March. In Robusta, initiation and differentiation of flower buds proceed at a faster rate than Arabica and a larger number of flower buds attain maturity by about January-February. Receipt of sufficient rainfall (25-40mm) triggers flowering. A period of moisture stress before flowering is beneficial in bringing about concentrated flowering. Flower opening occurs in 8-10 days after receipt of rainfall/ irrigation. Flowering in coffee is controlled by a hormonal mechanism. This hormone could be 'gibberellin' or a chemical related to 'gibberellic' acid. The pollen tube in Robusta takes about 8-12 h to reach the ovary and about 26-36 h for union of gametes under normal healthy blossom. Fruit set in coffee is influenced by plant health, timely blossom showers, severity of drought prior to blossom and the weather conditions prevailing on the day of the blossom. Debilitated plants due to over-bearing, severe disease incidence and inadequate nutrition adversely affect fruit set. Very late blossom showers may result in poor set, particularly if preceded by severe drought conditions.

Premature berry drop is a common feature every year. But the percentage of loss may differ from year to year depending on seasonal conditions varying from as low as 10% to as high as 50%. Apart from seasonal factors, berry drop may be due to physiological factors like carbohydrate deficiency or imbalance between carbohydrates and auxins during the development of berries. Continuous water logging ('wet feet' condition) aggravate berry drop. Under South Indian conditions fruits of Arabica mature 8 to 9 months after flowering and fruits of Robusta mature 10 to 11 months after flowering.

Fruit ripening is not uniform in coffee, in spite of almost simultaneous blossom in all nodes/branches. Endogenous production of ethylene, facilitated by more sunlight, helps ripening. Exogenous application of ethylene also hastens ripening. Since exogenous ethylene induces early senescence leading to pre-mature leaf shedding, growth hormone is needed to offset senescence. To hasten ripening in Arabica 100 ml of ethephon and 100 ml of Hormonal in 200 litres and for Robusta 50 ml of ethephon and 100 ml of Hormonal in 200 litres of water is recommended. 500 ml of solution is required for an Arabica plant and 660 ml of solution is required for Robusta plant. Ethephon solution may be sprayed on the fruits when about 10% of natural ripening is seen. Ethephon spray hastens ripening by 2 to 4 weeks.

Bean size is partly genetically determined and partly modified by environmental conditions. The potential size of the bean is determined by the mother tree but the ultimate size is determined in the period of rapid expansion following the pin-head stage and reflects the availability of soil moisture at this time. Hence, adequate rainfall during June to August is important in berry development. The size is also determined by certain cultural methods such as pruning, mulching and fertilizer applications.

Due to genetic as well as physiological/ environmental factors, many bean disorders are seen in coffee. Failure of endosperm to develop and fill the integument results in empty beans. This is mostly a physiological problem. However, it is caused by genetic factors also. Empty beans occur frequently in hybrids of two species having different chromosome numbers. Occurrence of elephant beans and triage are genetic aberrations. A single cavity in the ovary with two embryos is called as elephant beans and it usually break up during hulling. Three beans develop in a single fruit is called as 'triage'. When one of the integuments does not develop and the other one occupies the whole berry, a round bean known as 'pea berry' is formed. Though genetic factors are more responsible, inadequate pollination influences formation of pea berry. The percentage of pea berries range from 10 to 30. Higher percentage of pea berry is not desirable.

Black 'jello' beans are formed due to poor filling of endosperm occurring during the growth of endosperm. But 'black' bean formation is due to low accumulation of carbohydrates. Apart from depletion of carbohydrates, faulty fertilization and moisture deficit during June to August also cause these disorders. Arabica at lower elevation with overbearing is prone to produce more black beans. Proper management such as judicious pruning, optimum shade regulation, adequate and timely manuring, regular bordeaux sprays to control leaf rust and avoiding dieback help reduce black bean formation to a greater extent.

Drought management

For successful blossom and good yield 25 to 40 mm rainfall or equivalent irrigation is required for Arabica during March and for Robusta during February. Inadequate or uneven distribution of rainfall causes drought conditions affecting the growth of the plant as well as yield. Drought management envisages selection of drought tolerant material or increasing the solute concentrations in plant through foliar sprays of nutrients. Sln.9, Sln.10, Sln.4 and Sln.5B are relatively drought tolerant among popular coffee selections. In the case of Robusta all the recommended cultivars are drought susceptible. Maintaining adequate shade, providing mulching during summer months and irrigation are the methods to mitigate the effects drought in coffee plantation. Spraying of nutrient mixture containing 1 kg super phosphate, 750 g MOP and 1 kg $ZnSO_4$ in 200 litres of water at 45^{th} day after the last rainfall and again 30 to 45 days after the first spray @ 1L per plant found to minimise the drought effect and increase yield is recommended to tide over the drought.

In general, coffee in India is a rain-fed crop grown under varied climatic conditions with rainfall ranging from 1000mm to 3500mm. A rainfall as low as 40" (1000 mm) is sufficient for normal production, provided it is well distributed and received on time. About 1 to$1^1/_2$" (25-40 mm) of rainfall as 'blossom showers' in February for Robusta and in March for Arabica are essential for flowering and fruit set. Same quantity of rainfall 15-20 days after blossom as 'backing showers' are required for fruit set. To ensure adequate water supply for flowering/fruit set and to tide over any unprecedented drought during berry development, irrigation is being provided wherever adequate water sources are available.

Pest management

Coffee in India experiences huge loss due to serious pest problems like white stem borer in Arabica and mealy bug and shot hole borer in Robusta. In fact, over 80% of potential trouble from pests can be avoided by sound methods of cultivation in a suitable environment. The stable environment of a coffee plantation makes it particularly favourable for the practice of integrated pest management (IPM) involving chemical, cultural and biological control.

White stem borer (*Xylotrechus quadripes*)

White stem borer is a serious pest of coffee, causing major loss to coffee in India. Adult Female beetles deposit eggs in the cracks and crevices and under the loose scaly bark of the main stem and thick primaries, preferring the plants exposed to sun light. Hatched out grubs feed in the corky portion just under the bark and splits. Infested plants show externally visible ridges around the stem and exhibit symptoms like yellowing and wilting of leaves. However, such plants are less productive, yielding more of floats. Later, the larvae enter into the hardwood and make tunnels in all the directions. In some cases, the tunnels may extend even into the roots. After about 10 months adult emerges out by cutting an exit hole in the bark.

Control measures suggested are i) maintain optimum shade on the estates; ii) trace the infested plants prior to flight periods (i.e, during March and September); iii) collar prune the infested plants, uproot if the borer has entered into the root, and burn the affected parts; iv) remove the loose scaly bark of the main stem and thick primaries using coir glove or coconut husk to get rid of cracks and crevices; v) swab the main stem and thick primaries prior to flight periods once in April-May and once or twice in October-December (depending on the degree of infestation) with 10% lime solution; vi) if infestation is in the initial stage wrap the stems with sheets of gunny bag and spray chlorpyriphos+cypermethrin combination @1.2 ml/litre or chlorpyriphos 50EC-1.5 ml + cypermethrin 1.2 ml or chlorpyriphos 25EC 3 ml + cypermethrin 1.2 ml per 200 litres of water; vii) spray the main stem and thick primaries with neem kernel extract for good control of the pest.

Coffee berry borer (*Hypothenemus hampei*)

The coffee berry borer is another serious pest of coffee. It is exclusively monophagous and requires coffee berries for feeding and breeding. The adult berry borer bores into the berries through the navel region. Tunnelling and oviposition occur only in hard beans. The mother beetle lays about 15 eggs and eggs hatch in about 10 days. The larvae feed on the beans, making small tunnels. A typical pin hole at the tip of the berries indicates the presence of the pest. In case of severe infestation, 30 to 80% of the berries may be attacked, resulting in heavy crop loss. Proper adoption of cultural and phytosanitary measures is foremost in the management of coffee berry borer. Timely harvest is very important. No berries should be left over, either on the plant or on the ground. Spreading gunny bags or polythene sheets on the ground, during harvest will help to minimise gleaning. Maintain optimum shade and good drainage. Dipping infested berries in boiling water for 2-3 minutes kills all the stages inside. Drying coffee to the prescribed moisture level (parchment 10.5%, cherry 11.5%) prevents breeding of beetles in stored coffee.

Shot-hole borer (Xylosandrus compactus)

The shot-hole borer is a major pest of Robusta coffee. Adult beetle usually attack green succulent branches. After entering into the twig through the shot-hole made on the underside, female makes a longitudinal tunnel and lays as many as 50 eggs. The milky white larvae feed on the Amborsia. Life cycle is completed within 4 to 5 weeks. The incidence of pest reaches the peak during September to January, and gradually declines during the dry period. The buildup could be severe under heavy shade. Withered off dried branches with shot-holes indicate the presence of the pest. The attacked branches dry up fast, as tunnelling limits the flow of sap. Leaves above the point of attack fall prematurely. The terminal leaves wilt, droop and dry up. Severe infestation results in the loss of considerable number of productive branches. Due to the mode of attack and concealed nature of the pest, insecticide applications do not provide any economically feasible control. However, the incidence of shot-hole borer could be effectively contained by adopting the following measures: i) prune the affected twigs 2 to 3 inches beyond the shot-hole and burn from September onwards, as soon as the first symptoms of attack like drooping of leaves is noticed, and continue as a routine measure at regular intervals; ii) remove and destroy all the unwanted/infested suckers during summer as the pest prefers to breed in the suckers during dry period; iii) maintain thin shade and good drainage.

Mealy bug (Planococcus citri and P. lilacinus)

Mealy bugs are small, soft bodied insects attacking coffee and a wide variety of crops. Adult female is wingless, the oval body clothed with a mealy secretion in the form of small, white threads. Each female is capable of laying 100 to 1000 eggs. Life cycle is completed in about a month. Mealy bugs multiply rapidly during hot weather. Infestation becomes severe in summer. Intermittent showers and irrigation help in the build up of the pest. Excessive removal of shade in Robusta plantations often leads to flare up of mealy bugs. Control measures suggested are: i) maintain adequate shade; ii) control ants; iii) spray the affected patches with Ekalux 25 EC @ 300 ml or Folithion 50 EC @ 300 ml or Lebaycid 1000 @ 150 ml or Kerosene 4 litres in 200 litres of water, using a sapperlot/gator sprayer; iv) if the roots are infested, drench the soil near the root zone with any one of the above insecticides (other than kerosene) at the same dosage and add 300 ml of Plantvax 20 EC or 160 g of Bayleton 25 WP in 200 l water, if fungus association is noticed; v) bio-control: if *P. citri* is predominant, release, 17,500 to 25,000 parasitoids initially and 5,000 to 7,500 in the subsequent years until control is achieved. And if other species of mealy bugs dominate, then release 10,000 to 15,000 of the predator, *Cryptolaemus montrouzieri*.

Green scale (Coccus viridis)

Green scale is a summer pest, proliferating during hot dry weather. The insect sucks sap from the tender parts, congregating down on the under surface of leaves close to the midrib and veins, on the green shoots, spikes and berries. Heavy loss of the sap causes debility or even death of the plant. The infested leaves may curl up and tender twigs droop. The honeydew excreted by the scale forms a layer on the leaves and acts as a medium for the growth of the “sooty mould”. This hinders photosynthesis, thereby weakening the plant. Host plants and ant association are almost same as that of mealy bugs. Control measures recommended for green scale are: i) controlling ants as in the case of mealy bugs; ii) removing and burning weeds which harbour the scales; iii) spraying the affected patches with quinalphos 25 EC (Ekalux) @ 120 ml or Dimethoate (Rogor 30 EC) @ 170 ml in 200 L of water using a gator/ sapperlot sprayer along with 200ml of any wetting agent. For grown up plants dimethoate (Rogor 30 EC) may be used at a dosage of 600ml in 200 L of water.

Brown scale (Saissetia coffeae)

Brown scale is a sucking pest seen in coffee, active during summer months. The life history and symptoms follows the same lines as those of green scale in general. The honey dew feeding ants are seen with brown scale also. Like other sucking pests, this also has a wide range of host plants like citrus, Guava etc. Control measures recommended are: i) control of ants as in the case of mealy bugs; ii) removing and burning weeds which harbour the pest; iii) spraying the affected patches with quinalphos (Ekalux 25 EC) @ 300 ml in 200 L water along with 200 ml of any agricultural wetting agent.

Cockchafer or white grub *(Holotrichia spp.)*

Adults of cockchafers are reddish brown beetles. They feed on leaves of crop plants or forest trees and the adults emerge from March to June after the first summer shower. After mating, female beetle lays eggs in the soil. The hatched out creamy white grub feeds on roots. They are serious pests in new clearings and replanted areas. Grown up coffee plants normally withstand the attack. The young plants (1 to 5 years old) attacked by white grubs show yellowing of leaves and stunted growth. Such plants will wilt and die in summer period. Attacked plants can be easily pulled out as they are left with only the tap root. In order to control the pest following recommendations are made: i) collect and kill the grubs encountered while taking up digging and other farm operations; ii) install light traps after the first summer showers during March-June and kill the trapped adults; iii) apply Thimet 10 G at the dosage of 20 g per plant.

Hairy caterpillar *(Eupterote spp.)*

It is an important pest of Arabica coffee. The adult of hairy caterpillar is a brownish yellow moth, emerges in June/July. Eggs are laid in clusters of 100 to 150 on the under surface of the leaves of shade trees. Caterpillars of *E. canaraica* start feeding on leaves one or two days after hatching. They feed on leaves and cause severe damage by denuding the plants. Badly affected plants take 2 to 3 years to recover. They are gregarious and migrate from branch, moving closely one behind the other. They drop down on silken threads from shade tree to coffee during September/October. During this stage (paratrooping stage), the caterpillars may get dispersed by wind. Out breaks usually occur in a cycle of 3 to 4 years. Cardamom and shade trees like *Bischofia javanica*, *Syzygium jambolana*, *Eugenia jambolana* and *Erythrina lithosperma* are hosts of caterpillar. In order to control the incidence of hairy caterpillar recommended control measures are: i) collect and kill caterpillars; ii) collect and burn pupae from January to May; iii) install light traps in June/July for collecting and killing moths.

Root lesion nematode *(Pratylenchus coffeae)*

Though there are several species of nematodes attacking coffee, the root-lesion nematode, *Pratylenchus coffeae* has been found to be highly destructive to Arabica coffee. *P. coffeae* lays eggs in the root lesions. Development from egg to adult takes about a month. Nematodes feed and destroy the cortical parenchyma cells of the tap root, secondary roots and feeder roots. As a result, the outer layer of the tap root and secondary roots peel off and the feeder roots are lost, impairing water and nutrient absorption. *P. coffeae* causes 'juvenile foot-rot' of young Arabica plants and die-back or 'spreading decline' of bearings plants. Nematodes spread to other areas through implements, rain water, plants from infested nursery and soils from affected blocks. Exposure of soil in the nursery to sun, using sieved jungle soil and FYM and avoiding of bringing seedlings from nematode infested areas are the measures to control nematode in the nursery. While in field, uprooting and burning the affected plants, digging pits of 2' x 2' x 2' size and exposing the soil to sun for one year prior to planting, keeping the pits weed-free, planting the infested area with Robusta (if suitable) or Arabica-Robusta grafted plants (Arabica scion grafted on to Robusta root stock) are recommended to avoid the incidence of nematode.

Minor pests

Coffee bean beetle (*Aracerus fasiculatus*) is a pest of beans in storage and also affects coffee berries in the field. Drying the coffee to the prescribed moisture level and storing in well ventilated godown is suggested to avoid this pest. Snails (*Ariophanta solata*) are active during S.W. monsoon feeding on leaves of coffee and dadap. It is controlled by picking and dipping in hot water or salt solution. Liming and application of ash repels snails. Red borer (*Zeuzera coffeae*) affects coffee by boring into the young stem and primaries. The larva is reddish and hence the name. Affected branches should be cut and burnt. Thrips are minute organisms, less than 1 mm in size. They damage leaves by lacerating the leaf tissues. As damage is more in exposed areas during dry weather, optimum shade should be maintained to control thrips. Termites also cause crop loss in coffee. Locating the termite colonies and destroying the queen, placing Aluminium phosphide tablets (2 per mound) or pouring 60 ml of Chlopyriphos 20 EC help to control termites.

Diseases of coffee

Like pests, diseases also cause considerable loss in crop if left unchecked. All the diseases of coffee recorded in India are caused by parasitic fungal pathogens. Arabica is more susceptible to diseases than Robusta. In the case of integrated diseases management use of tolerant cultivars and more attention to upkeep of the plants in vigour play vital roles as natural enemies are rare, unlike in the case of pest management.

Coffee leaf rust *(Hemileia vastatrix)*

Coffee leaf rust is the most disastrous disease of coffee, caused by the fungus, *Hemileia vastatrix*. This fungus infects only the foliage of the genus *Coffea*. Wet weather during May to November, intermittent rains and sunshine, mist or rain during the dry weather from December to March are favourable to the disease. In the South-West monsoon zone disease is observed throughout the year, peak period being August to November. Pale yellow spots appear on the lower surface of infested leaves, later turning orange yellow powdery mass consisting of uredospores. Severely infested leaves fall prematurely. Sln.3 (S.795) and Sln.12 (Cauvery) are highly susceptible to the disease. Growing of rust tolerant Arabica varieties like Sln.5 (S.2931), Sln.9 (S.2790) or Chandragiri, avoiding cultivation of susceptible Arabica cultivars in lower altitudes of less than 2000 feet and providing optimum shade, etc., are recommended as preventive measures. For susceptible cultivars any one of the systemic fungicides like triademefon @ 0.02% *a.i.*, (Bayleton 25WP) @ 160g or hexaconazole @ 0.01% (Contaf 5%EC @400 ml in 200 L of water) during March and September/October and spot spray of triademefon @ 0.02% *a.i.*, (Bayleton 25WP) @ 160g during break in monsoon (August) are recommended. Additionally, apply freshly prepared Bordeaux mixture on the under surface of leaves before the onset of South-West monsoon (May-June) as a prophylactic measure.

Black rot *(Koleroga noxia)*

Black rot is the second important disease affecting both Arabica and Robusta, during the monsoon period. It is very common in all the coffee tracts, under the influence of heavy monsoon. It brings a crop loss of 10 to 20%. Continuous monsoon rain with saturated atmosphere of 95 to 100% RH, thick shade and valleys sheltered from sunlight are the favourable factors for this disease. The black rot pathogen infects leaves, developing berries and young shoots. The most striking symptoms are blackening and rotting of leaves, developing berries and young twigs. Affected leaves get detached from branches and hang down by means of slimy fungal strands. When the affected parts get dried, white web of mycelium will be visible. Thinning of shade in the endemic blocks before the onset of monsoon, centering and handling, cleaning of bushes by removing dead/dry branches, suckers, removing dried leaves fallen on the canopies and spraying Bordeaux (2kg $CuSO_4$, 2kg CaO in 200

L of water) on both leaves and berries before the onset of monsoon are should be carried out prior to the commencement of monsoon to prevent the disease. In affected blocks, it is advised to remove the affected leaves and berries, and spray 0.03% carbendazim (Bavistin 120 g/200 l water).

Coffee trunk canker (*Ceratocystis fimbriata*)

Generally the disease affects the plants aged above 10 years. Plants will be weak with no foliage formation with irregular lesions on the main stem. Ultimately branches start wilting and lead to the death of the plant. Uprooting and destroying the affected plants, avoiding bark injury to the plants and treating the affected plants with carbendazim are the measures suggested to control the disease.

Pink disease (*Corticium salmonicolor*)

Results in pink encrustation of branches. Infected branches may shed their leaves and entire branches may dry up and die. Affected plants show pink encrustation of the fungal growth. Spray 0.5% Bordeaux mixture as a prophylactic spray and in endemic blocks spray carbendazim 0.03% (120 g/200 litres of water) to control the diseases.

