

Plant Breeding in 21st Century



B.D. Singh
N.S. Shekhawat

Plant Breeding

in 21st Century

Realted Books

Title	Author
• A Handbook of Laboratory Solutions	<i>M.H. Gabb</i>
• Advances in Plant Physiology (Vol. 1-18)	<i>A. Hemantaranjan</i>
• An Introduction to Population Genetics Theory	<i>J.F. Crow</i>
• Basic Concepts of Plant Biotechnology (With MCQs)	<i>Vijay Prakash</i>
• Biofertilizer Technology	<i>S. Kannaiyan</i>
• Biology and Biotechnology of Anoxygenic Phototrophic Bacteria	<i>S. Girisham</i>
• Biotechnology Emerging Trends	<i>R.Z. Sayyed</i>
• Biotechnology of Microbes and Sustainable Utilization	<i>R.C. Rajak</i>
• Comprehensive Laboratory Manual of Life Science	<i>Jyoti Saxena</i>
• Crop Improvement and Mutation Breeding	<i>A.K. Sharma</i>
• CSIR NET: Part A (Hindi)	<i>Christy Varghese</i>
• Cytochalasin: Incidence and Biological Activities	<i>S. Kiran</i>
• Double Helix: DNA Sanrachna Ki Khoj (Hindi)	<i>H.C. Dube</i>
• Fundamentals of Agriculture	<i>R.L. Arya</i>
• Genetic Improvement of Field Crops	<i>C.B. Singh</i>
• Handbook of Mycological Techniques: Identification of Mycotoxigenic Fungi and Mycotoxins	<i>Rekha Bhadauria</i>
• Indiras Objective Agricultural Biotechnology 2nd Ed	<i>R.L. Arya</i>
• Indiras Objective Agriculture	<i>R.L. Arya</i>
• Laboratory Manual of Microbiology, Biochemistry and Molecular Biology	<i>Jyoti Saxena</i>
• MCQs in Plant Breeding Biotechnology and Seed Science	<i>K. Vanangamudi</i>
• Methods in Fungal Biology: A Manual of Laboratory Protocols	<i>A.K. Gautam</i>
• Microbial Biotechnology for Sustainable Development and Productivity	<i>R.C. Rajak</i>
• Mycology and Microbiology: A Textbook for UG and PG Courses	<i>C. Manoharachary</i>
• Objective Life Science MCQs for Life Science	<i>Kailash Choudhary</i>
• Perspectives in Biotechnology	<i>S.M. Reddy</i>
• Plant Biotechnology and Molecular Biology: A Laboratory Manual	<i>M.S. Punia</i>
• Plant Molecular Genetics	<i>S. Chakraborty</i>
• Plant Reproduction	<i>T. Pullaiah</i>
• Plant Tissue Culture: Theory & Practicals 2nd Ed	<i>T. Pullaiah</i>
• Plant Tissue Culture: Theory and Techniques	<i>Shailesh Kumar</i>
• Recent Trends in Biotechnology	<i>M.K. Rai</i>
• Seed Technology 2nd Ed	<i>Dhirendra Khare</i>

Plant Breeding in 21st Century

B.D. Singh
N.S. Shekhawat



Published by:

SCIENTIFIC PUBLISHERS (INDIA)

5A, New Pali Road, P.O. Box 91

Jodhpur 342 001, India

E-mail: info@scientificpub.com

Website: www.scientificpub.com

© 2019, Singh, B.D. & Shekhawat, N.S.

All rights reserved. No part of this publication or the information contained herein may be reproduced, adapted, abridged, translated, stored in a retrieval system, computer system, photographic or other systems or transmitted in any form or by any means, electronic, mechanical, optical, digital, by photocopying, recording or otherwise, without written prior permission from the publisher. Any breach will attract legal action and prosecution without further notice.