Anthracnose (*Colletotrichum gleosporioides*)

This results in twig dieback, stalk rot of berries/leaves and brown blight of leaves. Twig dieback is noticed during October to May, stalk rot of berries/leaves is observed during monsoon and brown blight of leaves is observed in exposed blocks. Maintain adequate shade to prevent twig dieback and brown blight of leaves. Prevent water logging and provide good drainage to prevent stalk rot. Spray 0.5% Bordeaux mixture as a prophylactic spray and in endemic blocks spray carbendazim 0.03% (120g/200 litres of water) to control the disease.

Root diseases

Brown root disease, red root disease, black root disease and santavery root disease are the four types of root diseases noticed in coffee. Among these, first three root diseases are seen both in Arabica and Robusta. Santavery root disease is seen only in Arabica and it is confined to Giris area in Chikmagalur and Yercaud region in Tamil Nadu. All these diseases are caused by fungi. Brown root disease (stump rot) is caused by *Fomes noxius*, red root disease is caused by *Poria hypolateritia*, black root disease by *Rosellinia bunodes* and *Rosellinia arcuata* and santavery root disease is caused by *Fusarium oxysporum*. Brown, black and red root diseases spread to neighbouring plants through root contact of infected stumps or plants. These also attack dadaps, silver oak and many other shade trees. The shade tree stumps and wooden logs in the farm are the main source of these diseases. Arial symptoms are almost same in all these cases. Affected plants show gradual yellowing of leaves and defoliation followed by death of the plant. In case of brown root disease, thick brown encrustation with fungal mycelium is seen near collar region of the root and in the case of red root disease root system shows red encrustation covered with soil, whereas in the case of black root disease, on the stem near the ground level fan-shaped black fungal mat with pellet like fructifications are seen.

In the case of brown, red and black root diseases, management practices are the same. In order to control the spread of the disease first thing to be done is isolating the affected plants and adjoining four plants with 2 feet deep and 1 feet wide trench. Soil removed from the trench should be put into affected area. Other measures to be adopted are uprooting the severely affected plants with the roots, burning and then applying 1 kg of CaO in the pit, drenching the soil with 0.4% Bavistin 50 WP (8 g/L of water) at 3 L per plant or 0.3% Vitavax 75 WP (4 g/L of water) when wilting is just seen, applying organic manure @ 10 kg per plant, removing the stumps of shade trees immediately or ring-barking before felling the trees to prevent infection and avoiding of carrying of soil/plant material from affected area. New seedlings should be planted only after about 6 months after taking control measures.

In the case of Santavery root disease the symptoms are sudden wilting, yellowing of leaves followed by defoliation and death of plants. Roots show brown to pinkish colour when cut open. Favourable factors for Santavery root disease are low or high soil temperature, poor physical conditions of soil, moisture stress, inadequate shade and wounds on the roots. In order to control the Santavery root disease uprooting and burning of the dead/dying plants, planting grafted plants (Robusta as stock and Arabica as scion) in affected blocks, applying 10 kg FYM/plant, correcting the soil acidity to pH 6.0-6.5 and drenching the soil with 0.4% Bavistin 50 WP (8 g/l of water) or 0.3% vitavax 75 WP (4 g/l of water) @ 3 litres per plant are recommended. Further, optimum shade should be maintained in the blocks and plants should be kept in healthy condition by providing adequate quantity of fertilizers and organic manures.

Coffee improvement

Coffea arabica and *Coffea canephora* are the two commercial varieties cultivated worldwide. Among these, *Coffea arabica* is preferred in the market as it is superior in quality with enticing aroma and low caffeine content. Nevertheless, *Coffea arabica* is susceptible to leaf rust disease and the dreaded pest, white stem borer. Though Robusta is resistant to coffee leaf rust and white stem borer, aroma is less and taste is bitter compared to Arabica. Moreover, Robusta is relatively susceptible to drought. Hence, the main focus of the breeding programme in Arabica is to evolve varieties having resistance to coffee leaf rust and white stem borer, whereas in Robusta, the objective is to evolve varieties with high aroma, better taste and drought tolerance.

However, Arabica is being more consumed, of high value and major focus of research programmes is to evolve Arabica varieties having resistance to coffee leaf rust. Studies conducted in different countries in this line have indicated that nine major genes S_H1 to S_H9 either in single or in combination are responsible for resistance in coffee plants to the leaf rust. Of these S_H1, S_H2, S_H4 and S_H5 are found in Ethiopian Arabicas, S_H3 in *C. liberica* and S_H6, S_H7, S_H8 and S_H9 are found in the inter-specific hybrid of Robusta x Arabica, Hybrido de Timor (HDT).

In India research programme on coffee was initiated during 1925. Prior to the establishment of research department, some of the innovative planters had developed coffee selections namely Coorgs, Chicks and Kents. Over the last nine decades, Central Coffee Research Institute has established a germplasm of around 360 Arabica accessions and 80 Robusta accessions including exotic and indigenous collections. Through its research programmes CCRI has released 13 Arabica and three Robusta selections.

Arabica selections from India

Sln.1 was developed by selection from the progenies of a natural hybrid of *C. arabica* x *C. liberica* and Sln.2 was developed by S.31 x S.22. Initially both these selections were popular but later were withdrawn due to bean defects. In order to overcome the bean defects of Sln.1, it was crossed with Kents and and Sln.3 was developed. Sln.3 was a high yielder and renowned for its quality and very popular among growers as S.795. Later, it became susceptible to new races of coffee leaf rust. Sln.4 was developed from composite Arabica collections from Ethiopia namely Cioccie, Agaro and Tafarikela. Cioccie and Agaro are tolerant to leaf rust. Tafarikela is susceptible. Nevertheless, Tafarikela is tolerant to drought. Sln.4 was later used to develop improved selections.

Sln.5A and Sln.5B were developed by crossing indigenous inter-specific hybrid (Devamachy) with S.881 and S.333. It is widely cultivated in Andhra Pradesh. Sln.5B, which was developed by crossing Devamachy with S.333, is a high yielder with improved bean size, better cup quality and with high field tolerance to leaf rust. It is popular in all Arabica growing regions. Sln.6 is an inter-specific hybrid between Robusta Sln.1R (S.274) with Kents Arabica. Sln.6 is also a popular selection grown in all Arabica regions, due to its field tolerance to leaf rust, improved bean size and cup quality. Sln.7 was developed as an attempt to exploit high density planting by exploiting the dwarf mutants. Dwarf mutant 'San Ramon' was crossed with S.795, and the resultant hybrid was crossed with Agaro and again the hybrid was crossed with HDT. The dwarfs among the progenies were utilised for high density planting. It is drought tolerant but a late ripener. Presently it is cultivated only in certain marginal areas. Sln.8 was developed by pureline selection from Robusta x Arabica inter-specific hybrid Hybrido de Timor. It is a moderate yielder. It is tolerant to leaf rust and is a popular selection. Sln.8 being tolerant to leaf rust was further crossed with Tafarikela, an introduction from Ethiopia, which is drought tolerant. The hybrid is drought hardy, with improved bean size and renowned cup quality and was released as Sln.9. This variety is popular and cultivated in all Arabica regions in India.

Sln.10 is a double cross hybrid of Catura x Cioccie and Catura x S.795. Catura is a high yielding variety, but, highly susceptible to coffee leaf rust. Sln.10 became susceptible to virulent races of leaf rust. Sln.11 is an inter-specific hybrid of *C. liberica* x *C. eugenoides*. It is highly tolerant to leaf rust and drought, but with small bean size and is a moderate yielder. It performs well in marginal areas of Andhra Pradesh. Sln.12, popularly known as Cauvery, is an interspecific hybrid between Catura and Hybrido de Timor. It is a high yielder with bold bean size and compact bush. It was resistant to leaf rust for about 10 years after release. But later it became susceptible to new races and it was replaced by other popular selections. Later Sln.13 (Chandragiri) was released by crossing Villa Sarchi (mutant of Burbon) and Hybrido de Timor. It is tolerant to all known races of leaf rust and bean size is bold. It is being cultivated in all Arabica regions of India.

Robusta selections from CCRI

Robusta selection 1R was developed by mass selection. Bean size and yield potential is higher compared to old Robusta. It is being cultivated all over Robusta growing regions. Later through further selection Sln.2R (Balehonnur Robusta series) was developed. It is collection of different 17 Robusta clones (BR series). Out of these, mixture of superior clones, BR-9, BR-10 and BR-11 was recommended for planting for better pollen compatibility and higher fruit set. Robusta selection Sln.3R was developed by crossing Sln.1R with *Coffea congensis*. Hybrid was superior in bean size and improved cup quality. Yield was on par with S.274. Bush size is compact and it is suitable for high density planting.

Harvesting

Fruits attain maturity within 8 to 9 months after flowering in Arabica and within 10 to 11 months after flowering in Robusta. Mature fruits should be carefully harvested and processed to prepare the commercial product called green beans. Careful handling of coffee and correct processing techniques adopted at the estate level are the most important steps which determine the quality of the end product *viz*., the coffee beverage. Faulty and unclean processing will cause 'offtastes' in the coffee cup.

For the preparation of both parchment and cherry coffees, picking of the right type of fruits is an essential part of processing. Coffee fruits should be picked as and when they become ripe. Under-ripe and over-ripe fruits will affect the final quality of coffee, the former tending to produce 'immature' beans and the latter 'foxy' beans. While picking and transporting picked coffee to the drying yard, damage to the coffee fruits should be avoided. Green cherries should be carefully sorted out before taking the ripe fruits for pulping. The green cherries may be dried separately for the preparation of cherry coffee. It is advisable to wash and dry frequently the bags used for collecting the harvested fruits. Bags in which fertilizers, pesticides and fungicides are stored should never be used for this purpose.

Primary processing

Coffee is processed in two ways (1) wet processing, by which plantation or parchment or washed coffee is prepared and (2) dry method, by which cherry or unwashed coffee is prepared.

Wet processing (preparation of parchment coffee)

a) Pulping

Preparation of coffee by the wet method requires pulping equipment and adequate supply of clean water. After harvesting, the fruits should be pulped (removal of skin) on the same day so as to avoid fermentation commencing before pulping. Fruits are fed to the pulper through a siphon arrangement to ensure uniform feeding and to separate lights and floats from sound fruits. Uniform feeding ensures proper removal of skin and prevents cuts and choking of the pulper discs. The pulped parchment passes through a sieve where the unpulped fruits and fruit skins are separated. Passing the parchment through a grading sieve will also help in separating the large and small sized beans. The skins separated by pulping should be removed from the vats.

b) Removal of mucilage

The mucilage on the parchment cover can be removed by 3 methods which are as follows:

1. Natural fermentation: The wet parchment obtained after pulping is kept heaped in vats and allowed to undergo natural fermentation brought about by bacteria. The pectin and non-reducing sugars present in the mucilage are digested by the bacteria and the mucilage is rendered soluble after about 36 to 48 hours. In the case of Arabica, the mucilage breakdown is completed in about 36hours and in the case of Robusta, fermentation will be completed only by 72 hours.

2. Treatment with alkali: Removal of mucilage by treatment with alkali takes about ½ an hour for Arabica and ¾ to 1 hour for Robusta. The wet parchment obtained after pulping is drained to remove excess water and is spread out in the vats uniformly. It is furrowed with wooden rakes and 10% solution of caustic soda (Sodium hydroxide) is evenly applied into the furrows using a rose can. About 1 kg of Sodium hydroxide dissolved in 10 litres of water is sufficient to treat 25 to 30 forlits of parchment. The parchment is agitated throughout and soaked for about half an hour. When the parchment no longer appears slimy, it should be washed thoroughly with clean water, repeatedly two to three times.

3. Removal of mucilage by friction: In this method, the pulped parchment coming out of the pulper is fed into the ‘aqua washer’. The aqua washer removes the mucilage by friction and the mucilage is washed away by the water passing through the machine. Thus the parchment coming out of the machine is free from mucilage. It is washed again in the vats once or twice and then taken up for drying.

c) Soaking

Overnight soaking of wet parchment in clean water helps to improve the colour of the parchment.

d) Washing

On completion of fermentation, the parchment is thoroughly washed with water repeatedly in the vats till all the mucilage is removed.

e) Drying of parchment coffee

Soon after the parchment coffee is washed, the excess water should be drained on specially constructed raised platforms or on perforated galvanized sheets. Surface drying is best carried out in trays provided with a wire-mesh bottom. The coffee may be turned frequently to facilitate quick drying and to prevent cracking of the parchment skin. In rainy weather, the trays may be kept under polythene covered erections. In the evening, coffee should be protected against mist. The surface drying in trays may take about 24 to 48 hours.

After surface drying, the parchment is spread over clean tiled or concrete drying floors. The parchment should be spread to a thickness of 7 to 10 cm and dried slowly. Rapid drying of washed coffee at this stage causes the parchment skin to split, which may lead to discolouration of the beans. Stirring and turning over of the parchment coffee once an hour is necessary for uniform drying. The parchment should be heaped and covered with polythene sheets early in the evening, until the next morning. The cover may be removed and coffee spread again the next day. Sun drying of parchment coffee may take about 7 to 10 days under bright weather conditions.

Dry processing or preparation of cherry coffee

For the preparation of cherry coffee, fruits should be picked as and when they ripen. When harvesting is done by one stripping, it is preferable to do so when 50% of the crop is ripened. Greens and unripe fruits should be sorted out and dried separately. The fruits should be spread evenly to a thickness of about 8 cm on clean drying yards. It is desirable to dry on tiled or concrete drying yards. Coffee should be stirred at least once an hour. The cherry coffee may be heaped and covered every day in the evenings and spread again the next morning. The coffee is dry when a fistful of cherry when shaken gives a rattling sound and a sample forlit records the same weight on two consecutive days. The cherry coffee would be well dried after 12 to 15 days. Each lot of cherry should be bagged separately in clean gunny bags.

Packing and storing coffee

Approximate moisture content in ripe cherry is 65%. After processing and drying, coffee should be dried to optimum moisture level. Drying is complete when beans are dried to a moisture level 10.5% in case of parchment coffee and 11.5% in case of cherry coffee. The dried coffee parchment should be packed in clean gunny bags and stored in godowns on wooden dunnage. After drying, coffee should be stored in a well ventilated store house. Fertilizers, pesticides or insecticides should not be stored together with coffee as coffee beans readily pick up foreign taints. Perfect cleanliness should be maintained all through the different stages of processing right from picking till the coffee is finally despatched to the curing works.

Out turn

Out turn is a scale or a unit indicating ratio of ripe cherry to dry parchment, dry cherry or clean coffee. Approximate ripe cherry to clean coffee ratio in case of Arabica is 17 to 19% and in case of Robusta, the ratio is 19 to 21%.

Secondary processing

Milling

Removal of parchment skin and silver skin from parchment coffee and husk from the cherry coffee is called milling. After milling skin and parchment peels are removed by winnowing and then clean coffee is subjected to grading.

Grading

Both Arabica and Robusta can have round beans, called pea berry (PB) or flat seeds called flats. Pea berry is separated manually or mechanically using PB band separators. Flats are then classified into A, B or AB according to the size of seeds. The different types and grades of coffee released for export are Plantation AA, A, B and C, Arabica cherry PB, AB and C, Robusta cherry PB, AB and C and Robusta parchment PB, AB and C. After completion of grading, garbling (sorting) is done to remove defective and discoloured beans then clean coffee (green coffee) is stored in ventilated godown for marketing.

Cup quality evaluation

Cup quality of coffee is influenced by variety, agronomic practices, climatic factors, primary processing, secondary processing, roasting, grinding and brewing. To maintain quality, care should be taken right from choice of varieties, cultivation, processing and brewing. Cupping is the method of systematic evaluation of aroma and taste characteristics. Cup quality evaluation is done by expert cup tasters at quality evaluation laboratories. The green coffee is roasted at 205°C in a suitable roasting machine till it turns to golden brown colour. Roasted beans are then ground in grinding machine to prepare coarse powder. Fresh powder is then put in a porcelain cup and brewed with 250 ml boiling water (around 95°C) and allowed to settle for 5 minutes. After removing the floats at a palatable temperature coffee is tasted for its quality.

Specialty coffees

Specialty coffees are exceptional coffees, better in quality compared to normal coffee either in taste or in visual appearance or both. Decaffeinated coffee, organic coffee, high altitude coffees, single origin coffee (estate coffee) and variety coffees are specialty coffees. As the consumers demand for unique coffee with finer qualities, growers are identifying coffees of unique origin and special characteristics and processing it with utmost care to promote as specialty coffee. Monsooned coffees from India are renowned specialty coffee fetching premium price in the global market. Apart from this, estate coffees, organic coffees and variety coffees are promoted by growers of India.

Indian filter coffee

Indian filter coffee is a special coffee preparation. Put 10 g (1 tablespoon) coffee powder to the upper unit of the coffee filter, insert plunger and make the coffee powder a uniform bed. Pour 150 ml freshly boiled water over the plunger. Allow it to brew for five minutes. Golden brown aromatic liquid will drip into the lower unit of the filter. Pour out the extract from the lower unit into the cups. Add 100 to 125 ml fresh hot milk into the extract and add sugar to taste. Indian filter coffee is ready.

Biology and cultivation of tea

V.V. Radhakrishnan
Genetics and Plant Breeding Division, Department of Botany, University of Calicut, Kerala – 673635, India.

The beverage prepared from the dried leaves of the tea plant is the most popular non-alcoholic drink of the common man. Commercial tea is obtained from three species of the genus *Camellia* belonging to the family Theaceae namely *Camellia sinensis* (L.) O.Kuntze (China type), *Camellia assamica* (Masters) Wight (Assam type) and *Camellia assamica* ssp. *lasiocalyx* (Planch ex Watt) Wight (Cambod type), which are known to produce commercially acceptable tea. Among the three species *Camellia sinensis* is the most commonly grown. Man's first use of tea plant as a pleasant beverage dates back to early days of human history. The tea leaf has to undergo several physical and chemical changes before it can be rendered fit for consumption. Based on the method of manufacture, commercial tea is classified as (a) green tea (b) black tea and (c) oolong tea. The most popular value added product is instant tea, a water soluble product of black tea. Today, tea is drunk all over the world and as each year passes more tea is being produced and consumed. India continues to be the world's largest exporter of tea, and more cups of tea are drunk throughout the world because it is a good tranquilizer and at the same time acts as a mild stimulant. The original habitat of the tea plant is Southeast Asia with warm wet summer and dry cold winter. Tea is a rain fed crop. It requires a rainfall of about 150 cm per annum. The temperature range required is between 13^{O}C and 30°C. Relative humidity should be around 80% but not less than 40% and the area should not be prone to frost and heavy wind. Tea plant requires strong acidic soil with pH between 4.5 and 5.5. At present commercial cultivation of tea extends from 44°N to 34°S. It enjoys the elevation of 300 m to 2500 m above the mean sea level. Most of the tea estates are located in slopes having 10%-33% gradient.

Origin and distribution

Tea is considered to be native of China. Some workers consider it belonging to North East India and adjoining part of Burma. Tea has its principal area of distribution in the South East Asia ranging from Nepal to Formosa and Japan. Three important types of cultivated tea tea namely China type, Assam type and Cambodia type are seen in these areas. Some other workers consider that tea originated somewhere in the lower Tibetan mountains.

Types of cultivated tea

China tea (*Camellia sinensis* (L.) O. Kuntze)

China tea grows into a big shrub, about 1-3 m in height, with numerous stems arising from the base of the bush near the ground level, giving rise to a dome shaped bush when fully grown. Leaf blades are generally leathery and dark green. Marginal veins of the leaf are generally indistinct. Flowers are borne singly or in pairs in the cataphyllary leaf axils. All the five sepals are persistent and leathery. Petals are 7 to 8 in number, cup shaped. Ovary white, densely hairy, three locular. Stigma is apical, capsule 1 to 3 loculate, containing 1 to 3 seeds.

Assam tea (*Camellia assamica* (Masters) Wight)

Assam tea grows in to a small tree with a vertical branching system and a distinct trunk, sometimes up to one third of the height of the tree. The tree generally grows to a height of about 10 m to 15 m. Leaves are typically dependent and thin glossy with more or less acuminate apex and distinct marginal veins. Leaf blades are mostly broadly elliptic, 8 to 20 cm long and 3.5 to 7.5 cm wide. Flowers are single or in pairs developing from the cataphyllary leaf axils. Sepals are 5 to 6 in number, unequal, leathery and persistent. Petals are 7 to 8 in number, white and devoid of any pigmentation. Ovary is three locular. Style typically three. Stigma linear. Fruit and seed more or less same as in China type.

Cambod tea (*Camellia assamica* ssp. *lasiocalyx* (Planch, ex Watt) Wight)

Cambod tea reaches a height of about 6 to 8 m. Leaves are more or less erect, glossy and yellowish-green when young and light green at maturity. Size of the leaf is intermediate between those of Assam and China types and leaves are generally elliptic. Ovary 3 to 4, sometimes 5 locular. Styles 3 to 5, free.

Fruit and seed similar to other varieties.

Planting and aftercare

Tea is propagated either through seeds or by clonal methods. Seeds are viable up to six months and prior to sowing, seeds are put in water and only the sinkers are used and floaters rejected. Seeds germinate in4-6 weeks and the cracked seeds are transplanted in polythene sleeves. Polythene sleeves of 10 cm width and 30 cm height are used for raising seedlings in the nursery. A mixture of jungle black soil with sand in the ratio of 1:1 is filled in the bag. Approximately 2 kg of soil-sand mixture is needed per sleeve. Top 10 cm of the sleeve is filled with red soil in order to induce proper rooting. The seedling will be ready for planting in the main field in nine months of time. Clonal planting materials are prepared from single node cuttings, multiple node cuttings or by tissue culture. Clonal cuttings are planted in polythene sleeves for germination and after germination they are planted in the main field as in the case of seedlings.

While preparing the land for new planting, measures to conserve soil and water must be borne in mind. Provisions for boundary, contour and leader drains to facilitate draining of the surplus water and prevent soil erosion are made, besides staggered trenches. In the case of new planting, to avoid the incidence of root diseases, after felling the trees, root system is removed to the extent possible. Burning of jungle growth is not advisable as ash being alkaline will increase the pH of soil. In the case of replanting, old shade trees are removed leaving the young ones in the field. The land is leveled into an even slope to facilitate easy cultural operations and proper drainage. A pit size of 30 x 45 cm^2 is recommended for tea planting. However, in clayey soil and drought prone areas, deeper pits are advisable. Aluminium sulphate at the rate of 100 gm per pit is applied and thoroughly mixed with soil if the soil pH is more than 5.5. The polythene sleeves are cut and removed without damaging the roots while planting. Planting is completed in June, where the plantations receive the South West monsoon while it is advisable to complete it in September in areas under North East monsoon regime.

Training of young tea

Proper training of young tea plant is necessary to achieve good canopy cover, proper development of frames and more number of plucking points per unit area. Centering or cutting the leader stem is the first agronomic practice executed after planting the tea plant in the field. Centering offers release from apical dominance and induces laterals. It should be done four to six months after planting during favourable climatic conditions. The first plucking after centering is termed as tipping and two tier tipping for proper spread is recommended in training of young tea plants. First tipping at 35 cm height for increasing the tertiaries and second tipping at 50 cm to induce the density of plucking points is suggested. Tipping should be done at green and semi hard wood portion and the tipped in material must contain only 3-4 leaves and a bud. Crop shoots produced after two tier tipping have to be removed periodically. Mother leaf plucking during lean periods and level plucking during high plucking months are recommended to ensure the sustained productivity and health of young tea and it is essential for better frame development. Cutting the branches of tea bush at a pre-determined height and a t a specified interval is known as pruning. This important operation is carried out to maintain the convenient height for plucking, to induce more vegetative growth, to remove the dead and defective wood and to remove knots and interlaced branches. Pruning of young tea plants is carried out normally in fifth year, which is known as formative pruning. If tea plants are left unpruned, they will grow as high as 30 feet.

Tea is a shade loving plant and therefore planting shade trees and their management is considered as a routine cultural operation in tea plantations. The best permanent shade tree for tea plantation is silver oak (*Grevillea robusta*). Tea requires only sparse shade and hence the optimum stand of shade is retained based on growth of the tree, altitude of the garden and other aspects of the field.

Manuring

Tea responds to manuring and it has been estimated that to produce 100 kg of made tea, tea plant utilizes on an average 10.2 kg of N, 3.2 kg of P_2O_5 and 5.4 kg of K_2O. Manuring in tea starts from the nursery stage itself. Once they strike roots at about 4 months after planting, 30 g of soluble mixture (Ammonium phosphate 35 parts, Potassium sulphate and Magnesium sulphate 15 parts each and Zinc sulphate 3 parts) is dissolved in 10 L of water and is applied with rose can for about 900 plants. Manuring in tea depends on many factors like age of the plants, organic and nutrient status of the soil, soil pH, nature of pruning and field potential of the tea bushes.

Plant protection

Pests

The major pests that infect the tea plant include root pests, stem borers and leaf pests. The major root pests are nematodes and cock chafer grubs. Nematodes are microscopic worms infecting roots resulting in the development of knots or galls. Affected roots become defunct. Plants exhibit chlorosis and stunted growth. In nursery, heat treatment is practiced to control the nematodes. The soil sand mixture is spread on a GI sheet and heated from below. Optimum temperature is 60-80°C. Chemical treatment with Carbofuran 3G 20g per cubic feet of soil is also effective. Neem cake @ 2kg per bush is recommended in the field.

Cock chafer grubs (*Holotrichia* sp.) find access to the nursery either through the soil or through undecomposed farmyard manure. The grubs damage the bark and roots of young plants leading to their death. Heat treatment of soil and use of granular insecticides are recommended.

The red coffee borer (*Zeuzera coffeae*) and the polyphagous borer *Sahyadrassus malabaricus* are the major stem borers infecting tea. The red coffee borer bores the young stem of the plant and the larvae tunnel downward and make holes at intervals to eject excreta and wood particles. Thick branches are preferred by *Sahyadrassus malabaricus*. The borers make holes in the stem and cover the entrances with a frassy mat formed from chewed wood and silk. To control stem borers, the affected stem region is cut and removed and Quinalphos is applied using ink fillers. The holes are covered with clay paste also.

The major leaf pests are mites, thrips and tea mosquito bugs. Mites like pink mite (*Acaphylla theae*), purple mite (*Calacarus carinatus*), red spider mite (*Oligonychus coffeae*), scarlet mite (*Brevipalpus australis*) and yellow mite (*Polyphagotarsonemus latus*) infect tea. If infestation is high, Dicofol, Quinalphos or Monocrotophose is sprayed. *Scirtothrips bispinosus* is the major thrip infecting tea.

These thrips prefer young leaves and buds. Both adults and larvae feed on the plants and cause lacerations of tissue which appear as streaks. The leaf surface becomes uneven, curled and matty. The feeding marks on the unopened buds appear as two parallel lines on the leaves. Chemical treatment with Phosalone, Monocrotophos, Quinalphos or Dimethoate is recommended. The tea mosquito bug *Helopeltis theifera* infects tender leaves and buds and causes dark brown colour. Spraying of Thiodan 35 EC at appropriate dozes is recommended.

Diseases

There are root diseases, stem diseases and stem diseases that infect tea. The major root diseases include red root disease, brown root disease, root splitting disease, Xylaria root disease, black root disease, charcoal stump rot, violet root rot and Diplodia root disease. Red root disease is caused by *Poria hypolateritia*. The disease can be easily identified by the characteristic mycelial strands that the fungus forms on the surface of the root. The fungus spreads very fast but kills the bush slowly. Brown root disease is caused by *Fomes noxius*. The roots get encrusted with a mass of soil, sand and small stones to a thickness of 3-4 mm, which cannot be easily washed off. In advanced stages of the disease, the wood of the root turns soft and spongy with honey comb like reticulation. *Armilaria mellea* causes root splitting disease in tea. The most characteristic symptom of the disease is the development of longitudinal cracks in the bark. When the bark of the root is lifted, a thick mat of white mycelium can be seen. Xylaria root disease is caused by *Xylaria* sp. The very first symptom of the disease is the retardation of growth. The affected plants remain dormant with absolutely no flush growth. The affected roots are covered by typical black, ribbon like compact strands of fungal hyphae that almost completely cover the root surface. Black root disease is caused by *Rosellinia arcuata*. Diseased bushes die suddenly and the withered leaves remain attached to the stem for some time. The roots are covered with black strands of mycelia, more or less woolly in appearance, which run longitudinally along the surface of the root and sometimes unite to form a network. The above diseases can be managed by preventing their occurrence and spread by eradicating the pathogen. Soil drenching with certain fungicides and soil application of biocontrol agents are effective in controlling them.

Charcoal stump rot is caused by *Ustulina zonata*. The presence of white or cream coloured delicate fan shaped patches of mycelium and irregular black double lines on the wood surface of the root are the characteristic symptoms. The dead bushes are uprooted and disposed off. The area is then sprayed with 1%^ Copper oxychloride. Replanting is done only after 1-12 months. Violet root rot is caused by *Spaerostilbe repens*. The affected bush exhibits a debilitated appearance. The leaves become thin, yellow and drooping. The bark of the root becomes deep violet to inkish violet in colour. Improvement of drainage to take away excess water, forking of still soil to increase aeration and improvement of soil conditions by green manuring, mulching and application of compost will help in recovery. *Botryodiplodia theobromae* causes Diplodia root disease. The failure of the bushes to recover after pruning or die back of new shoots formed after pruning is the initial symptom of the disease. The bushes show a weak appearance with unhealthy frames and small leaves. Application of an adequate fertilizer to help the bushes to put on vigorous growth is the remedial measure proposed.

The stem diseases include collar canker and thorny stem blight. Collar canker in tea is caused by *Phomopsis theae*. The main symptoms of the disease are chlorosis, cessation of growth, profuse flowering and canker on stems. To control the disease, remove the affected portion by pruning to the healthy wood and apply copper fungicides to cut ends. Soil drenching with systemic fungicides and soil application and wound dressing with biocontrol agents are effective.

Thorny stem blight is caused by *Tunstallia aculeata*. The characteristic feature of this disease is the formation of thorny projections on the stem. These thorny projections are the apices of the fructifications of the pathogen. The severely affected bushes are uprooted and burnt to avoid risks of further spore production. Soil drenching with fungicides and wound dressing with biocontrol agents provide good control of the disease.

Blister blight caused by *Exobasidium vexans* is the major leaf disease in coffee. The fungus affects only young succulent leaves and stems. Translucent spots occur within 3 to 10 days and well developed lesions are seen within two weeks. The lesions are sunken on the upper surface and convex at the lower surface. Affected leaves are distorted and irregularly rolled. The disease can be controlled effectively by spraying a combination of COC and Nickel chloride at a regular interval of 5-7 days.

Crop improvement

Introduction, selection and hybridization are the mainstay of the improvement programmes for superior planting material in any crop. The first efforts to improve the tea plant started by way of introduction and selection of superior jats. The first scientific attempt to select improved tea in Northeast India was made by Stiefelhagen brothers in 1860 by establishing standard sources of the tea seeds. The seed grown plants are not uniform as they are genetically diverse. In some cases the yield and quality are unpredictable but the planters wanted uniform plantations and as a result clonal method of propagation came to existence.

Genetic resources programme is one of the priorities in crop improvement research. The priority areas should be viewed primarily from three different angles namely collection of variability, evaluation of collected cultivars and conservation. The old seed grown tea populations are highly heterogeneous and thus are the gold mines of genes. The need for collecting tea germplasm in India has gained further importance due to massive uprooting of old seed grown sections to be replaced with a few popular clones such as UPASI 9, UPASI 3, ATK, TRF 1, CR 6017, SA 6, etc., which will lead to narrow genetic base. If genetic variability of such areas are not collected and conserved now, they will be lost forever. Such an alarming situation of the tea germplasm in India leads us to intensify the efforts of collecting the genetic diversity and conserving and utilizing the same. The wide bush-to-bush variation in any field of seed grown tea will be apparent to any observer but the extent of variability is perhaps not fully realized until yields or yield components of a large number of bushes are recorded separately.

Selection

Different workers have suggested selection criteria for yield and yield related characters in tea. Size and surface area of a bush in a mature tea field are the criteria recommended for estimating yield by Visser (1969). A positive correlation between yield and leaf size was observed by Satyanarayana and Sharma in 1982. In a mixed population where chinary bushes also exist, selection for leafiness will tend to be biased in favour of the shrubby China type. In general, such bushes will be less productive in areas where large leaf Assam type bushes can be grown. Leaf size, which is related to size and weight of shoot, has also been used as a yield criterion. Correlation between leaf size, leaf number and yield were also observed.

From South India, in 1966, Venkataramani clearly pointed out that seedling plants in a population exhibit tremendous variation amongst themselves with regard to different characters. It is not therefore surprising to assume that some of the variations are such as to adopt the plants possessing them better to the conditions in which they grow. It is a common knowledge that in a tea field, some bushes are attacked less by fungi, mites etc., and that some bushes recover quickly from pruning than others. The advantage of such variations is to be exploited scientifically. When the selection programme was started in UPASI-TRF, prime importance was given to yield and quality. Resistance to blister blight and mites received only secondary consideration because immunity or high resistance to blister blight and quality do not go hand in hand. In practice no one selection could be really resistant to all pests and diseases and a selection that is satisfactory for yield and quality might not highly or totally be susceptible to the most common pests and diseases. It has been pointed out that selection of the mother bush is the most important and that the future of the vegetatively propagated progeny would greatly depend on initial selection. But the combination of high crop yield and outstanding cup qualities is likely to occur only very rarely

Vegetative propagation of tea

The genetic makeup of perennial crops is highly heterozygous and the unique characteristics of such plants are lost if they are propagated by seed. For commercial purposes it is essential to have certain desirable characters such as high yield, good quality and resistance to pests and diseases. Since seed propagation does not ensure the availability of plants true to the parent, the propagation of superior varieties has to be done through vegetative means in tea.

Harvesting and processing

Harvesting in tea involves the collection of young growing shoots comprising the apical bud, the internodes and two or three leaves immediately below it, which constitute the crop. Collection of two leaves and a bud is known as fine plucking while harvesting three leaves and a bud is termed as light plucking. In order to increase labour productivity and to harvest entire crop during the high cropping months, shears have been introduced and used. Motorized machines are also used for harvesting. In India, plucking is carried out throughout the year. Even then, there are two big flushing periods, from April to May when about 25 per cent of the annual crop is gathered, and a second flush in September to December when about 35 to 40 per cent of the annual crop is harvested. Commercially, tea may be divided into three basic classes namely black or fermented, green or unfermented and oolong or semi-fermented. Besides these three types, instant tea, a water soluble form of black tea is also manufactured in limited quantities. There are five principal operations in the preparation of black tea and they are:

Withering

About 75 per cent of the fresh weight of a fresh tea leaf consists of water even on a dry day and nearly half of this has to be removed before the fibres of the leaf and stalk will stand the strain of rolling without breaking up. The leaf is spread thinly over withering racks arranged one above the other horizontally, and allowed to remain there for 12 to 18 hours to lose its excessive moisture. Sometimes, heated air is forced over these racks if the atmosphere around is humid. The leaf slowly and evenly becomes soft and flaccid and ready for rolling.

Rolling/leaf maceration

Rolling imparts the characteristic twist to the leaf, breaks the leaf cells, and exposes the juices to the air for fermentation to set in. After half an hour's rolling the leaf is removed in aluminium trolleys to a sifter and roll breaker. The movement causes the broken leaves and fine particles to fall below and the rest is taken out after rolling. The latter is again rolled for the second time with increased pressure. After the second roll, all the leaves still more or less green and flaccid are transferred to the fermenting drum.

Fermentation

During fermentation, the tannin in tea is partly oxidized and the leaf changes colour and turns bright coppery red. The rolled leaf is spread on tiles or aluminium or glass sheets and the oxidation which has commenced during rolling continues. The period of fermentation generally extends from three to three and a half hours, but this includes rolling time as well. As a general rule, the shorter the fermentation, the more pungent the liquor is, and the longer the fermentation the softer the liquor and deeper the colour.

Drying or firing

After the leaf changes its colour, the leaves are subjected to drying or firing. The essential function of this process is to arrest further oxidation of the leaf and to remove all moisture excepting a small amount of roughly 3 to 5 per cent. The drying machine is the largest machine required in a tea factory. The automatic tea drier is a large steel oven inside which the leaves travel slowly to the bottom while hot dry air is continuously forced into the oven. Careful regulation of temperature is essential, as excessive heat will scorch the leaves while lack of it will result in improper drying. Generally, the process known as first firing removes only three-fourth of the total moisture of the fermented leaves. After a period of cooling, they are fed into another drier and the latter known as second firing removes the remaining moisture and the tea from this second drier is the finished product.

Grading and sorting

Grading is carried out on mechanically oscillated sieves, similar to those used in the green stage, and fitted with meshes of appropriate size. It is the essence of good manufacture that teas should be sorted daily and not exposed to the air. After sorting tea is graded and given various names such as Orange Pekoe, Pekoe, Fannings and Dust; but these are only indicative of size and not of quality. Finished grades are stored in airtight bins until a sufficient quantity is accumulated to fill a consignment.

Different methods of tea processing

Orthodox tea

Orthodox teas are manufactured using orthodox rollers in the process of rolling. In this method, the leaves are rolled inside the rollers and as a result of the pressure exerted by the rollers the leaves are crushed and the sap gets smeared on the leaf surface.

CTC tea

CTC stands for cutting, tearing and curling. Here, rollers are designed in such a way that the leaves get cut, teared and curled in the process. The product is called CTC tea.

Instant tea

Powder tea, which is also known as instant tea is manufactured in separate factories. To make the powder, an ordinary tea infusion is evaporated and dried; the powdered solid matter thus obtained serving as a product to be infused again.

Green tea

Green tea can be broadly classified in to two categories: Pan or Chinese green tea and Sencha or Japanese green tea. The essential difference between the two is that pan tea is half fermented and in sencha the green leaf is steamed as soon as it is received for processing to activate the enzyme polyphenol oxidase and then dried in stages till it reaches a moisture content of 34%. On the other hand, pan tea is allowed to ferment slightly and roasted in a hot pan to prevent further fermentation. In both the methods the green colour of the leaf is preserved throughout the manufacture and the end product is green.

Grades of tea

There are different grades attributed to processed tea based on the method of processing, size of the granules and also the quality of the tea. The major grades of orthodox tea are whole leaf, broken, fannings and dust. The major grades of CTC tea are broken, fannings and dust and in the case of green tea the major grades are whole leaf, broken, fannings and dust. All the above types are further classified in to further grades based on the size of the leaf/granule/dust.

Biology and cultivation of natural rubber

P. M. Priyadarshan
Former Deputy Director, Rubber Research Institute of India, Kottayam- 686009, Kerala, India.

Natural rubber has been an essential commodity not only for the tyre industry but also for more than 50,000 products that hold elasticity as an attribute. Natural rubber is produced from over 7,500 plant species distributed among 300 genera of seven families, namely Euphorbiaceae, Apocynaceae, Asclepiadaceae, Asteraceae, Moraceae, Papaveraceae and Sapotaceae. The prime source of natural rubber worldwide is *Hevea brasiliensis* (Willd. Ex. A. de. Juss. Müll-Arg.). Among the alternate sources of rubber available, *Parthenium argentatum* Gray and *Taraxacum kok-saghyz* Rodin are currently exploited commercially on a small scale in semi-arid regions and temperate regions respectively.