Disclaimer: While every effort has been made to avoid errors and omissions, this publication is being sold and marketed on the understanding and presumption that neither the editors (or authors) nor the publishers nor the printers would be liable in any manner whatsoever, to any person either for an error or for an omission in this publication, or for any action to be taken on the basis of this work. Any inadvertent discrepancy noted may be brought to the attention of the publisher, for rectifying it in future editions, if published.

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the editors and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The editors and publisher have attempted to trace and acknowledge the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission and acknowledgement to publish in this form have not been obtained. If any copyright material has not been acknowledged please write and let us know so that we may rectify it.

Trademark Notice: Publications or corporate names may be trademarks, and are used only for identification and explanation in bonafide intent without intent to infringe.

Reprinted from the book 'Molecular Plant Breeding' by B.D. Singh & N.S. Shekhawat (Pages: 544 Page and Year: 2018)

ISBN: 978-93-89061-27-7

eISBN: 978-93-89061-28-4

Printed in India

To

Satish C. Maheshwari

A world-famous scientist
and
an inspiring teacher

Preface

The prehistoric humans domesticated a diverse group of wild plant species, which ultimately gave rise to our present-day crops. Domestication permitted the development of agriculture, which prompted the humans to shift from nomadic to settled life style, and allowed the evolution and refinement of culture and civilization. An inevitable consequence of these developments was the incessant increase in human population, which is over 7.7 billion at present and is expected to cross 9.0 billion by the year 2042. It has long been realized that the crop yields are considerably improved by selecting lines with desirable features for cultivation. In view of this, extensive systematic research activities were devoted to the development of improved crop varieties leading to the formulation of the various schemes and methods of plant breeding. The success of breeding programmes depends mainly on the genetic variation(s) available to the breeder, and the effectiveness of the selection procedures for the characters being improved. The bulk of plant breeding research has been focussed on the development of methods to satisfactorily resolve the above two issues.

Plant breeding has been highly successful in evolving improved crop varieties to provide for the growing needs of the ever expanding human population. But the climatic changes associated with the global warming, and the unfavourable effects of the modern-day agricultural practices on the biotic and abiotic components of the agricultural environment are inevitably adversely affecting crop yields. Therefore, the plant breeders have the dual challenge of developing climate smart crop varieties endowed with higher yielding ability, and resistance to the emerging pathogens and insect pests within progressively shorter time spans than ever before. Thus, plant breeders need to be able to access the desired genes and use them in their breeding programmes, and to devise such breeding strategies that enable them to develop new varieties in as short a period as possible.

Plant breeders are always in search of useful genes that could be deployed in the crop varieties to create in them the desired phenotypes. This search has enabled them to utilize related wild species as donors of valuable traits to many

of our crops. But many useful genes remain inaccessible to the breeders due to sexual incompatibilities. The development of recombinant DNA technology provided an opportunity to transfer and express in plants genes from any source and, thereby, create plants with novel traits. The transgenic technology has been considerably refined and used to develop many crop varieties with useful novel traits; a large number of these varieties have been approved for commercialization and are in cultivation since 1996. The transgenic varieties possess such useful traits as disease and insect pest resistance, resistance to drought, improved produce quality, and even higher yields. It is projected that the transgenic technology will enable the development of climate smart crop varieties by bringing together the necessary genes from various sources.

In spite of the reported all-round positive impact, including beneficial effects on the environment, the consumer acceptance of transgenic varieties has been, if anything, lukewarm. The researches directed at the use of DNA for unequivocal identification of human individuals had the pleasant and highly useful side-effect of the development of DNA-based molecular markers. DNA markers have found a variety of applications in the various disciplines of biology, of which perhaps the most notable is that in the field of plant breeding leading to the emergence of marker-assisted plant breeding. Markers have enabled reliable and efficient indirect selection for traits, mapping and selection for quantitative trait loci, and more particularly, selection for various traits at the seedling stage and in off-season crops/greenhouses. Thus, markers allow rapid advance of generations and, thereby, drastically reduce the time required for the development of new crop varieties. Most commercial and many national breeding programmes are using the marker technology to achieve a variety of objectives.