The molecule of natural rubber is a *cis* 1,4 polyisoprene $[(C_5H_8)_n]$ where n may range from150 to 20,00,000, and is the end product of around 21 biochemical steps. Production of a molecule requires at least 48 hours. Shaving of bark of the tree (tapping) yields rubber latex from the turgid laticifers of the bark and the flow of latex ceases upon plugging of the laticifers that happens as a natural phenomenon after 3 to 4 hours of latex flow.Latex is a white cytoplasmic colloidal suspension containing mainly rubber particles and some non-rubber particles, organelles, proteins and serum. Latex particles are negatively charged on their surface and latex has a plasticity index (pI) between 3 and 5. This confers a colloidal stability to latex at basic pH, whereas latex coagulates at low pH.

Natural rubber is produced in South East Asia (92%), Africa (6%) and Latin America (2%). The main producing countries are Thailand (4.17 million t in 2014, accounting around 37% of global output), Indonesia, Malaysia, India, China, Vietnam and also Sri Lanka, Brazil, Liberia, Côted'Ivoire, Philippines, Cameroon, Nigeria, Cambodia, Guatemala, Myanmar, Ghana, Democratic Republic of Congo, Gabon, Bangladesh, Laos and Papua New Guinea. *Hevea* rubber is depicted in ancient religious documents from Mexico dating back to AD 600 and has a long history before domestication. However, the discovery of vulcanization (heating rubber with sulfur) by Charles Goodyear in 1839 resulted in explosive advancements in product manufacturing.

The latex found in the inner bark of *H. brasiliensis* is obtained by tapping (shaving the bark with a sharp knife) and collection of latex in cups. Addition of an acid, such as formic acid, solidifies rubber. The solidified rubber can then be pressed between twin rollers to remove excess water to form sheets. The sheets are commonly packed in bales for shipping. Rubber is also commonly transported in the form of concentrated latex derived through centrifugation. The strip of latex coagulated on the tapping panel (lace) and the lump left out in the cup (cup lump)

Some rubber yielding plants other than *Hevea brasiliensis*

Scientific name	Common name	Distributional range
Castilla elastica Sessé	Panama rubber tree	AMERICA (Mexico, Central America, Western South America)
Ficus vogelii (Miq.) Miq.	West African rubber tree	AFRICA (Micronesia, Northeast Tropical Africa, East Tropical Africa, West Central Tropical Africa, West Tropical Africa, South Tropical Africa, South Africa, Western Indian Ocean area)
Funtumia africana (Benth.) Stapf	Lagos silk rubber tree	AFRICA (East Tropical Africa, West Central Tropical Africa, West Tropical Africa, South Tropical Africa)
Manihot glaziovii Muell.Arg.	Ceara rubber	AMERICA (South America)
Holarrhena floribunda (G. Don) Durand & Schinz	False rubber tree	AFRICA (West Central Tropical Africa, West Tropical Africa)
Funtumia elastica Stapf	Lagos silk rubber	AFRICA (Northeast Tropical Africa, East Tropical Africa, West Central Tropical Africa, West Tropical Africa)
Ficus elastica Roxb.	Indian rubber plant	ASIA-TROPICAL (India, China, Malaysia)
Parthenium argentatum Gray	Guayule	NORTHERN AMERICA (South Central U.S.A., Mexico)
Taraxacum kok-saghyz Rodin	Russian dandelion	ASIA-TEMPERATE (Russia, China)
Cryptostegia grandiflora R. Br.	Palay rubber	ASIA (India)

that form the 'scrap' of commerce also fetches income to the planter.

Hevea rubber nowadays is cultivated as far north as 25° North (Yunnan province, China) and as far as 21° South in Brazil. The main production zone confined between 15° N and S. Strong international demand for natural rubber is driving expansion of industrial scale and smallholder monoculture plantations, with >2 million ha established during the last decade. Mainland Southeast Asia and Southwest China represent the epicentre of rapid rubber expansion.

History of domestication

History of *Hevea* recapitulates the names of five distinguished men: (i) Clement Markham (of the British India Office); (ii) Joseph Hooker (Director of Kew Botanic Gardens); (iii) Henry Wickham (naturalist);

(iv) Henry Ridley (Scientific Director of Singapore Botanic Gardens); and (v) R.M. Cross (Kew gardener), with Kew Botanic Gardens playing the nucleus for rubber procurements and distribution. As per directions of Markham, Wickham collected 70,000 seeds from the Rio Tapajoz region of the Upper Amazon (Boim district) and transported the collection to Kew Botanic Gardens during June1876. Seeds reached Kew on 14th of June 1876. Unlike popularly believed, this was not a corrupt evasion of law, as an official statement *Borracha no Brasil* in 1913 says it's only a goodwill of Government of Brazil. Of the 2899 seeds germinated, 1911were sent to the Botanic Gardens, Ceylon (now Sri Lanka), during 1876, and 90% of them survived at the Henarathgoda Botanical Garden. During September 1877, 100 *Hevea* plants specified as 'Crossmaterial' were also sent to Ceylon. In June 1877, 22 seedlings not specified either as Wickham or Cross, were sent from Kew to Singapore, which were distributed in Malaya and formed the prime source of 1,000 tappable trees found by Ridley during 1888. Mixture of Cross and Wickham materials might have occurred, as the 22 seedlings were unspecified. One such parent tree planted during 1877 was available in Malaysia even after 100 years. The rubber trees covering millions of hectares in South-east Asia are believed to be derived from very few plants of Wickham's original stock from the banks of the Tapajoz. After a review of the history of rubber tree domestication in East Asia, one would draw the conclusion that the modern clones have invariably originated from the 1911 seedlings sent to Ceylon during 1876. Also, Charles Farris could transport some seedlings to Kolkata in India (erstwhile Calcutta) during 1873. Hence, the contention that the modern clones were derived from '22seedlings' is debatable.

Developments in domestication of rubber after 1880 commenced in Singapore Botanic Gardens. Under the direction of Henry Nicholas Ridley, who took over as Director of SBG in 1888, the garden became a centre for research on *H. brasiliensis*. Ridley developed an improved method of tapping rubber trees that resulted in better yield of latex. His innovation revolutionized the region's economy. The arrival of 22 seedlings in Singapore did not create the Malaysian plantations overnight. The price of coffee had been high due to production problems in Brazil but, by the mid 90s, these problems had been overcome whilst fungal disease was attacking the Malaysian plants. In 1895, upon advice from Henry Ridley, Tan Chay Yan planted 43 acres of *Hevea* on his estate at Bukit Lintang in Malacca and the Kindersleys planted further 5 acres in Selangor. These were the first commercial rubber estates in Malaysia and, as the coffee market collapsed, more and more planters turned to rubber.

Significant development on the propagation of *Hevea* rubber occurred after 1910. The contribution to propagation and breeding of *Hevea* made by P.J.S. Cramer (Bogor, Indonesia) during 1910–1918 is note worthy. He made a trip to the Amazon and succeeded in getting seeds of *Hevea spruceana* and *Hevea guianensis*. Cramer also conducted experiments on variations observed in 33 seedlings imported from Malaysia in1883 from which the first clones of the East Indies were derived. Along with van Helten, a horticulturist, he could standardize vegetative propagation by 1915. The first commercial planting with bud-grafted plants was undertaken during 1918 in Sumatra's eastcoast. Ct3, Ct9 and Ct38 were the first clones identified by Cramer. Commercial ventures gradually spread with the introduction of bud grafting and 'generative' and 'vegetative' selection methodologies were simultaneously used that resulted in seedlings and grafted clones.

The first introduction of rubber to India was during 1873 from Ceylon (now Sri Lanka) when 28 *Hevea* plants were planted in the Nilambur Valley of Kerala state in South India. During the period 1880–1882, plantations on an experimental scale were raised in different parts of South India and the Andaman islands. *Hevea* was first introduced to Vietnam in1897 by the French, but was rejuvenated only after 1975 because of the long lasted war.

Botany of *Hevea brasiliensis*

Hevea is easily recognizable from its characteristic trifoliated leaves. The genus is basically composed of 10 species: *H. brasiliensis, H. guianensis, H. benthamiana, H. pauciflora, H. spruceana, H. microphylla, H. rigidifolia, H. nitida, H. camporum* and *H. camargoana*. Seven species are found in the upper Rio Negro region, considered to be the center of origin of the genus. *Hevea brasiliensis* is found in Southern areas outside of this center, in the upper Rio Madeira, where five other species are represented. It has generally been assumed that the species are freely inter-compatible. Consequently, *Hevea* species might be considered as a species complex, due to the absence of a strict barrier to recombination between species. Many efforts led to the identification of certain types which were formerly presented as other possible species. *H. paludosa* was identified in Brazil in 1905 and is often considered as an 11th species.

All *Hevea* species have $2n$ = 36 chromosomes, with the exception of one triploid clone of *H. guianensis* ($2n$ = 54) and the existence of one genotype of *H. pauciflora* with $2n$ =18. Although *Hevea* behaves as a diploid, it is believed to be an amphidiploid ($2n$ = 36; x = 9) that stabilized during the course of evolution. Similar to other tropical trees, *Hevea* normally takes 4–5 years to attain the reproductive stage. Though the capacity to flower is retained thereafter, the periodicity and the quantitative importance of flowering vary from clone to clone, as in other tropical trees. Rubber tree is monoecious, with lateral inflorescences (branched panicles) bearing both staminate and pistillate flowers that appear in the last phase of the defoliation–refoliation process during wintering. Rubber reaches maturity when it attains 50 cm trunk girth (tappable girth) at 125 cm height, so as to harvest latex. The immature phase of rubber is around six to seven years.

Hevea shows seasonal flowering in response to alternation of seasons. In the northern hemisphere, March–April is the main flowering season, and a short spell of secondary flowering prevails in August–September in many areas. It seems reasonable to presume that geographic location has a bearing on whether the trees flower during the secondary season. While it flowers and sets seeds during both the seasons in Malaysia, the southern parts of India experience flowering in March and April only. In north east India, Tripura state experiences flowering and seed set during both the seasons, but seeds are less viable during the secondary season. The appearance of female flowers takes 10–12 days more than male flowers (dichogamy), and, due to incomplete protrandry, some of the male flowers emerge after the appearance of female flowers. In Manaus and São Paulo (Brazil), which are located south of the equator, *Hevea* flowers only during September–October.

Inflorescences are borne in the axils of the basal leaves of the new shoots that grow out after wintering. The inflorescence is a many branched, shortly pubescent panicle bearing flowers of both sexes. The larger female flowers are borne at the end of the central axis and main branches while the smaller and more numerous male flowers appear on other parts of the panicle. Flowers are greenish yellow, with a bell shaped calyx having five triangular lobes but no petals. Such pentamerous flowers and a tricarpellary ovary are typical of the *Euphorbiaceae* and the alternation of vegetative and reproductive phases with the formation of inflorescences at the end of the dry season implies a tight control of flowering time. Staminate flowers have ten anthers arranged over a staminal column in rows of five each. The pistillate flower consists of a three celled ovary with three short sessile stigmas. For each pistillate flower, about 70 staminate flowers are found.

Hevea appears to be obligatorily insect pollinated and predominantly cross fertilized. The strongly scented flowers of mature inflorescence attract insects (pollinators) that are mostly midges and ants of the families *Heleidae* and *Ceratoponoidae*. The viability of pollen grains can be as high as 90%, but on average is only about 50%. Due to incomplete protrandry, *Hevea* clones may undergo assortative mating. Clones that have early anthesis of female flowers will preferentially get pollinated by clones wherein female flowers are yet to emerge. So, in a multi-clone population, possibility of random mating can always occur. However, due to incompatibility barriers among clones and issues relating to fruit set, seed set may not occur in the expected rate.

Fertilization occurs within 24 h after pollination and unfertilized female flowers quickly wither. Clones vary greatly in flowering, fertility and fruit set. This ranges from near sterility to prolific fertility. There is no evidence of self incompatibility. The mature fruit is a large three lobed capsule, 3–5 cm in diameter, having a woody endocarp and a thin, leathery mesocarp, and contains three seeds. The fruit reaches its maximum size in about 80–90 days and the endocarp becomes woody in about 110 days. The endosperm matures in about 130 days and the cotyledons get pressed to the endosperm. Thereafter, the moisture content of the capsule wall declines when the fruit is about 140 days so that the dry capsules dehisce explosively into six pieces with dispersal of seeds up to 15 m from the tree.

Seeds are large (3.5–6.0 g) and ovoid with the ventral surface slightly flattened. The seed coat, or testa, is hard and shiny, brown or grey brown with numerous darker mottles or streaks on the dorsal surface, but a few or none on the ventral side. The hilum can be seen as a shallow, approximately circular depression on the ventral surface and the micropyle is adjacent to it. A papery integument lines the inner testa and encloses the endosperm, which fills the seed. The embryo is situated in the middle of the endosperm with the radicle pointing towards the micropyle. The two white, veined cotyledons are pressed against the endosperm and enclose the plumular end of the axis of the embryo. The endosperm, which forms 50–60% of the weight of the seed, contains semi-drying oil which can be used as a rather poor substitute for linseed oil. If seeds are not sown in 10–15 days, they lose viability on storage as a result of the production of hydrocyanic acid (HCN).

Vegetative growth of the plant

Growth in the length of stem is discontinuous, with rapid elongation of an internode towards the end of which a cluster of leaves is produced. This will be followed by a rest period for the scale leaves to develop around the terminal bud. This sequence is repeated and leaves are produced in whorls separated by bare stem. Young scions of bud grafts elongate internodes for 2–3 weeks followed by a rest period. Although the elongation of stems is intermittent, their girth increases continuously. New flushes in the mature tree appear at any time of the year. The spirally arranged trifoliate leaves hang downwards approximately parallel to the petioles and are reddish or bronze in colour and gradually become green. The angle with the petioles will now be increased to 180°, in which position they remain until they senesce. The mature laminae are shiny dark green on their upper surfaces and paler, glaucous green below. Leaves are trifoliate and glabrous, arising on petiolules with long petioles (about 15cm) bearing extra floral nectaries at the point where petiolules merge. Nectar is secreted only on the new flush of leaves during flowering. The leaflets are elliptic or obovate with the base acute and the apex acuminate; they have entire margins and pinnate venation. Clones can be identified through a closer examination of the architecture of leaves.

Wintering

Trees of more than 4 years exhibit defoliation or 'wintering', a term used to describe the annual shedding of senescent leaves which renders the trees wholly or partly leafless for about 15–20 days. Defoliation is followed by terminal bud bursting in 15 days and the expansion of new leaves in a week. There used to be a yield depression during defoliation and more markedly during refoliation. In areas experiencing a dry period, the duration of wintering tends to be short and refoliation is completed fast, thus minimizing yield reduction. Most of the non-traditional rubber growing areas above 15°N fall under this category. There are marked differences between clones in wintering behaviour. A few tend to shed and replace part of their foliage simultaneously over a relatively long period and may thus show no very obvious signs of wintering, while at the other extreme some become completely leafless for a time. The majority are intermediate between these extremes.

Root heterogeneity and stock–scion interactions

A major part of rubber breeding efficiency can be attributed to the grafting technique which enables the multiplication of elite genotypes at the level of the bud-grafted part (aerial part of the tree). Unfortunately, cloning the whole tree (aerial part and roots) for the development of single component clonal trees by the cutting technique (self-rooted marcots and mist-propagated cuttings) generates a high ratio of uprooting due to lack of tap root and inadequate anchorage. Notwithstanding, a bud-grafted population has a high level of homogeneity and should exhibit intra-clonal variation in yield to a minimum.

Ecophysiology of rubber

Rubber planters are under permanent pressure to raise land productivity while protecting the environment as a result of: (i) decrease in the amount of cultivable land; (ii) the change in human lifestyles increasing the demand for rubber; and (iii) environmental issues generating a demand for natural rubber over synthetic rubber. This increasing demand has prompted rubber cultivation to be rapidly expanded into non-traditional rubber growing areas. The principal way of achieving high productivity has been the development of high yielding clones with desirable characteristics through rigorous breeding and selection. Supplementary approaches to achieve greater productivity have been the determination of an optimum tapping schedule and soil management to maintain fertility. All these parameters affect the overall growth and physiology of trees.

Before the rubber tree can produce latex, it needs to attain maturation of the leaves, the organs of photosynthesis. Leaves attain maturity in around 35–40 days after emergence. In addition to phytohormonal equilibrium, leaf maturity can be regarded in terms of CO_2 balance and the maturity leads to a series of characteristics such as leaf expansion, chlorophyll accumulation and formation of photosynthetic apparatus (photosystems I and II and carboxylative enzymes), stomata, cellwall and supporting structures. The dry matter increase in rubber tree leaves is directly related to the balance between CO_2 assimilation from photosynthesis and its release by respiration. During the juvenile phase, the CO_2 balance in the rubber tree is especially affected by significantly higher respiration. The higher respiration rates that occur in the juvenile phase seems to indicate a higher metabolic activity (growth respiration), during which energy released is required to synthesize structural compounds and chlorophyll. To reach net photosynthesis, the young leaves need to increase the concentration of CO_2.

Propagation systems

As in any other tree species, *Hevea* is also multiplied by both seeds and vegetative means. There are different kinds of rubber seeds such as: (i) legitimate; (ii) illegitimate; (iii) ordinary; (iv) monoclonal; and (v) polyclonal. Among these, monoclonal and polyclonal seeds are produced in specially raised plantations. The other types of seeds are collected from commercially established plantations.

Polyclonal (polycross) seeds, which are hybrid seeds, are produced in plantations called polyclonal seed gardens. In these gardens, several clones are planted intermixed so as to maximize cross pollination. Clones planted in these gardens should possess desirable characters such as: (i) high yield; (ii) disease resistance; (iii) vigour; (iv) ability to produce good seedling families; and (v) profuse production of seeds. All the clones should preferably flower simultaneously.

Vegetative propagation of rubber is carried out mainly by bud grafting. Propagation through rooted cuttings is possible in rubber but is not generally practiced due to unsatisfactory development of the root system, especially the taproot. The principle involved in bud grafting is the replacement of the shoot system of a genotype with that of another more desirable genotype. The method of bud grafting adopted is a modified form of the forket method of patch bud grafting. In this process, a patch of the bark of the seedling plant (stock) is replaced by a bud patch taken from the clone to be multiplied (scion). A thin film of polythene is wound over the bud patch for water proofing. After 21 days, the polythene is taken off. The bud patch gets attached to the stock permanently and becomes a part of it. The stock is then cut off above the bud-grafted portion and the grafted bud develops into a new shoot (scion) and then into a two part tree.

Depending on the colour and age of the buds, three main types of bud grafting are practiced. These are: (i) brown (conventional); (ii) green; and (iii) young bud grafts. In the first method, older buds having a brown colour are used, while in the other two, tender green buds are utilized. Depending on the part of the stock where bud grafting is carried out, the classification would be: (i) base bud grafting; (ii) crown bud grafting; (iii) over bud grafting; and (iv) high bud grafting. The bud patch used for brown bud grafting has a length of about 5 cm and a width of about 1.5 cm. For preparing the bud patch, two parallel vertical cuts having a length of 5 cm are made on two sides of a bud, 1.5 cm apart. Then, two horizontal cuts are made connecting the lower and upper ends of these cuts. Latex is allowed to ooze out and meanwhile incisions are made around neighbouring buds of the same bud wood. When the oozing of latex stops, it is wiped off and the bud patch marked out by the four cuts is stripped off. The inner side of the bud patch is examined for the presence of the core of the bud, which appears as a slight projection. If that is not present, the bud patch should be discarded. The bud patch is then gently placed in the bud grafting panel after lifting the flap. Due care must be taken not to injure the cambium. The panel is bandaged using a polythene strip. Bandaging should commence at the bottom and move upwards in a close tight spiral that can end with a knot. It requires 15–20 days for the bud patch to heal and form part of the stock. The presence of green colour on the bud when the bud is scratched indicates initial success of bud grafting.

Latex production and harvest

Latex is a colloidal suspension. It is a stable dispersion (emulsion) of polymer micro-particles in an aqueous medium. It is a complex emulsion consisting of proteins, alkaloids, starches, sugars, oils, tannins, resins and gums that coagulate on exposure to air. Besides rubber particles, latex contains sub-cellular elements like lutoids, plastids, the Fre-Wyssling particles whose role is not clearly understood and ribosomes. However, neither the nuclei nor the mitochondria are expelled during tapping.

Latex usually contains 25% to 50% dry matter, 90% of which is made up of rubber. Tapping causes loss of cell constituents from the laticifers. *Hevea* rubber is a macromolecule formed by chains of 5-carbon isoprenic units – the *cis* 1,4 polyisoprene $(C_5H_8)_n$ where n may range from 150 to 20,00,000. This high molecular weight polymer is formed from sequential condensation of isopentenyl diphosphate (IDP) units. IDP is a common intermediate for the production of numerous classes of isoprenoids produced in plant kingdom. These units are the precursor of numerous other natural isoprenic substances (sterols, carotenoids, etc.). A close study of its structure has shown that the isoprenic bonds are mainly of the *cis* form; less than 0.2% is in the *trans* form and these make the first 'geranyl geranyl' links in the polyisoprene chain. The average molecular weight is between 2,00,000 and 8,00,000.

Laticifers are the major locations of rubber biosynthesis. Numerous classes of isoprenoids are produced through IDP as a common intermediate. The mevalonate (MVA) pathway has been the conventionally studied pathway for isoprenoid biosynthesis since the 1950s. This cytosolic pathway of rubber formation was demonstrated through incorporation of radiolabelled pathway intermediates such as mevalonate and 3-hydroxy-3-methylglutaryl coenzyme A (HMG CoA) into rubber. Recently, the plastidic I-deoxy-D-xylulose 5-phosphate/2-C-methyl-D-erythritol 4-phosphate (MEP) pathway is being considered as a possible alternative route for rubber biosynthesis. The expression of l-deoxy- D-xylulose 5-phosphate synthase (DXPS) in *Hevea* latex and leaves suggests that the MEP pathway exists in the laticifer and therefore could provide an alternative means of generating IDP for *cis*-polyisoprene synthesis.

Latex flow rate and the changes in tapping panel turgour pressure have a direct relation with the anatomical aspects of the laticifer system. The latex vessels (laticifers) are arranged in concentric cylinders among the phloem tissue. Elongated laticifer cells are laid down in each cylinder end to end with their end walls dissolved, thus forming sets of continuous articulated tubes. These cylinders appear as rings in a cross section, known as 'latex vessel rings'. Lateral connections between adjacent latex vessels within the same ring occur, and the laticiferous system is thus made up of a complex network of interconnected vessels gaining the name 'anastomosing latex vessels'. There are no connections between adjacent latex vessel rings. Hence, when the tree is tapped, latex thus exuding originates not only from the latex vessels of the trunk that are cut, but also from connected latex vessels of the same latex vessel ring that are uncut, but that lie within the proximity of the 'drainage area' of the tapping cut. Similarly, tapping panel turgour pressure has a bearing on the changes in the drainage area as a whole. On tapping, release of pressure occurs to a greater extent in the latex vessels than in the surrounding tissues. This results in a rapid elastic expulsion of latex flow through the vessels along the pressure gradient. The gradient is highest near the cut and becomes smaller with increasing distance away from the tapping cut. Latex flow ceases after two hours when plugging happens by the bursting of lutoids. The early tapping systems slowly evolved into the modern systems largely by reducing the number of cuts and the frequency of tapping.

There is a need to open trees for tapping as soon as the required minimum girth has been obtained. While the budded trees have cylindrical trunks and can be opened at a height which tappers can reach without any aid, seedling trees are conical with a bigger girth at the base of the tree and hence, a lower height of opening is recommended. With conventional tapping the recommendation is to open bud-grafted trees for tapping with a girth of 46 cm and above (when 70% of the trees have attained) attained at a height of 1.5 m from the ground. For seedling trees, the convention is to open when a similar girth is reached at a height of 75 cm from the ground.

The latex vessels in the bark traverse from bottom left to top right at an angle of 30^0 in an anti-clockwise direction. Hence, a cut from the high left to low right will severe a greater number of latex vessels which lead to the current practice of sloping cut from high left to low right on all spiral cuts. Similarly, 25^o slope is preferred for seedling because it results in lesser bark consumption and a smaller area of bark that will be lost when the cuts reach ground level without much loss of yield. Further, the presence of a thick corky layer in bark provides a channel for the flow of latex. Since the bark thickness is less in bud-grafted trees, the latex may overflow the sides of the tapping cut with a 25° slope; which is an additional reason for having 30° slope in bud-grafted trees. When the tapping cut approaches the base, a new cut on the opposite panel can be similarly opened. Tapping Panel Dryness (TPD) is a syndrome encountered in rubber trees, characterised by spontaneous drying up of the tapping cut resulting in abnormally low yield or stoppage of latex production.

Post-harvest processing

Tapping of a rubber tree is preceded by clearing the tapping panel, and the tree lace and the lump remaining in the cup are collected by the tapper before tapping the tree. This lump and lace are dried and pressed to form 25/50 kg blocks. These fetch a comparatively lower price commercially, but can form raw material for the production of crepe and block rubber. Such blocks are used for manufacturing tyres. The collected latex is diluted with twice the quantity of water and 1% Formic acid is added to coagulate the rubber. After coagulation, the 'rubber slabs' are passed through rubber rollers to squeeze the water out. Popularly, in addition to using smooth and ribbed rubber rollers, automated sheeting batteries are also used for higher efficiency. Rubber sheets thus formed are smoked and dried in the smoke house and made into bales. Latex as such is not generally used for making products due to its low dry rubber content (DRC). 100 g of latex contains only 30 g to 32 g of rubber depending on the season. Latex can be subjected to centrifugation using specially designed latex centrifuges that can yield latex with 60% DRC, popularly known as *cenex*. Double centrifuged latex is also used for making specified latex products. Latex can also be concentrated by creaming process.

Rubber products can be manufactured either from dry rubber or from latex. Dry rubber products are generally made by moulding, calendaring or by extrusion methods. Latex products are made by dipping, casting or by extrusion. Dry rubber products like door mats, bushes and even tyres are made by moulding. Thin products like microcellular sheets are made by calendaring and products like rubber hoses are made by extrusion methods. An automobile car has more than 500 parts made of rubber starting from bushes, beadings, wipers to tyres. Latex products like rubber bands, balloons, gloves, condoms etc. are made by dipping the moulds in compounded latex whereas foam products like mattresses are produced by casting and latex threads are made by extrusion method. After shaping, the products are vulcanized by heating in sunlight or in hot air ovens.

Products and processes generating ancillary income

Hevea honey and wood are the two supplementary income generating sources that can raise significant income from rubber plantations. Neither male nor female flowers secrete nectar, but it is secreted by the extra-floral nectaries (on young leaf petioles and fleshy scales of young shoots). Over the years, honey bee rearing saw major vicissitudes due to non-availability of bees many a times. In India, there was a rehabilitation measure through the introduction of *Apis mellifera* with a reported average yield of 60 kg/hive/year compared to 19.46 kg/hive/year for the popular Indian honey bee *viz., Apis cerana indica*. On an average, 15 to 20 *A. cerana indica* hives can be placed per ha and the average yield is 12 kg/hive/year. The honey flow period of rubber plants ranges from January to March and during this period honey bees collect large quantities of nectar from the extra floral nectaries.

Rubber wood is composed of fibres, vessel elements, axial parenchyma and rays in different proportions similar to that of other hardwood species. The fibres are lignified or partially lignified and are 1.1 mm to 1.5 mm in length and about 22 µm in thickness and the vessels are small to moderately large with one to four pores per mm^2. The structure and distribution pattern of pores enhance the chemical impregnation capacity of rubber wood during preservative treatments. The lumen of the pores is usually filled with balloon like parenchymatous outgrowths called tyloses which are a characteristic feature of rubber wood. For temporary protection, a dip treatment with a number of insecticides and fungicides is carried out. In long-term, the wood preservatives are allowed to penetrate deep into the timber for complete preservative penetration either through dip diffusion process or pressure impregnation process.

Crop improvement

The aim of a breeding programme in rubber is to derive a clone with enhanced dry rubber yield and if possible, with improved secondary attributes like resistance to diseases and high/low temperature stresses. The efficient use of the available genetic variability in the form of clones is further augmented through bud-grafting. However, the longtime needed for genotype evaluation and low seed set are added constraints for the production of recombinants. The main source of modern clones is the Wickham population with much low genetic variability. Of late, concerted efforts to integrate new Amazonian wild population offer new vistas for the production of new clones.

While considering planting in a new area that may be suboptimal for rubber growth the best plants to use are polyclonal seedlings to ensure maximum stand development, sacrificing yield since these areas are affected by stress conditions. However, evaluation of established clones gives quick information on what clones are suitable for a new area. While the rubber producing countries have selected vivid clones suitable to their traditional environment, RRIM 600 seems to be the universally accepted clone for all non-traditional areas of the world.

Natural pollination was the basis of 'random seedling populations' and of 'mother-tree seedlings'. Natural pollination was exploited by creating polyclonal seed gardens with the best mixed clones, planted in isolated sites in order to protect them from outside pollen. Natural pollination in seed gardens can lead to a certain amount of selfed seedlings with potential inbreeding. Recombination breeding programme is practiced in rubber by controlled hand pollination for the production of full-sib families, followed by three selection stages *viz*., Seedling Evaluation Trial (SET), Small Scale Clonal Trial (SSCT) and Large Scale Clonal Trial (LSCT). The process is cyclical, with the best clones becoming candidates for recombination in the next cycle.

From around 500 kg/ha in primary clones to more than 2500 kg/ ha in the best current clones, rubber breeding has come a long way primarily due to recombination breeding and selection of clones under RRIM and PB series. RRIC 100 series released in Sri Lanka during 1970s is yet another example. Much of the hybridization work in Malaysia (RRIM, Prang Besar), Indonesia, India, Côte d'Ivoire, Brazil, Thailand and Vietnam further strengthened the array of hybrid clones. These clones are known for their adaptability to specific hydrothermal/agro-climatic situations. At least 16 primary clones played major role and can be considered as prime progenitors of many modern clones. Many valuable recombinants must have been lost during the course of assortative mating of primary clones and of hybrid clones followed by subsequent directional selection for yield under varied geo-climates. The breeding policy has been mainly to cross 'the best with the best' (GAM, Generation-wise Assortative Mating), with strong emphasis on precocious yield in selection within Wickham material. But it could be considered to take more advantage of genetic analysis and of quantitative estimation procedures, especially for the assessment of clonal general combining ability (GCA) for growth and latex yield improvement. Breeding for disease resistance has to take account of specific aspects related with host-pathogen interactions.

The aforesaid breeding scheme is of the past, and lately, *Hevea* breeding has been compelled to undertake drastic reduction in the years consumed for completing a breeding cycle and for derivation of clones. SSCTs and LSCTs are well avoidable. The scheme proposed here is to start with SETs comprising hybrid seedlings. The course normally followed is to evaluate through test tapping and select the best yielding seedlings. Presuming that a seedling can never reflect the yielding attribute during adult stage this step needs to be suitably modified. The families of hybrid seedlings are to be raised in closer spacing (2 or 3 m) and allowed to attain tappable girth. These seedling trees are to be evaluated with a reference clone. (Selections from such evaluations are to be further laid under clonal nursery, only to reconfirm the yield potential). The high yielding seedling trees are to be made bud-wood points, only to have enough bud-grafted plants for block level commercial evaluations. Once the yielding potential of the clonal derivative is confirmed under block trials, the clone is set for recommendation. When a normal breeding cycle takes 35 to 40 years, through skipping SSCTs and LSCTs, the scheme proposed can complete a breeding cycle in 17 years.

Rubber clones are denominated with a first part in letters (abbreviation of the origin) and a second part in numbers. A list of denominations with their emblematic clones that were developed during the first half of the 20th century, such as AVROS (AV49, AV255, AV352, AV2037), Bodjong Datar (BD5, BD10), Djasinga (Djas 1), Glenshiel (Gl1), Gondang Tapen (GT1), Kali Djeroek (KD1), Landb. Mij. Oud Djember (LMOD 53), Lands Caoutch Bedrijf (LCB 1320), Pataroeman (Pat 190), Pilmoor (PilD 65), Prang Besar (PB 186), Proefstationvoor Rubber (PR 107=LCB 510), Tjirandji (Tjir1, Tjir16), Waringiana (War4), etc. are the prominent ones. Some major clones developed from the important rubber research institutes around the world include IRRI clones (Indonesia, Indonesian Rubber Research Institute (clones IR), MDF clones (clones collected in the Madrede Dios, Peru by Firestone), RRIC clones (Sri Lanka, Rubber Research Institute of Ceylon), RRII clones (India, Rubber Research Institute of India), RRIM clones (Malaysia, Rubber Research Institute of Malaysia), RRISL clones (SriLanka, Rubber Research Institute of Sri Lanka), RRIT clones (Thailand, Rubber Research Institute of Thailand), RRIVclones (Vietnam, Rubber Research Institute of Vietnam), etc.

It is difficult to provide yield data for different clones which successively emerged in clone recommendations since there has been no standard for characterizing the yield level of the clones over time in the successive experimental programmes. The mean annual yield over 10 tapping years with 550 kg ha^{-1} for unselected Wickham seedlings, 1175 kg ha^{-1} for PilB 84 (selected in the 1920s), 1425 kg ha^{-1} for RRIM 501 (1928–1931), 2000 kg ha^{-1} for RRIM 600 (1937–1941) and 2125 kg ha^{-1} for RRIM 712 (1947–1958) are the records available. Deriving clones at definite intervals is challenging to the breeder, for which refinements in the methodology followed to reduce breeding cycle time and to assess the yielding potential are prime.

Biological constraints and their management

It is noteworthy that unlike other clonal species, *Hevea* is not affected by viral diseases. Apart from South American leaf Blight (SALB), other diseases of economic importance are the Gloeosporium leaf disease (*Colletotrichum gloeosporioides*), powdery mildew (*Oidium heveae*), and the Phytophthora leaf fall (*Phytophthora* spp.). Clonal specificity is evident towards resistance to these diseases.

South American Leaf Blight (SALB - caused by *Microcyclus ulei*) that is singularly devastating is a stress factor limiting the yield of *Hevea*. It has played and still plays a major role in the history and in the geographic distribution of rubber industry in the Americas. On one hand it prevents Latin America from developing rubber cropping in all the otherwise favourable climatic conditions, and on the other hand it represents a permanent major threat to the crop in Asia and Africa. Some amount of breeding work, mainly based on back cross technique has been undertaken in the past to incorporate resistance to these diseases in high yielding clones. Resistance sources appear to be absent in high yielding Wickham population, but rather frequent within the Amazonian germplasm. Conidia and ascospores cause infection and both are equally important in completing the disease cycle. Rain plays an important role in the spread of leaf blight. It is believed that rain is the most effective disseminator of large masses of spores and wind is the chief means of dispersal. Outbreaks of leaf blight occur when the daily temperature is below 22^0 C for longer than 13 h, RH over 92 per cent for a period longer than 10 h and rainfall above 1 mm per day for the previous seven days. The fungus can affect petioles, green stems, inflorescences and fruits. But the most obvious infection is on young leaves on the abaxial surface of four to nine day old, expanding tender leaves. They appear as greyish-black lesions covered with olive-green powdery sporulating masses. The causal fungus *Microcyclus ulei* (P. Henn.) von Arx & E. Muller *(Dothidella ulei* P. Henn.) is specific to *Hevea* species only. Several plant protection operations are being carried out for controlling this disease. Aerial spraying (8 -10 rounds) is done using benomyl 300 g, thiophanate methyl 200 g or mancozeb 2 kg in 30 L water per ha at intervals of 7 to 10 days. For fogging 200 g thiophanate methyl or 1 kg mancozeb are being used in 6 to 8 L of agricultural spray oil per ha at intervals of four to seven days. Systemic fungicides like chlorothalonil (Daconil), triforine (Saprol) and triadimefon (Bayleton) are found promising in small-scale trials.

Abnormal leaf fall is the most destructive disease in India and occurs during the southwest monsoon months of June, July and August. It infects pods, leaves and tender shoots causing heavy defoliation and die-back of tender twigs. The first report on this disease from India was in 1910 from estates near Palapilly, in Trichur district, Kerala state. In due course, the disease spread to all other rubber growing districts. Rainfall is the most important predisposing factor for the initiation and spread of the disease. In the traditional rubber cultivated areas of India, a continuous spell of 250 to 350 mm rain for 7 to 10 days without intermittent hot sunshine, with minimum and maximum temperatures within the range of 22^0C to 25^0C and 26^0C to 30^0C respectively and relative humidity (RH) above 90% are most congenial for the outbreak of the disease. Under such conditions of low temperature and very high atmospheric humidity, the disease spreads rapidly and assumes epidemic proportions. Under normal monsoon, the disease starts by the middle of June and reaches the peak by the middle of July. However, when monsoon is late, very heavy incidence is noticed from the middle of July to middle of August. Different species of *Phytophthora* are reported to be causing pod rot, bark rot, patch canker and leaf fall diseases of rubber in various countries. The species most common in the traditional areas is P. *meadii*. Prophylactic spraying of rubber plants with 0.75 per cent Bordeaux mixture is the very popular method. It was noticed that addition of 0.5 per cent zinc sulphate to 0.5 per cent Bordeaux mixture could give adequate protection and reduce the cost of spraying by about 35 per cent when compared to spraying with 0.75% or 1% Bordeaux mixture.

Powdery mildew disease was first reported from Indonesia. Tender leaves at the brown or light green stage are highly susceptible. The presence of dull cool weather with intermittent light showers during refoliation predisposes the plants to severe disease attack. Prevalence of mist, dew and cloudy days with 75 to 80 per cent relative humidity are favourable for disease development. Early wintering clones usually escape from the disease because the climatic conditions during their refoliation period are not favourable for the disease development. Late wintering clones are usually severely affected. The optimum temperature for germination, infection and sporulation ranges from 25^{0}C to 30^{0}C. The fungus is disseminated by airborne conidia. The peak sporulation is around noon. *Oidium heveae* Steinm an obligate parasite is responsible for the disease. Leaf fall due to powdery mildew adversely affects the growth and yield of rubber trees. Dusting with sulphur gives effective control of powdery mildew disease. Spraying wettable sulphur is preferred only in nurseries and young rubber plantations as repeated spraying in mature areas is expensive and impracticable. Sulphur dust having a minimum of 70% sulphur is generally used for dusting. The dust should be dry, free flowing and should pass through 325 mesh sieve (particle size 40 microns). Dusting is done at the rate of 11-13 kg/ha at an interval of 7 -10 days. Three to six rounds of dusting are usually required.

Corynespora cassiicola (Berk. & Curt.) Wei is an important plant pathogenic ascomycete causing the damaging Corynespora Leaf Fall (CLF) disease. A small secreted glycoprotein named cassiicolin was previously described as an important effector of *C. cassiicola*. *Corynespora* causes leaf spot and leaf fall diseases. First reported in India from seedling nurseries, it was then reported from Malaysia, Nigeria, Indonesia, Sri Lanka and Thailand. The disease has now been found in almost all rubber growing regions. The environmental factors favouring disease development are high humidity, a temperature of 28^{0}C to 30^{0}C, humid air and cloudy weather. Spraying of benomyl, mancozeb, captan or propineb is recommended for affected nursery plants. Four to five rounds of spraying with tridemorph (Calixin 0.6/ha) or mancozeb (Dithane M45 1.5-3 kg/ha) are recommended for *Corynespora* control in Indonesia.