Plant breeding has freely and gainfully utilized the developments in the other disciplines of biology to enrich its arsenal to enhance its capability to development of crop varieties designed to meet the changing requirements of agricultural production systems. The transgenic and marker technologies have emerged as extremely powerful tools for modification of crop genotypes. These technologies are progressively being integrated into breeding programmes. As a result, a modern plant breeder needs to be adequately familiar with the transgenic and marker technologies.

The book *Molecular Plant Breeding in 21st Century* is designed to provide a combined overview of plant breeding tools and techniques along with those of transgenic and marker technologies, each presented in a separate section of the book. This book is intended for graduate students offering an introductory course in plant breeding, and for those pursuing M.Sc. programmes in botany. It would also be useful for the students appearing in various competitive examinations. We have given special attention to keep the text simple and easy-to-understand and enjoyable, but at the same time comprehensive and detailed. Therefore, we made enormous efforts to make the content of this book as pleasant as possible for broad range of readers.

The authors are appreciative of the sincere efforts by Mr. Tanay Sharma and his production team, including the reviewers, editors and the graphics designers, of Scientific Publishers, Jodhpur. The authors like to extend their thanks to all the team for their commendable efforts, as a result of which the book has been brought out speedily in an excellent published form.

With this edition, we aim to serve a wide range of readers' groups with the intention of contributing towards technological advancement in molecular plant breeding. In the end, we would like to express our heartfelt appreciation for our family members, whose affectionate support gave us the courage to undertake this project and the energy to successfully complete the same.

B.D. Singh
N.S. Shekhawat

June 30, 2019
Varanasi, Jodhpur

Contents

Preface

vii

Part A

Basics of Plant Breeding

1. Introduction	1
1.1. Introduction to Plant Breeding	1
1.2. The Growing Food Needs and Declining Agricultural Resources	2
1.3. Major Developments	4
1.4. Activities In Plant Breeding	9
1.5. Domestication	11
1.6. Genetic Resources	12
1.7. Modes of Reproduction	16
1.8. Qualitative and Quantitative Traits	19
1.9. Achievements	22
1.10. Undesirable Consequences of Plant Breeding	23
1.11. Limitations of Plant Breeding Methods	24
1.12. Conclusions	25
PRACTICE QUESTIONS	26
RELEVANT LITERATURE	26
2. The Relevance of Genetics and Genomics in Plant Breeding	28
2.1. Introduction	28
2.2. Genes and Chromosomes	28
2.3. Cell Division	30
2.4. Inheritance of Qualitative Traits	31
2.5. Inheritance of Quantitative Traits	40
2.6. Population Genetics	46
2.7. Cytoplasmic Inheritance	47
2.8. Molecular Genetics	50
2.9. Epigenetics	54
2.10. Genomic Imprinting	58
2.11. Genome Editing	59
2.12. Genomic Resources	62
PRACTICE QUESTIONS	64
RELEVANT LITERATURE	65

3. Tools of Plant Breeding	66
3.1. Introduction	66
3.2. Introduction to Genetic Resources	66
3.3. Pollination Control	68
3.4. Hybridization: <i>Intraspecific and Interspecific</i>	81
3.5. Heterosis and Inbreeding Depression	89
3.6. Polyploidy	94
3.7. Mutation Breeding	105
3.8. Somaclonal Variation	112
3.9. Selection	113
PRACTICE QUESTIONS	119
RELEVANT LITERATURE	120
4. Breeding of Self-Pollinated Crops	122
4.1. Introduction	122
4.2. Methods of Selection	122
4.3. Hybridization	126
4.4. Pedigree Method	126
4.5. Bulk Method	131
4.6. Single Seed Descent Method	134
4.7. Use of Haploids for Rapid Isolation of Homozygous Lines	136
4.8. Backcross Method	136
4.9. Multiline Varieties	141
4.10. Population Breeding Approach	142
4.11. Rapid Isolation of Homozygous Lines (<i>hybrid Sorting</i>)	143
4.12. Hybrid Varieties	144
4.13. Participatory Crop Improvement	145
4.14. Breeding of Often Cross-pollinated Crops	147
4.15. Breeding of Asexually Propagated Crops	147
4.16. Mutation Breeding	150
4.17. Conclusion	150
PRACTICE QUESTIONS	153
RELEVANT LITERATURE	153
5. Breeding of Cross-Pollinated Crops	154
5.1. Introduction	154
5.2. Selection in Cross-pollinated Crops	157
5.3. Recurrent Selection	162
5.4. Hybrid Varieties	172
5.5. Synthetic Varieties	187
5.7. Achievements With Synthetic and Composite Varieties	192
5.8. Conclusion	192
PRACTICE QUESTIONS	193
RELEVANT LITERATURE	193

6. Breeding for Biotic Stress Resistance	194
6.1. Introduction	194
6.2. Breeding for Disease Resistance	194
6.3. Breeding For Insect Resistance	213
6.4. Conclusions	226
PRACTICE QUESTIONS	228
RELEVANT LITERATURE	228
7. Breeding for Resistance to Abiotic Stresses	230
7.1. Introduction	230
7.2. Breeding for Drought Resistance	230
7.3. Breeding for Resistance to Salinity Stress	239
7.4. Breeding for Salinity Stress Resistance	241
7.5. Breeding for Resistance to Mineral Stresses	243
7.6. Breeding for Resistance to Temperature Stress	249
7.7. Achievements of Breeding for Abiotic Stress Resistance	256
7.8. Conclusions	256
PRACTICE QUESTIONS	257
RELEVANT LITERATURE	258
8. Breeding for Quality Traits	260
8.1. Introduction	260
8.2. Breeding for Nutritional Quality	262
8.3. Inheritance of Nutritional Quality Traits	262
8.4. Elimination of Anti-nutritional Factors	263
8.5. Breeding for Enhanced Vitamin Content	264
8.6. Protein Content and Quality	265
8.7. Oil Content and Quality	270
8.8. Sources for Quality Traits	274
8.9. Breeding Approaches for Quality Traits	275
8.10. Limitations of Breeding for Quality	277
PRACTICE QUESTIONS	277
RELEVANT LITERATURE	278

Part B

Transgenic Technology

9. The Basic Techniques of Transgenic Technology	281
9.1. Introduction	281
9.2. Plant Tissue Culture	282
9.3. Regeneration of Complete Plantlets	288
9.4. Recombinant DNA Technology	292
9.5. Transgenic Plants	306
9.6. Gene Constructs for Plants	307
9.7. Marker or Reporter Genes	309
9.8. Vectors for Plant Transformation	312
9.9. Genetic Transformation of Plants	318

9.10.	Genetic Transformation of Chloroplasts	324
9.11.	Transgene Integration and Inheritance	327
	PRACTICE QUESTIONS	328
	RELEVANT LITERATURE	329
10.	Transgenic Plants for Resistance to Biotic and Abiotic Stresses	330
10.1.	Introduction	330
10.2.	Objectives of Transgene Expression	331
10.3.	Abiotic and Biotic Stresses	331
10.4.	Herbicide Resistance	332
10.5.	Insect Resistance	334
10.6.	Virus Resistance	340
10.7.	Disease Resistance	346
10.8.	Salinity and Drought Tolerance	349
10.9.	Conclusions	350
	PRACTICE QUESTIONS	351
	RELEVANT LITERATURE	352
11.	Transgenic Plants with modified Quality and other Novel Traits	353
11.1.	Introduction	353
11.2.	Endogenous Gene Suppression	353
11.3.	Slow Fruit Softening Tomato	358
11.4.	Modification of Oil Quality	359
11.5.	Modification of Protein Quality	361
11.6.	Modification of Starch Quality	364
11.7.	Golden Rice	366
11.8.	Male Sterility	368
11.9.	Edible Vaccines	369
11.10.	Biochemical Production	371
11.11.	Crops for Biofuel Production	373
11.12.	Conclusions	374
	PRACTICE QUESTIONS	376
	RELEVANT LITERATURE	376
12.	Biosafety Issues Related to and Adoption of Transgenic Crops	378
12.1.	Introduction	378
12.2.	Potential Benefits From Transgenic Crop Varieties	379
12.3.	GM Crops Approved for Commercial Cultivation	380
12.4.	Adoption of GM Crops By Farmers	381
12.5.	Agronomic Impact of Transgenic Crops	382
12.6.	Economic Benefits from Transgenic Varieties	383
12.7.	Consumer Acceptance of Transgenic Crop Produce	384
12.8.	Social Impact of Transgenic Crops	384
12.9.	Risks From GM Crops	385
12.10.	Regulation of GM Crop Varieties	386