Biotechnology and genomics

The attainment of yield plateau and prevalent intra-clone variations in the yield of *Hevea* prompted researchers to tackle these problems through employing the modern tools of biotechnology. However, higher yield alone would not encourage cultivation of *Hevea*, since the species is sensitive to biotic and environmental attributes and physiological disorders. The long breeding cycle and the large size of the crop also make breeding time consuming. Biotechnology applied to *Hevea* can be discussed under two headings: (i) *invitro* culture; and (ii) molecular breeding. While *in vitro* culture deals mainly with regeneration and propagation, molecular breeding includes identification, characterization, introduction and expression of novel genes. The emergence of genomics has overshadowed the relevance of *in vitro* culture. The conspicuous reason for this is that *in vitro* culture was attempted by several laboratories worldwide, but progress had been very minimal as the techniques envisaged could not be commercialized successfully. On the other hand, genomics worked meticulously that could make inroads into the intricacies of *Hevea* culture and development faster than any other branch of science.

Experimentation with *in vitro* culture of rubber commenced during the 1960s with Chua in 1966 attempting to derive callus cultures from the plumule tissues of seedlings. The effects of osmotic concentration, carbohydrates and pH of the culture media were also studied. Later, the RRIM took the initiative of undertaking large scale tissue culture work through maintaining callus cultures from various explants. It expanded to somatic embryogenesis and micro-propagation through stem explants. While anther culture was employed to achieve purelines first and exploitation of heterosis thereafter, micro-propagation and somatic embryogeny were used to generate homogeneous populations. Although research on *in vitro* culture commenced nearly 45 years ago, even after rigorous experimentation, these areas are still in their infancy due to short comings towards commercial applicability. Expectations of better performance of these multiplication techniques are based on three considerations: (i) cloning the root system would generate new and more homogeneous root stocks or monogenetic clones; (ii) selection of clonal roots would improve the exploitation of existing genetic variability; and (iii) use of rejuvenated clonal plant material would potentially provide important agricultural attributes towards higher growth, latex yield and resistance to wind and dryness.

The Rubber Research Institute of Ceylon (RRIC) was the first to carry out culture of anthers to raise haploid plants. However, the first plants from *Hevea* pollen were made available by Chen during 1977 at the Baoting Institute of Tropical Crops, Hainan, China. Since then, at least four laboratories in China took the lead in researching production of haploid plants *in vitro*. Research on this line remained inconclusive. Attempts towards protoplast culture and fusion were carried out using young immature leaves, using discs of pith in the apical part of young green shoots or anther calli. Protoplast-derived calli developed somatic embryos. Subsequently, they germinated in to plants on the same medium. Fusion of protoplasts was aimed at hybridizing different *Hevea* species for breeding resistance to SALB. Not much headway was made in this line of work. *In vitro* germination of mature and immature zygotic embryos issued from hand pollination has been considered as a way of improving the success rate of genetic recombination in rubber. Good results (90% success in germination) were achieved only for immature embryos that were at least 3–3.5 months old after fertilization. It also appeared that immature seeds of this age could be germinated *in vivo* under controlled conditions. However, this procedure, which is expensive, did not appear to guarantee increased efficiency, nor was it a means for rescuing rare progenies.

Somatic embryogenesis in rubber is becoming standardized in different laboratories worldwide as an efficient system for plant regeneration from cells. At the same time efforts have been made to transform *Hevea* cells in order to increase genetic variation in a targeted way and complement plant breeding efforts with the possibility of modifying already selected high performing clones with specific genes (addition or inactivation), while avoiding meiotic recombination. However, in the short term, genetic transformation is becoming a powerful tool for investigating how the rubber genome functions with the assistance of targeted mutations.

Conventional rubber breeding takes more than 25 years to develop a new clone, but genetic transformation is the quick alternate method to introduce desirable genes. The first transformation report in *Hevea brasiliensis* was published in 1991, through *Agrobacterium* mediated transformation. In 2003 Rubber Research Institute of India reported successful development and establishment of transgenic rubber plant with SOD gene for their further evaluation. Unfortunately, due to issues related to ethics, till date none of these transformed genotypes has been taken to the planter's field for commercial evaluation or utilization.

Genomic technologies were taken up by various research groups working with *Hevea*, in order to increase knowledge and also to identify new targets for breeding and/ or complementing genetic transformation, and to assist rubber breeders in various strategies. Derivation of draft genome is the 'trendy research' of late. As *Hevea* genome has now been published four times, yet not everyone comes up with the same findings.

Crops of Kerala – An overview
Gregor Mendel Foundation, Calicut University, Kerala, India (2018).

Biology and cultivation of teak

T.K. Hrideek, Suby and M. Amruth
Kerala Forest Research Institute, Peechi, Thrissur, Kerala-680653, India.

Tectona grandis, L.f. popularly known as teak, is a tropical hardwood tree belonging to the family Verbenaceae. It is native to South and South East Asia mainly to India, Myanmar, Laos, Indonesia and Thailand. Teak wood is one among the highly valued tropical timbers in the world. It is extensively raised as monocrop plantations within and outside its natural range in tropical areas of Central and South America, East and West Africa and Carribean. The word teak derives from Tamil *tekku*, Malayalam *thekku* and Portuguese *teca*. In India, teak grows well in natural forests of central and south India i.e., from North Madhya Pradesh up to South Kerala. Teak timber fetches a very high price in the market because of its characteristic grain, colour, strength and durability; hence the practice of establishing teak plantations is in vogue wherever the soil and climate support its growth. In India, regular teak plantations were successfully established from 1842 under the initiative of the British East India Company, and this is considered as the first successful attempt to grow teak plantations across the globe. The period previous to British dominance has seen a restriction on the extraction of teak timber. Most obvious control was taxation and prohibition of its use for construction other than by the elites of society. So teak came to be known as a royal timber and a vehicle of exertion of political power in the society. The provocation for teak planting in the 19th century in India by the British East India Company stands as a testimony to the unique qualities of the teak timber which still makes it popular.

Context of organised teak planting

During the 17th and 18th centuries, there were increased and organized efforts made (by the formation of joint-stock trading companies) by European political powers for acquiring a monopoly in the maritime trade in spices with the Asian and South East Asian hinterlands. This gradually culminated in the political domination over these lands and maritime domination of trade. One of the crucial determinants of maintaining maritime dominance in trade and war was owning strong and durable seafaring vessels. Traditionally it was the Oak timber which was available in abundance in Europe that made it possible to construct dependable naval fleet for the British. Search for a substitute for oak timber ensued by the end of 18th century, as the oak forests of Europe run out of timber. Teak emerged as a suitable substitute and soon there were missions set up to see how the huge demand for teak timber for building large ships can be satisfied. Some of the provinces had conservators posted to oversee extraction and supply of the teak timber to the Bombay Docks where ships for the East India Company were built. Though forests of Malabar and Burma came to a sharper focus in terms of timber extraction, soon there was a realization that initial calculations of the inexhaustible quantity of extractable teak timber in these forests are wrongly founded. As a result, there were several attempts made to cultivate teak as a monocrop plantation, especially in localities where teak was found growing well in natural forests. One such locality was Nilambur in Kerala which belonged to the Malabar district of Madras Presidency which was under direct rule of the Company. So efforts were on to establish a teak plantation in Nilambur in Kerala from early decades of 19th Century. The then Malabar collector Canoly who directly oversaw the experiments was assisted by Mr. Chathu Menon. As there existed no previous documentation and standardization of methods on every aspect of plantation development including induced seed germination, mass production of seedlings, spacing and planting, tending and thinning, everything had to be developed from scratch through trial and error. At the end of numerous unsuccessful attempts, the first successful Teak plantation in the history emerged by the mid 19th century in Nilambur. These plantations belonged to the batch planted in 1840s by Mr. Chathu Menon and Mr. Conolly who were instrumental in standardizing the methods of teak planting and were considered originators of the plantations of teak and founders of tropical forest plantation forestry. Between two decades from 1842 to 1862, Mr. Chathu Menon raised more than a million teak trees in the Nilambur Valley.

Though developments in iron ore processing and metallurgy contributed to the design and building of superior quality ships than those built with teak, the heavy demand for teak continued due to the large scale expansion of the railway network where sleepers made of teak were preferred due to its durability and physical properties. As the British crown which assumed political domination (following the mutiny of 1857) had perceived railway expansion as a matter of internal security as it enabled troop movements, teak continued to be a matter close to maintaining political dominance.

These developments had manifold consequences: first of all, teak was very much at the center of the newly emerging science of tropical forestry in all its diverse dimensions and aspects. Secondly, teak had a place in the newly emerging institutions of forestry in the 19th century such as the Forest Department and much later the Forest Research Institute. Research and development activities on teak productivity contributed to an astonishingly voluminous literature in silviculture, entomology, forest pathology and wood science and technology which still continues to grow. Thirdly, all these colonial anxieties around this beautifully grained native wood had made it a globally valued and sought after commodity.

Major variants of teak

There are many variants in teak differentiated in terms of their characteristic wood quality including texture, colour and grain. The factors triggering this variation could also vary widely including the phenotypic expression in response to provincial environmental factors like climate and soil. Some of these variants such as Nilambur teak (Malabar teak), Konni teak, Middle American teak, Western African teak, Godavari Teak, Burmese teak, etc. are the well known names in the world's timber Industry. There are a total of 23 types of teak woods in India and the major ones are the following.

1. Nilambur teak: It is also known as Malabar teak. This variant grows faster than others, yields larger log dimensions and contains straight grain with golden yellowish brown color, often with darker streaks.
2. Adilabad teak: It grows in Rajulmaddugu locality of Andhra Pradesh. It is known for its rose coloured heartwood, attractive texture and fetches high price.
3. CPT (Central Provincial teak): This is a close-grained and slow grown teak grown in the drier zones of central India. It has a deep colour, twisted or wavy grains give the attractive appearance and fetches a higher price.

4. Dandeli teak: It is a slowly grown teak grown in Dandeli area (Karnataka, India) and the wood is with close grain and dark colour.
5. Godavari teak: This variant is native to Godavari region in Andhra Pradesh. The wood is especially with great ornamental value owing to its grain.
6. Konni teak: It is also a slowly grown teak with close grain and darker colour grown in the Konni area of Kerala state of India.

Other than these well-known Indian teak wood variants used for making furniture, there are several other species of teak wood which are imported to India. The most popular among the imported teak wood is the Burma teak (also called Myanmar teak), which has a rich golden brown colour and straight grain pattern. Myanmar accounts for almost 1/3rd of the total teak production in the world. African and South American teaks such as Ghana teak and Columbiana teak are also used in making furniture. Teak wood originating from other South Asian countries such as Indonesia (Java teak), Thailand, and Malaysia also find their ways in the market.

Teak provenances in Kerala

There are several teak provenances identified across the globe wherever teak has a natural population. A provenance is ‘the geographical source or place of origin from which a given lot of seed or plants are collected’; the provenance is also ‘material from such a source or origin; often restricted to imply material from a specified race.’ Nilambur, Konni, Vazhani, Parambikulam, Thamaravellachal and Arienkavu are the well-known provenances in Kerala. Among these, the Nilambur and Konni teak are well known for their colour and quality.

Nilambur teak: The Nilambur teak is sought after stock right from the colonial period itself due to its structural characteristics and unique design of the trunk. The presence of deeply weathered parent material, riverine alluvium on the flood-plain of Chaliyar River, well-drained soil and pronounced and alternating wet and dry seasons are the characteristic features of the Nilambur valley that determine the characteristic phenotypic expression. This locational advantage of Nilambur was a factor for choosing it as a site of raising plantation in the early 19th century. The peculiarities of Nilambur teak have resulted in obtaining it a unique GI (Geographical indication) status. Normally bark of the teak tree has a dark brown colour, and that of the Nilambur teak is of golden colour. As mentioned above, the precisely alternating wet and dry seasons help the formation of a clear annual ring. This results in attractive grains and characteristic design of the teak wood. The soil characteristics of the Nilambur valley is thought to have a decisive role rendering a golden hue to the wood. Nilambur teak with its heartwood rich with teak oil protects it from fungal and pest infestations. The chemical named Caoutchouc is the reason for this oil secretion. This was the reason why teak wood was chosen for making large seafaring vessels in the past. Nilambur teak has less sapwood and it has high durability. Presence of Tectoquinone and Naphthoquinone provides immunity from termite damages and infestation from insects and fungus even in the wet weather. As the growth is faster Nilambur teak is considered more productive than other teak provenances. A single instance that the Nilambur teak continues to be the choicest wood that goes into the making of the British luxury car Rolls-Royce despite the fact that Teak is grown in more than 70 countries stands testimony to the unquestioned supremacy of Nilambur teak. However, there is a concerted effort to be made to protect the genetic base of the natural teak of Nilambur as it is fast eroding.

Konni teak: Konni teak is a well known provenance in the international wood market. This once enjoyed the same degree of popularity as did the Nilambur teak in the timber market. By the mid 19th century Ayilyam Thirunal, the king of Travancore Princely

State made attempts to raise teak plantation in the Konni region of the state, for the teak from the region was already recognized for its unique qualities. Travancore went ahead with expanding the teak plantations that it had successfully established with a regular annual target fixed on the land areas to be brought under the teak planted each year. From 1920s the expansion of teak plantations received a boost in the Travancore state as Taungya was introduced as a technology for raising large scale plantations of teak. The authorities of Travancore had perceived teak planting as a progressive enterprise and long term investment for the state and had made efforts to adopt new technologies and know-how in expanding their plantation base. By the last decades of the 19th century, Travancore had many experienced officials from Nilambur appointed as assistant conservators who oversaw planting in Konni. Top officials such as Diwan Ramayankar and British residents used to visit Konni to evaluate state efforts in improving teak plantations. Konni teak fetched the highest price in the international market due to its dark brown hue and sharp grain from annular rings compared to the Burma and Nilambur teaks. Apart from this, the presence of a larger percentage of Tectoquinone and Naphthoquinone makes Konni teak more resistant to scratch rims and fungus and ensure its longevity. The characteristics of local weather and soil along with the genotypic content of the provenance probably determine these features of Konni teak. The growth rate of Konni teak is low when compared to teak grown in other places. After Nilambur the natural forests of Konni has a denser stock of teak. Since selection and clear felling was intensely practiced in this forest tract as elsewhere in the state up to a few decades back, the depletion of natural teak forests has severely affected the genetic diversity of teak. So conservation of the genetic diversity and stock of the Konni teak available in the early plantations and natural forests in the region is a major concern.

Properties of teak wood

The properties of teak wood which make it attractive in timber market are mainly the durability, strength and comparatively low weight. Teak wood has a low proportion of softwood. Hardwood is golden in colour and then it darkens as it gets older, which can be reverted to the original when polished. Annual rings of the tree are very prominent which increases the aesthetic value of the timber. In some cases more than one annual ring is produced in a year and are known as pseudo rings. These pseudo rings provide better appearance and help to fetch a higher price for the timber. The newly cut wood produces a distinct aroma that is comparable to the smell of leather. The chemical composition of extracts from teak is complex and almost all the anthraquinones (e.g. 2-methyl anthraquinone) found in the wood are effective against termites. Tectoquinone is another characteristic metabolite similar to anthraquinone. The compounds such as Naphthoquinone (1,4-naphthoquinone) present in teak wood helps to resist fungal attack. The oil in the teak wood makes it termite proof and resistant to borers. This oil when applied to other timber logs increases their durability. The reason behind the oil production is a chemical caoutchouc as mentioned before. The soil and climate influence the strength of the teak wood. It is well established that teak grown on the west coast is much better than the one grown in central India. The wood gains strength as it attains an age of 50 and compared to wood from middle portion of the tree bottom and top portion has higher strength.

Breeding strategies for teak

Though research on various aspects of silviculture teak began way back in 19th century when the first plantations were attempted, organized programmes for conservation and improvement of the genetic stock of teak in India began only by 1962 by the Forest Research Institute, Dehradun.

Subsequently, in Kerala also similar efforts were made from 1979 under the supervision of Kerala Forest Research Institute, Peechi. Genetic improvement of teak focused mainly on identifying phenotypically superior trees from its various natural growing regions and deploying them as vegetatively propagated clones in seed orchards.

The aim of tree breeding for timber is to improve the growth rate and tree form so that higher volumes, the larger length of clear bole and straight grained timber are available in short rotation. It is also aimed to minimize the quantity of low grade timber due to branch knots, flutes, buttress, spiral grain and blisters. Resistance to defoliator and skeletoniser insect attack is also a desired feature. Concurrent improvement in the aforementioned features cumulatively contributes to the increased productivity of forest land and improved quality of timber for market.

Kerala is one of the prime teak growing states of India. Attempts to genetically improve the planting stock were made as early as 1961 when Kedharnath and Mathews did the first selection of plus trees of teak. Fifty trees, outstanding in growth and stem form designated as plus trees were selected in different teak growing areas of Kerala using check tree method. Later in 2004, another 61 new plus trees were selected from Thenmala, Konni, Malayattur, Thrissur, Parambikulam, Nilambur, Wayanad, Vazhachal and Kannur Divisions. The status of these plus trees was evaluated recently and it was found that most of the trees had lost markings; some of them were felled or fallen and not feasible to identify them in the natural forest tract. At present, as per records 94 plus trees are available in Kerala which includes 31 plus trees selected during 1980-82.

Characters of plus trees

The characters used to identify the plus trees are not aimed to capture the expression of their phenotypic and genotypic features which can be used for the scientific improvement of the stock based on genetic principles. In the procedure, the first step is Plus Tree Selection. A plus tree is a phenotypically outstanding individual with a number of desirable traits. While selecting plus trees of teak, each superior tree is compared with at least 5 trees within a radius of 50 meters from the plus tree. During the process of selecting plus trees, the main objective is to select trees for higher productivity without giving any consideration for wood quality. The main criteria for selecting plus trees are i) superiority in terms of height and length of clear bole ii) superiority in terms of girth at breast height (gbh) iii) straightness, iv) absence of bumps, flutes, epicormic shoots, buttresses, twisting, etc v) narrow compact crown with light branches vi) absence of diseases and other defects.

Assessment of plus trees for selecting elite tree

During the process of selecting an elite tree from plus trees, wood quality is also considered additionally as a key parameter since it is the preferred feature in the timber market. Hence it is necessary to study the different wood properties such as density, grain, colour, etc. To achieve the selection of elite trees, progeny test or clonal evaluation may be used. These tests also provide information on genetic variance, heritability of characters and genetic combining ability. Recently Kerala Forest Research Institute together with Institute of Forest Genetics and Tree Breeding has initiated a programme to identify elite trees from plus trees.

Seed production

The use of improved seed or plant materials is essential to increase the growth and quality of plantations. Large quantities of quality seeds are required for the planting of teak; to meet up the immediate demand, seed stands and seed production areas are identified and maintained. To obtain such improvements, seed production areas and/or seed orchards are required.

Seed production areas: A Seed Production Area (SPA) is a converted plantation or a natural stand of teak for seed production. In this process plantations with trees showing superior vigor and growth compared to the adjoining areas are selected and converted to seed production areas after the removal of inferior trees. The SPAs seem to be the most practical short term option for improved seed production programmes. An abundance of improved seeds can be achieved within one year of establishment of an SPA. Through the SPA option, the gain in volume of growing stock in plantations is 5-15% over the routine seed sources. At present, Kerala has around 1500 ha of plantations designated as teak SPAs.

Clonal seed orchards: Clonal Seed Orchard (CSO) is another option of seed source establishment. It is a plantation of mixed population derived from plus trees, designed, established and managed for seed production purposes. Clones of plus trees are used as a source of planting material for the orchard. Usually, bud material is used and clone banks are established by grafting the buds to stocks raised from locally available seeds. The establishment of clone banks facilitates the subsequent collection of seed and bud material from the plus trees and ensures that the genetic material is available from them even if the plus trees themselves are lost. Very recently KFRI has developed a technology to produce clones using epicormic buds of teak without grafting. This method helps to avoid the problems due to graft incompatibility. Generally, the CSO starts producing seeds at 10-15 years and its initial gain is about 25% over the base population.

Seedling seed orchard (SSO): Seed orchard is fundamentally a collection of phenotypically superior and diverse individuals of a species, which is silviculturally managed to produce phenotypically and genotypically superior seed crop through the process of open pollination. Establishment of seed orchards using superior clones from diverse regions has been an important strategy of genetic improvement programmes of teak. It is assumed that the offspring developed through random mating among the superior types would also be genetically superior. The main purpose of establishing seed orchard is to mass produce such genetically superior seeds, which are easily accessible and collectable.

Silvicultural practices in teak

Site selection

The planting site has a strong effect on the growth, development and wood quality of teak plantations. The productivity of a plantation can be greatly improved through the selection of a correct site for the plantation programme. It is noted that the teak distribution pattern in its natural range is discontinuous or patchy. Size, quality, density, and the form of teak trees vary from one location to another. There are several factors which control the distribution and growth pattern of the species. The major factors include the amount and distribution of rainfall, moisture, soil and light.

Teak grows naturally in a wide range of climatic conditions, from the very dry (500 mm/year) to the very moist (up to 5,000 mm/year). Under very dry conditions, the tree is usually stunted and shrubby. Under very moist conditions, the tree is large and fluted and usually behaves like a semi-evergreen species; the wood quality is poor in terms of colour, texture and density. For the production of high quality wood with optimum growth, rain fall should be between 1200 mm and 2500 mm with a marked dry season of 3-5 months.

Soil: Teak grows best on deep, well drained alluvial soils derived from limestone, schist, gneiss, shale and some volcanic rocks such as basalt. Conversely, the species performs very poorly on dry sandy soil, shallow soil, acidic soil (pH < 6.0) derived from laterite or peat bog and on compacted or waterlogged soil. Teak soil is relatively fertile with high calcium, phosphorus, potassium, nitrogen and organic matter contents. Studies have indicated that teak requires relatively large amount of calcium for its growth and development and teak has been named as a calcareous species. The amount of calcium content in the soil is also used as an indicator of teak site quality. The optimum pH range for better growth and quality is between 6.5 and 7.5.

Light: One of the important factors which affect the growth of teak is the availability of light. Hence, it requires a high intensity of light for its growth and development. Teak needs 75-95% of light intensity in a day for its normal growth.

Other factors: Apart from rainfall and moisture, soil and light intensity, other factors such as temperature and elevation also play important roles in limiting the distribution and growth pattern of the species. It is known that teak grows well under warm and humid conditions. A series of studies in controlled environments have indicated that the optimum temperature for growth and development of the species is 27-36°C. This range of temperature is normal within teak's tropical range. Teak poorly tolerates cold and frost conditions during winter period. Under the frost conditions, seedlings and saplings are severely damaged and they die, which is one reason why the species cannot grow at elevations.

Seed quality

The success of planting programmes depends not only on site quality but also on the genetic quality of the planting materials. Although the growth and yield of the plantation can be largely improved through site selection, stem quality (i.e., straightness, persistence of stem axis, branching, flowering, etc.) is strongly controlled by genetic make up. The use of improved seeds (i.e., from seed production areas, seed orchards and plus trees) is essential in the improvement of growth, stem quality and other characters of the plantation. It has been estimated that by using such improved seed, the gain in growth and/or volume of production in the plantation is increased (from base populations) by 5-25%, depending on types of seed source and planting site. The best period to collect seeds is November to March and seeds are collected from Teak SPAs.

Propagation

Seed propagation

Teak seed processing mainly comprises of cleaning, grading and supply/storage of quality seeds. As the first step in seed cleaning the feathery calyx is removed by rubbing the seeds in a gunny bag. The separated fragments of calyx are removed by winnowing. The seeds are then size graded using a seed grader. Fruits below 9 mm size are discarded. In order to get optimum and uniform germination from teak seeds, pre-sowing treatment is essential. The most common and widely accepted method of 'alternate wetting and drying' is followed. In this the graded seeds are soaked in moist gunny bags during nights and spread out in the open for sun drying on the following day; the procedure is repeated for seven consecutive days. Termite aided mesocarp removal is another pretreatment method used for seed germination in teak. The teak seeds are spread on a tray and placed in a termite infested area. The termites enter the tray and feed on the mesocarp in about 2 weeks. These seeds are sown in the nursery beds.

Nursery practices: Raised beds (30 cm high, supported with split areca stems) of 10 m x 1 m are formed. Sand and soil mixed with FYM form the top layer. Sowing is done after the bed is watered. Usually, sowing is done by the broadcast method or dibbling in April-May. Seed rate is 3-5 kg of seeds per bed. After sowing, the seeds may be pressed into the beds. A thin layer of soil also can be sprinkled to cover the seeds. The beds are also mulched with green leaves to reduce evaporation losses. One-year-old seedlings of 1-2 cm (thumb thickness) at the thickest portion below the collar are uprooted from mother beds and used for making stumps. Stumps with 15-20 cm of root at 2-3 cm of stem prepared with a sharp knife are commonly used for planting. Teak seedlings can be produced in shorter duration by using polythene bags or root trainers. Three to four month old teak seedlings are pricked out from the germination beds into polythene bags (30 cm x 20 cm) in the month of March/April.

Poly bag seedlings: In this, before germinating the seeds, soil, sand and dry dung or compost mixed in 3:2:1 proportion is filled in polythene bags and seeds are sown. After 90 days seedlings are ready for planting.

2. Clonal propagation: This method was developed by Kerala Forest Research Institute. Usually, epicormic buds from plus trees are used to prepare clonal plantlets. To prepare vegetative rooted cuttings, branches with appropriate size are collected from the lower part of the crown of trees and brought to laboratory/mist chamber as soon as possible and these are allowed to produce epicormic shoots. After 20 days epicormic buds are collected at the 'three leaf stage' and leaves are removed carefully. Cuttings of about 20 cm in length and 1.5 to 2 cm diameter are made using a sharp knife. The basal end of the cutting is dipped in water immediately to prevent air bubbles entering the vascular system as it may later interfere with the absorption of growth regulating substances to be administered at the next stage. Indole 3-butyric acid (IBA) is used as a rooting hormone. The treated cuttings are planted in root trainers filled with vermiculite and are kept in a humidity chamber at 95% RH. After about 15-20 days, epicormic shoots produce roots. The rooted epicormic shoots are transferred to poly bags filled with potting mix and hardened in the mist chamber for 10-15 days.

3. Micropropagation: Apart from SPAs and CSOs, tissue culture is another option for mass supplying of genetically improved materials for planting programmes of this species. This technique of propagation has been developed successfully for commercial propagation of selected plus trees. In this technique, shootlets are produced under laboratory condition and are then transferred to glasshouse conditions for rooting. The rooted shootlets or plantlets are transplanted for stock production.

Spacing

The initial spacing of seedlings adopted in teak plantation varies (1.8 m × 1.8 m to 4 m × 4 m) depending on many factors like site quality, cost of establishment, thinning regime, small wood utilization and planting system (e.g. agroforestry, intercropping etc.). However, site quality seems to be the priority factor directing the size of spacing in the teak planting programme. Under the dry site conditions, where the initial growth rate of the plantation is poor (e.g. < 1.0 metre per year in height), close spacing of 2 m × 2 m is the most suitable. Conversely, the initial spacing can be wider up to 4 m × 4 m, for cost reduction, under good site conditions. 3 m × 3 m spacing also has been recommended. However, in areas where wider spacing is required for the application of agroforestry systems or machine weeding, the 4 m × 2 m spacing is used.

Planting time

Planting time has a significant role in determining the survival and growth of teak plantations, especially when stump planting is practiced. The most suitable planting time for teak is soon after the arrival of the monsoon showers or at the beginning of the rainy season. Phenological development studies showed the importance of planting time, especially on growth. Teak has only one growth flush period throughout the year. Shoot growth which starts soon after the first shower (late April) reaches its peak at the beginning of the rainy season (May-June), thereafter it declines sharply in the middle of the rainy season (July-October) and ceases during the dry season (November-April). It is also recommended that teak may be planted just prior to, or during the growth flush period, i.e., between May and early June, depending largely on the arrival of the first monsoon rain.

Weeding

Teak is a light demanding species and its growth and development are reduced sharply under poor light conditions. Teak is very susceptible to weed competing for nutrients and light. Hence, intensive weeding is necessary during early establishment of the plantation, i.e., 1-3 years. Six or seven weedings may be necessary during the first two years.

Thinning

Key determinants in the proper development of teak trees are well-timed thinning and pruning. Thinning refers to the removal of underperforming trees in the plantation which is cut and sold prematurely, thus allowing the best trees to continue developing fully with more space and soil nutrients. Meanwhile, pruning refers to the cutting of the side branches off the main trunk of the trees while they are growing. This is done to ensure straight and high quality logs. Initially, there will be 2500 seedlings in a hectare when seedlings are planted in 2 m x 2 m spacing. The seedlings are densely stocked in this manner to encourage seedlings to grow straight and develop a straight bole. As the canopy develops thinning is performed. There are two types of thinning — mechanical and silvicultural. Thinning is carried out normally at 4, 8, 12, 16, 20 and 24 years of age. The first two thinnings at 4th and 8th years are called mechanical thinning where trees in the alternate diagonals and in a straight row respectively are removed.

In first thinning half of the saplings are removed (i.e., 1250 assuming that 2500 seedlings are planted) and in the second thinning from the remaining, a half of the saplings (625) are removed. After the second mechanical thinning, distance between the saplings increases to an average of 4 m. The subsequent four thinnings are called silvicultural thinnings or normal thinnings where stunted and poorly grown trees are selectively removed. The yield obtained during thinning operations is termed as thinning yield. The trees that remain after the different thinnings are felled at the rotation age of the plantation in an operation called final felling. This is a clear felling. The rotation age is the age of the plantation when it is finally felled.

Major pests of teak

Insect damage is a serious problem in teak plantations. This is especially so where intensive farming is practiced, e.g. in well irrigated plantations. The most common insects that cause severe damage to plantations are defoliators and stem borers.

Defoliators

Defoliators are insect larvae and they cause severe defoliation and, hence, reduce growth rate, apical dominance and seed production capacity of the trees. The most important defoliators inflicting severe damage in teak plantations throughout the tropics are *Hyblaea puera* Cramer (Hyblaeidae) and *Eutectona machaeralis* Walker (Pyralidae). Outbreaks of these insects may occur 2 to 3 times during the growing season. After the outbreaks, especially of *Hyblaea puera*, the plantation growth rate may be reduced by as much as 75%. Control of outbreaks of these insects requires the application of chemicals and biological agents like *Bacillus thuringiensis*. *Hyblaea puera nucleopolyhedro virus* (HpNPV) is a biocontrol agent developed by Kerala Forest Research Institute against *Hyblaea puera*.

Stem borers

Stem borers cause severe damage in young plantations (1-5 years old). Damaged trees may die back or top break causing reduction in growth rate and stem quality. The most damaging stem borer in young teak plantations is the red or coffee borer *Zeuzera coffeae* Nietner (Cossidae). In old plantations, i.e., over 10 years, it is the beehole borer *Xyleutes ceramicus* which proves to be most damaging. It causes severe damage to the standing trees and also reduces the value of timber. At present, there are no practical chemical or biological methods for controlling outbreaks of the beehole borer. Silvicultural treatments such as weeding, control burning, thinning and intercropping are the only methods which can reduce the insect populations.

Major diseases of teak

Teak suffers from a large number of diseases and disorders. Diseases affecting teak are broadly grouped into diseases of wider occurrence, serious diseases of restricted occurrence and potentially serious diseases. Foliage diseases like leaf spot and leaf blight caused by *Phomopsis tectonae*, *P. variosporum*, *Phoma glomeratum*, *P. eupyrena* and *Colletotrichum* state of *Glomerella cingulata* are widely distributed in teak stands. Teak foliage rust caused by *Olivea tectonae* occurs throughout the range of distribution of teak in India and causes severe premature defoliation of the affected plants. The phanerogamic parasite *Dendrophthoe falcata* var. *pubescens* causes severe damage to the teak stands, especially in older ones. Serious diseases of restricted occurrence include root, butt and heart rot diseases and die back caused by *Phialophora richardsiae* associated with an insect borer, *Alcterogystia cadambae*. Potentially serious diseases affecting teak stands include pink disease caused by *Corticium salmonicolor*, bacterial wilt caused by *Pseudomonas tectonae* and stem canker and die back caused by *Phomopsis tectonae*. Among these, the pink disease has emerged as a serious threat to young teak stands, especially those raised in high rainfall areas.

Conclusion

Teak plantations have been widely established throughout the tropics with the main objective to producing high quality timber. Three main factors affect growth and quality of the plantation: site quality, seed supply and silvicultural management. Site quality has a direct effect on the growth and development of the plantation. The rotation age can be greatly reduced through site selection. Teak grows well on moist sites. To produce high quality timber trees, the site should have pronounced dry period of 3-5 month duration. The typical teak soil is deep, well drained, and alluvial with high calcium, organic matter and other elemental content. The soil pH is 6.5-7.5. Teak is a light demanding species. As a result, intensive weeding in 1-5 year old plantations is very important.

A large quantity of improved seeds can be obtained through establishment and management of Seed Production Areas and Seed Orchards. Clonal propagation *in vivo* and by tissue culture is a viable option for mass production of quality planting stock. Appropriate and timely silvicultural management must be carried out to improve both the growth rate and quality.

Due to various reasons which include Government policies of conversion of teak plantations to natural forest for wildlife conservation needs, soil depletion due to continuous rotation of monoculture teak plantation, etc., there is a perceptible decrease in the area and quality of teak plantations in Kerala. The current low production of timber and low productivity of plantations do not match with the high demand for teak wood. An alternate strategy could be to promote cultivation of teak in the homesteads and farm holdings along with other crops. Retaining teak in the homestead is an age old practice in Kerala homesteads, but it leaves a lot desired in terms of developing suitable packages and protocols for teak based agroforestry practices, with better input of improved planting materials, information, institutionalization and market integration. Yet another alternative is to promote plantations of teak in private lands as monocrop or mixed stands if not planting at small scale. Teak is also a suitable tree when it comes to seeking additional revenue to the grower in terms of carbon financing. Developing teak cultivars suitable for these planting situations in homestead and small scale plantations is a challenge to breeders.

Conservation and propagation of *dasamula* group of medicinal plants

A.V. Raghu
Kerala Forest Research Institute, Peechi, Thrissur, Kerala-680653, India.

India has an impressive wealth of medicinal plants, almost all of them native to the country. More than 7000 species are reportedly used for medicinal purposes, most of them being exploited recklessly for the extraction of drugs. It will be prudent to study the science and status of indigenous medicinal plants for evolving efficient strategies for conservation and management. Medicinal plants are viewed as a possible bridge between sustainable development, affordable health care and conservation of the vital biodiversity. Importance of medicinal plants is still growing although it varies depending on the ethnological, medical and historical background of each country. Medicinal plants are also important for pharmacological research and drug development, not only when plant constituents are used directly as therapeutic agents, but also when they are used as basic materials for the synthesis of drugs or as models for pharmacologically active compounds. In recent times, however, due to the increasing realization of the health hazards and toxicity associated with the indiscriminate use of synthetic drugs and antibiotics, there has been a renewal of interest in the use of plants and plant based drugs throughout the world. According to WHO, the resurgence of public interest in traditional medicine is on the increase because of a sweeping green wave and a large number of plant drugs are now sold in the 'health food shops' all over the world including the developed world.

Ayurveda has long been the main system of health care in India, although western medicine has become more widespread especially in urban areas. About 70 percent of India's population live in rural areas; about two thirds of rural people still use ayurveda and medicinal plants to meet their primary health care needs. Ayurveda and variations of it have also been practiced for centuries in Pakistan, Nepal, Bangladesh, Sri Lanka, Tibet, etc. Currently, about 5,000 products are included in the "pharmacy" of ayurvedic treatments. Historically, plant compounds have been grouped into different categories according to their effects. For example, some compounds are thought to heal, some to relieve pain and some to promote vitality. Ayurvedic plants have been classified in to several groups like *dasamula*, *dasapuspa*, *tribhala*, *trikatu*, etc. which are used in combination for different purposes.

Dasamula group of medicinal plants

Dasamula (ten roots) is one of the best known drug group of classic ayurveda. The drugs include *vilva*, *kasmari*, *syonakah*, *patala*, *agnimanthah*, *prsniparni*, *saliparni*, *brhatidvayam* (two plants) and *goksurah*. It is a special combination of ten plants with the ability to act on a wide range of health problems, those caused by both *vata* and *kapha*. The ten plants include five herbaceous plants known as *laghu panchamula* and five trees known as *bruhat panchamula*. *Desmodium gangeticum* (Linn.) DC. (Family: Papilionaceae), *Pseudarthria viscida* (Linn.) W. & A. (Family: Papilionaceae), *Solanum melongenea* var. *insanum* (Linn.) Prain. (Family: Solanaceae), *Solanum violaceum* Ortega (Family: Solanaceae) and *Tribulus terrestris* Linn. (Family: Zygophyllaceae) *are* used as the source of *laghu panchamula* and *Aegle marmelos* (Linn.) Corr. (Family: Rutaceae), *Gmelina arborea* Roxb. (Family: Verbenaceae), *Oroxylum indicum* (L.) Vent. (Family: Bignoniaceae), *Stereospermum colais* (Dillwyn) Mabb. (Family: Bignoniaceae) and *Premna corymbosa* Rottl. (Family: Verbenaceae) as the source of *bruhat panchamula* in South India. Many of these plants are red listed.

As per the text *Sarngadhara Samhita*, *dasamula* nourishes the lean, stimulates vitality and gives progeny to the childless. It is an excellent tonic for convalescence and general debility. It is used in the form of *asava*, *arishta*, *avaleha*, *churna*, *ghruta*, *kwath* and *taila*. It is also used as the basic ingredient in many other preparations. *Dasamula* is a popular health tonic, beneficial to gastric, respiratory, cardiovascular, nervous and urino genital systems of the body. It is digestive, carminative, stomachic, antispasmodic, analgesic, expectorant, cardiac, antirheumatic, antihelmintic, restorative and is a rapid cell rejuvenating tonic. The plants coming under this group are described below briefly.

Laghu panchamula

1. *Desmodium gangeticum*

Desmodium gangeticum is used as the drug source of *prsniparni* in Kerala. However, some materia medicas consider *Uraria lagopodioides* and *Uraria picta* as the drug source of *prsniparni*. *Desmodium gangeticum* (Linn.) DC. (Family- Papilionaceae) is a sub erect, diffusely branched undershrub, 90 cm-120 cm in height with a short woody stem and numerous prostrate branches with soft grey hairs; leaves unifoliolate, alternate, stipulate, leaflet ovate-acute, 14 cm x 10 cm; flowers small, pink in terminal elongate racemes; calyx campanulate, hairy outside, with triangular teeth; corolla papilionaceous, exserted; stamens diadelphous; ovary sessile, many ovuled, style filiform, incurved, stigma capitate; fruit compressed, moniliform, 6-8 seeded. The drug is a good cardiotonic, useful in the treatment of cardiac disorders. It is hot, sweet, diuretic, laxative and nervine tonic. It overcomes corruption of *tridosa*, burning sensation, fewer, cough, difficult breathing, dysentery, thirst and vomiting and is useful in *vatarakta*, insanity and ulcers.

2. *Pseudarthria viscida*

Kerala physicians have by and large accepted *Pseudarthria viscida* as the drug source of *saliparni*. However, some publications equate it with the two species of *Uraria*, namely *Uraria lagopodioides* and *Uraria picta*. *Pseudarthria viscida* (Linn.) W. & A. (Family- Papilionaceae), the drug source of *saliparni*, is a perennial viscid pubescent semi-erect diffuse undershrub, 60-120 cm long with slender branches, more or less clothed with whitish hairs; leaves 3 foliae, terminal leaflet rhomboid-ovate, acute, 8 cm x 8 cm, laterals obliquely ovate-acute or rhombiform, subcoriaceous; flowers small, pinkish white in long terminal branched racemes; calyx 2 lipped, campanulate, hairy outside, 4-teethed; corolla exerted, stamens diadelphous; ovary subsessile with many ovules. Style incurved, stigma capitate; fruit densely viscid-hairy, flat, linear-oblong, one celled legume; seeds 4-6, compressed, brownish black. *Saliparni* is bitter, hot, tonic, aphrodisiac and promoter of body tissues. It is strength giving and it overcomes intermittent fever, *vata*, urinary diseases, tumours, oedema, burning sensation, difficult breathing and toxic conditions.