12.11.	Safety of GM Food	388
12.12.	Environmental Risks From GM Crops	390
12.13.	Transgene Dispersal VIA Pollen And DNA	392
12.14.	Issues Relevant to Agriculture	393
12.15.	Conclusions	394
	PRACTICE QUESTIONS	395
	RELEVANT LITERATURE	396

Part C

Molecular Markers

13. Molecular Marker Systems and Trait Phenotyping	401	
13.1.	Introduction	401
13.2.	Genetic Markers	402
13.3.	Isolation and Purification of DNA From Plants	405
13.4.	Polymerase Chain Reaction	405
13.5.	Restriction Fragment Length Polymorphism	406
13.6.	Randomly Amplified Polymorphic DNA	409
13.7.	Amplified Fragment Length Polymorphism	410
13.8.	Diversity Array Technology	411
13.9.	Sequence Characterized Amplified Regions	413
13.10.	Simple Sequence Repeat (SSR) Polymorphisms	413
13.11.	Inter-SSR (ISSR) Markers	416
13.12.	Start Codon Targeted Polymorphism	416
13.13.	Single Nucleotide Polymorphism	417
13.14.	Cleaved Amplified Polymorphic Sequences	419
13.15.	Allele-specific PCR	422
13.16.	High Throughput Genotyping	422
13.17.	Trait Phenotyping	426
13.18.	Conclusions	429
	PRACTICE QUESTIONS	430
	RELEVANT LITERATURE	430
14. Marker-Trait Associations	432	
14.1	Introduction	432
14.2	Populations for Linkage Mapping	432
14.3.	Populations for Association Mapping	445
14.4	Some Relevant Facts about Mapping Populations	446
14.5	Linkage Mapping of Markers and Genes	446
14.6	Linkage Mapping of QTLS	453
14.7	Association Mapping	457
14.8.	Conclusions	462
	PRACTICE QUESTIONS	463
	RELEVANT LITERATURE	463

15. Applications of Molecular Markers in Plant Breeding	464
15.1. Introduction	464
15.2. Germplasm Characterization and Conservation	464
15.3. Diversity and Phylogenetic Analyses	466
15.4. DNA Fingerprinting	466
15.5. Evaluation of Genetic Purity of Parental Lines and Seed Lots	468
15.6. Positional Cloning of Genes	469
15.7. Selection of Parents for Hybridization	471
15.8. Marker-assisted Selection	471
15.9. Marker-assisted Backcrossing	472
15.10. QTL Introgression and other issues	481
15.11. Marker-assisted Recurrent Selection	482
15.12. Novel Breeding Schemes	484
15.13. Genomic Selection	484
15.14. Achievements with MAS	487
15.15. Advantages of MAS	487
15.16. Limitations of MAS	488
15.17. Conclusions	488
PRACTICE QUESTIONS	489
RELEVANT LITERATURE	489

Part D

Miscellaneous

16. Variety Release, Seed Multiplication and Intellectual Property Rights	493
16.1. Introduction	493
16.2. Release of New Varieties	493
16.3. Seed Multiplication	496
16.4. Intellectual Property Rights	504
16.5. Conclusions	513
PRACTICE QUESTIONS	514
FURTHER READINGS	514
Subject Index	516
Author Index	541

Part A.
Basics of Plant Breeding