3. *Solanum melongena* var. *insanum*

Solanum melongena var. *insanum* and *Solanum violaceum* are considered as the source plants of the drugs coming under *brhatidvayam* in Kerala. However, other species of *Solanum* like *Solanum virginianum* are also considered as drug source of *brhati* somewhere. *Solanum melongena* var. *insanum* is a much branched, very prickly, grey-pubescent undershrub; leaves simple, alternate, ovate or elliptic-ovate, acute, 7-12 cm x 6-8 cm, oblique at base, irregularly lobed, stellate-pubescent, prickly along the nerves; flowers purple, 1-4, extra-axillary; calyx lobes 5, lanceolate, thick stellate-pubescent; corolla rotate, deeply five cleft, lobes 5, triangular; stamens 5, free, epipetalous; ovary villous; berry oblong-globose, 3 cm across, fruiting calyx enlarging. Root, fruits and leaves are the useful parts. *Brhati* is reported to be constipating, digestive, acrid and bitter. It helps vitiated tridosas and cures dyspepsia, fever, respiratory and cardiac disorders, skin ailments, vomiting, ulcers and poisonous affections.

4. *Solanum violaceum*

Solanum violaceum is the second member of *brhatidvayam*. *Solanum violaceum* Ortega (Family- Solanaceae) is an armed shrub; leaves simple, alternate or sub-opposite in unequal pairs, grayish green, ovate or oblong, sinuately lobed, 9-3 cm x 6-9 cm, base oblique or unequal sided, stellately wooly or downy beneath, prickly along the mid nerve; flowers pale purple, regular in 8-10 flowered, extra-axillary racemes; calyx cupular, lobes 5, triangular, thick, prickly; corolla rotate, deeply 5 cleft; stamens 5, free, filaments very short, anthers oblong-lanceolate; ovary glabrous, style stellately pubescent; berry globose, smooth, light green, variegated with dark green when young and orange-yellow when ripe. Root, fruits and leaves are the useful parts. *Brhati* is reported to be constipating, digestive, acrid and bitter. It helps vitiated tridosas and cures dyspepsia, fever, respiratory and cardiac disorders, skin ailments, vomiting, ulcers and poisonous affections.

5. *Tribulus terrestris*

Tribulus terrestris is the source plant of the drug *goksurah*. However, *Pedalium murex* is also used as the source plant of this drug somewhere. *Tribulus terrestris* Linn.(Family- Zygophyllaceae) is an annual or perennial prostrate herb with many slender, spreading branches up to 90 cm in length, commonly found throughout India, up to an altitude of 5,400 m. Leaves are simple, pinnate, opposite, leaflets 4-7 pairs, almost sessile or with very short petioles, oblong, entire, to 1.7 cm x 0.5 cm, villous; flowers bright yellow, solitary, extraaxillary; sepals 5, free, linear-acute; petals 4, free, golden yellow, obovate, rounded at apex; stamens 10, inserted at the base of an annular lobed disc, filaments free; ovary sessile, hairy, 5-celled, style short, stigma 5 lobed; fruit 5 angled, spinous, tuberulate, schizocarp, separating into 5 cocci, each with a pair of spines on them; seeds several in each coccus with transverse partitions between them. Flowers and fruits are seen almost throughout the year. Flowering starts within 20-35 days and the fruit matures in 14 days after the formation of seed.

Bruhatpanchamula

1. *Aegle marmelos*

Aegle marmelos is the source plant of *vilva*. It is an armed tree with axillary straight spines single or paired and three foliolate alternate leaves. The North Indian and South India varieties show some morphological differences. The North Indian variety is taller with larger leaves and fruits and it has been reported that the large fruited forms are tetraploid. *Aegle marmelos* (Linn.) Corr. (Family-Rutaceae) is a spiny tree sparsely distributed throughout India on the plains and in the hilly tracts up to 1300 m elevation. The plant is a medium sized armed deciduous tree with straight, sharp, axillary thorns and yellowish brown shallowly furrowed corky bark. Leaves are alternate, 3-foliate, leaflets elliptic, lanceolate or oblong-obovate obtuse, terminal one 4.5 cm x 2.5 cm, lateral ones smaller, glabrous, margin sub crenulate; flowers white, sweet-scented in axillary panicles; calyx tube copular, lobes 4 or 5; petals 5, white, oblong, thick, gland-dotted, spreading; stamens many, inserted around the disc; ovary ovoid, 10-celled with many ovules; berry ovoid, 8 cm x 6 cm, woody; seeds many. It is useful in diarrhoea, dysentery, dyspepsia, stomachalgia, cardiopalmus, vitiated conditions of *vata*, seminal weakness, uropathy, vomiting, intermittent fever, swellings and gastric irritability. The leaves are astringent, laxative, febrifuge and expectorant, and are useful in ophthalmia, deafness, inflammations, catarrh, diabetes and asthamatic complaints. The tender fruit is bitter, astringent, antilaxative, digestive and it promotes digestion and strength, overcomes *vata*, colic and diarrhoea. The ripe fruits are astringent, sweet, aromatic, cooling, febrifuge, laxative and tonic and are good for the heart and brain in dyspepsia.

2. *Gmelina arborea*

Gmelina arborea is the source plant of the drug *kasmari*. The plant is a moderate sized unarmed deciduous tree with simple opposite leaves. *Gmelina arborea* Roxb. (Family- Verbenaceae) is an unarmed moderate sized deciduous tree 15-20 m in height with whitish grey corky lenticellate bark. Leaves are simple, opposite, long-petioled, broadly ovate-acuminate, glabrous, green above, soft, fulvous tomentose beneath; flowers showy, yellow tingled with brown outer side, in dense terminal pendunculate panicles; calyx campanulate, pubescent outside; corolla tube short; fruits fleshy ovoid drupes, orange yellow when ripe, seeds hard and oblong. The whole plant is used as medicine. It is astringent, bitter, digestive, cardiotonic, diuretic, laxative and pulmonary and nervine tonic. It promotes digestive power, improves memory, overcomes giddiness and is useful in burning sensation, fever, thirst, emaciation, heart diseases, nervous disorders and piles. The roots are acrid, bitter, sweet, stomachic, tonic, laxative, galactagogue and antihelminthic. The flowers are sweet, refrigerant, bitter, astringent and acrid, and are used in treating leprosy and skin diseases. The fruits are acrid, sour, sweet, refrigerant, bitter, astringent, aphrodisiac, trichogenous, alterant and tonic. They are used for promoting the growth of hair and for anaemia, leprosy, ulcers, constipation, strangury, leucorrhoea and colitis.

3. *Oroxylum indicum*

Oroxylum indicum is the source plant of *syonakah*. The plant is a tree with large opposite bipinnate leaves. *Oroxylum indicum* (L.) Vent. (Family-Bignoniaceae) is a medium sized deciduous tree with soft light brown bark with corky lenticels. Leaves are very large, 90-180 cm long, 2-3 pinnate with 5 or more pairs of primary pinnae, rachis very short, cylindrical, swollen at the junction of the branches, leaflets 2-3 pairs, ovate or elliptic acuminate, glabrous; flowers large, pale purple, in long terminal racemes; calyx large, leathery, oblong, campanulate, truncate; corolla large, fleshy; fruits flat capsules, up to 1 m long, tapering to both ends, woody; seeds very many, flat winged all round except at the base. The fresh root bark is soft and juicy and cream yellow to grey in colour. It is sweet, later becoming bitter. On drying, the bark shrinks, adheres closely to the wood and becomes faintly fissured. Roots, leaves, fruits, seeds and bark are the useful parts of this plant. The roots are sweet, astringent, bitter, acrid, refrigerant, anti-inflammatory, anodyne, aphrodisiac, expectorant, appetizing, carminative, digestive, antihelminthic, constipating, diaphoretic, diuretic, antiarthritic, febrifuge and tonic. They are useful in vitiated conditions of *vata* and *kapha,* in inflammations, dropsy, sprains, neuralgia, hiccough, cough, asthma, bronchitis, anorexia, dyspepsia, flatulence, colic, helminthiasis, diarrhoea, dysentery, strangury, gout, vomiting, leucoderma, wounds, rheumatoid arthritis and fever. The leaves are stomachic and anodyne and are useful in stomachalgia, flatulence, cephalalgia, ulcers, splenomegaly and vitiated conditions of *vata*. The tender fruits are expectorant, carminative and stomachic, and are useful in cough, bronchitis, dyspepsia, flatulence, colic and leucoderma.

4. *Stereospermum colais*

Stereospermum colais is used as the drug source of *patala* in Kerala. However, *Stereospermum suaveolens* is being used as the drug source in some other parts of India. *Stereospermum colais* is the white flowered species and *Stereospermum suaveolens* is red flowered. *Stereospermum colais* (Dillwyn) Mabb. (Family: Bignoniaceae) is a large deciduous tree. The branches and leaves are pubescent. Leaves are opposite, imparipinate; leaflets 7-9, 7-15 cm x 4-7 cm, thin, coriaceous, obovate to lanceolate, acute or rounded, often unequal sided at base, acute to caudate-acuminate at apex, entire or shortly serrate; flowers fragrant, yellow with reddish veins in lax terminal cymose panicles; calyx campanulate, glabrous; corolla bilabiate; stamens 4, filaments with a tuft of wooly hairs; capsule pendulous, 4-angled or ribbed, 30-40 cm x 1 cm. Roots, leaves, flowers, fruits and seeds are the useful parts of the plant. The roots are bitter, astringent, arid, anodyne, appetizer, constipating, diuretic, lithontriptic, expectorant, cardiotonic, aphrodisiac, anti-inflammatory, antibacterial, febrifuge and tonic. They are useful in vitiated conditions of *vata*, dyspepsia, diarrhoea and renal and vesical calculi.

5. *Premna corymbosa*

Premna corymbosa is used as the drug source of *agnimanthah* However, Ayurvedic Formulary of India suggests *Clerodendrum phlomides* as the real source of the drug and *Premna corymbosa* as the substitute. Some workers opine that these two can be used as substitutes for each other as they have similar properties. *Premna corymbosa* is a small sized tree with simple opposite and aromatic leaves. *Premna corymbosa* Rottl. (Family-Verbenaceae) is a small sized tree; leaves highly aromatic, simple, opposite, elliptic-ovate, acute, 5-9 cm x 3-6 cm, irregularly toothed, thin, coriaceous, dark green and shining above, dull below; flowers small, greenish white in many flowered, terminal, short-peduncled, corymbiform, cymose panicles; calyx cupular, persistent, becoming slightly larger and saucer shaped in fruit; corolla obliquely funnel shaped, 4 or 5 lobed; stamens 4, filaments hairy at base; ovary 2 or 4 celled, 4 ovuled, style linear, ending in a shortly bifid stigma; fruit globose drupe, 4 mm across, black when ripe. Root, root bark and leaves are used in medicine. *Agnimanthah* is reported to be acrid, bitter, astringent, cardiotonic, carminative, laxative, stomachic and tonic. It improves digestive power and is useful in constipation, fewer, heart diseases, neurological diseases and rheumatism. It overcomes *kapha* and *vata* disorders, anaemia, piles, oedema, poison, anasarca and abdominal diseases. Traditionally, this drug is highly valued for its anti-inflammatory property.

Conservation and propagation

In the case of *dasamula* destructive collection of drugs is severe since roots are the sources of active compounds. Hence, research towards either genetically improving the species for higher production of the active component or increasing the production of the compounds under *in vitro* culture conditions is essential. The commercial demand of *dasamula* is presently fulfilled by wholesale suppliers through rural and tribal collectors residing in/ near forest areas. Due to depletion of natural flora and increased demands, need for systematic cultivation and large scale multiplication has been realized recently and hence taken up for studies.

Today many medicinal plants face extinction or severe genetic loss, but detailed information is lacking. For most of the endangered medicinal plant species no conservation action has been undertaken. There is an urgent need to conserve the *dasamula* group of plants since they may become extinct if the reckless exploitation continues. The best way to ensure the conservation and availability of medicinal plants is to propagate them using advanced techniques. In the case of rare, endangered or over exploited plants, propagation and cultivation is the only way to provide material without further endangering the survival of those species. Cultivation has pharmacological advantages over wild collecting. Wild collected plants normally vary in quality and composition, due to environmental and genetic differences. In cultivation, this variation and the resulting uncertainty of the therapeutic benefit are much reduced. The plants can be grown in areas of similar climate and soil, they can be irrigated to increase yields and they can be harvested at the right time. Cultivation also greatly reduces the possibility of misidentification and adulteration.

In situ conservation in the natural habitats is the best method. But, due to climate change and anthropogenic influences, natural wild habitats of medicinal plants are getting devastated rapidly. Hence the only alternative is *ex situ* conservation. Moreover, conventional methods of propagation adapted by the natural populations of medicinal plants help them to increase their population size very slowly only. Under the circumstances, standardization and improvement of propagation techniques and growing them under human care is very essential to meet the growing demands of medicinal herbs. The first step in this direction involves sourcing and handling of propagules or propagates. Seed propagation, vegetative propagation and *in vitro* propagation protocols are being developed in medicinal plants and *dasamula* group is not an exception.

Seed propagation

Seed propagation can be carried out in all the members of *dasamula* except *Premna corymbosa*. Seeds can be germinated in nursery beds. In some of the plants like *Gmelina arborea* and *Stereospermum colais* pre-treatment of the seeds with water soaking increased the speed of germination as well as germination percentage.

Stereospermum colais shows poor germination percentage (25-30%) even under nursery conditions and this can be overcome by sowing the seeds immediately after extracting the seeds. Mature fruits collected directly from the trees before dehiscing were suitable for achieving good germination. Germination on direct sowing on a seedbed is efficient, technically less demanding and cost effective in all the species. This can also help for the step-by-step transplantation to potted soil and the subsequent hardening of seedlings. Large scale production of these species using seeds is an easy and reliable method and it will help to increase the resource availability for pharmaceutical use and at the same time help in conservation of these species.

Vegetative propagation

The goal of vegetative propagation is to produce progeny plants identical in genotype to a single source plant. Vegetative propagation through stem cuttings and air layers can be carried out in *Premna corymbosa*.

Stem cuttings

Propagation through stem cuttings is an easily cost effective propagation method. Many new plants can be obtained in this way in a limited space from a few stock explants. It is inexpensive, rapid, and simple and does not require the special techniques necessary in grafting, budding or micropropagation. In addition to this parent plant is usually reproduced exactly, with no genetic change.

Air layering

Layering is a form of rooting cuttings in which adventitious roots are initiated on a stem while it is still attached to the plant. The rooted stem (layer) is then detached and transplanted, and becomes a separate plant on its own roots. Layering is valuable to produce a relatively small number of large sized plants of a special cultivar in an outdoor environment with a minimum of propagation facilities.

In *P. corymbosa* quick and higher rooting was observed in all the layers just after 15 days of layering. On an average, 20 roots per layer with an average length of 10 cm were observed on the 30th day of layering. Absence of callus was also noted on the layers. Encouraging results may be due to the favourable climatic condition that prevailed in the locality. All the layered plants established in the nursery very well. Furthermore, the proposed method is convenient, practical and suitable for large scale propagation of this species.

In vitro propagation

In vitro propagation not only facilitates large scale production of the plant, but also underpins the use of all other biotechnologies in conservation and use. The advantages of being able to multiply a given genotype with relative ease, with a low risk of introducing or reintroducing pathogens, and with a low risk of genetic instability, need not be emphasized in this technique. *In vitro* propagation protocols for *dasamula* species like *Aegle marmelos*, *Gmelina arborea*, *Oroxylum indicum*, *Stereospermum colais*, *Solanum violaceum*, *and Tribulus terrestris* have been developed. However, further standardization of the protocols for their large scale utilization is the need of the hour. Moreover, the herbal pharmaceutical industry should come forward to accept such new developments in science so that effective conservation, propagation and utilization of the rare and endangered medicinal plants become more effective.

List of contributors

1. Ms. Surekha Y. Pawar
Research Scholar,
Genetics and Plant Breeding Division, Department of Botany,
University of Calicut,
Kerala - 673635.

2. Dr.K.T. Chandramohanan
Assistant Professor & Head, PG Department of Botany,
Government Brennen College,
Thalassery,
Kerala - 670106

3. Mr. T.S. Jishinprakash
Research Scholar,
Plant Biotechnology Division,
Department of Botany,
University of Calicut,
Kerala - 673635

4. Dr. A. Yusuf
Assistant Professor, Plant Biotechnology Division,
Department of Botany,
University of Calicut,
Kerala - 673635

5. Dr. K. Samsudeen
Principal Scientist,
Crop Improvement Division,
Central Plantation Crops Research Institute,
Kasaragod,
Kerala - 671124

6. Dr. N.R. Nagaraja
Scientist,
Crop Improvement Division,
Central Plantation Crops Research Institute Regional Station,
Vittal,
Karnataka - 574243

7. Dr. K.S. Ananda
Principal Scientist & Head,
Central Plantation Crops Research Institute Regional Station,
Vittal,
Karnataka - 574243

8. Dr. M.K. Rajesh
Principal Scientist,
Crop Improvement Division,
Central Plantation Crops Research Institute,
Kasaragod,
Kerala - 671124

9. Dr. B. Sasikumar
Former Principal Scientist & Head,
Crop Improvement & Biotechnology Division,
Indian Institute of Spices Research,
Kozhikode,
Kerala - 673 012

10. Dr. V.V. Radhakrishnan
Professor, Genetics and Plant Breeding Division,
Department of Botany,
University of Calicut,
Kerala - 673635

11. Dr. V. Prajitha
Research Scholar,
Cell and Molecular Biology Division,
Department of Botany,
University of Calicut,
Kerala - 673635

12. Dr. John E. Thoppil
Professor,
Cell and Molecular Biology Division,
Department of Botany,
University of Calicut,
Kerala - 673635

13. Dr. V.B. Sureshkumar
Deputy Director,
Regional Coffee Research Station,
Narasipatnam,
Andhra Pradesh - 531116

14. Dr. P.M. Priyadarshan
Former Deputy Director,
Rubber Research Institute of India,
Kottayam,
Kerala - 686009

15. Dr. T.K. Hrideek
Scientist,
Forest Genetics & Tree Breeding
Department,
Kerala Forest Research Institute,
Peechi,
Thrissur,
Kerala - 680653

16. Ms. Suby
Research Fellow,
Forest Genetics & Tree Breeding
Department,
Kerala Forest Research Institute,
Peechi,
Thrissur,
Kerala - 680653

17. Dr. M. Amruth
Scientist,
Sociology Department,
Kerala Forest Research Institute,
Peechi,
Thrissur,
Kerala - 680653

18. Dr. A.V. Raghu
Scientist,
Extension & Training Division,
Kerala Forest Research Institute,
Peechi,
Thrissur,
Kerala - 680653

Gregor Mendel Foundation was instituted in 1991 to promote studies and research in Genetics, Breeding and Biotechnology. The headquarters of the foundation is Department of Botany, University of Calicut, Kerala, India. The foundation organizes Gregor Mendel Birthday Lectures, Seminars and Symposia and also publishes Gregor Mendel Foundation Proceedings.

This book contains essays on the most important crops of Kerala State of India like rice, coconut, arecanut, pepper, cardamom, vanilla, coffee, tea, rubber and teak which have formulated the destinies of the people of Kerala from time to time, an essay on grain amaranths which are often referred to as the newly emerging food crops and another essay on *dasamula* group of medicinal plants which are familiar to any keralite as the source materials of the ayurvedic medicinal combination *dasamula*.

ISBN 978-81-935133-0-9

9 788193 513309

Gregor Mendel Foundation
Department of Botany
Calicut University, Kerala - 673 635, India