

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable cultivation of potatoes

Volume 1: Breeding improved varieties

Edited by Professor Gefu Wang-Pruski
Dalhousie University, Canada



 burleigh dodds
SCIENCE PUBLISHING

Contents

Series list	x
Acknowledgement	xv
Introduction	xvi

Part 1 Plant physiology and breeding

1	Advances in understanding potato plant physiology and growth <i>Curtis M. Frederick, University of Wisconsin, USA; Masahiko Mori, Obihiro University of Agriculture and Veterinary Medicine, Japan; and Paul C. Bethke, USDA-ARS and University of Wisconsin, USA</i>	3
1	Introduction	3
2	Crop rotation, planting and initial crop development	4
3	Development of the potato plant	7
4	Potato responses to water and heat stresses	12
5	Potato responses to nutrient availability	16
6	Additional factors affecting sustainable production	18
7	Summary	20
8	Future trends	20
9	Where to look for further information	21
10	References	21
2	Understanding ageing processes in seed potatoes <i>Paul C. Struik, Wageningen University and Research, The Netherlands</i>	33
1	Introduction: seed tubers as the main propagules in potato production	33
2	Quality characteristics of seed tubers	34
3	Dormancy and physiological age	35
4	The importance of seed quality as a yield-limiting and quality-determining factor	38
5	Understanding dormancy, bud activation, initial sprout growth and apical dominance	40
6	Understanding ageing in sprouts and mother tubers	43
7	Analysis of the dynamic development of physiological age and resulting crop performance	46
8	Causes of variation in physiological age and options for manipulation	49
9	Summary and future trends	50
10	Where to look for further information	51
11	References	52
3	Ensuring the genetic diversity of potatoes <i>John Bamberg and Shelley Jansky, USDA-ARS, USA; Alfonso del Rio, University of Wisconsin-Madison, USA; and Dave Ellis, International Potato Center (CIP), Peru</i>	57
1	Introduction	57
2	Acquisition of potato genetic material	62

3	Classification of potato genetic material	65
4	Preservation of potato genetic material	67
5	Evaluation and enhancement of potato genetic material	69
6	Legal custody and access to potato genetic material	71
7	Conclusion and future trends	73
8	Where to look for further information	75
9	References	75
4	Advances in conventional potato-breeding techniques <i>Jai Gopal, ICAR-Central Potato Research Institute, India</i>	81
1	Introduction	81
2	Parental line selection	82
3	Progeny selection	85
4	Improving the speed and success rate of selection	89
5	Summary	92
6	References	92
5	Hybrid potato breeding for improved varieties <i>Pim Lindhout, Michiel de Vries, Menno ter Maat, Su Ying, Marcela Viquez-Zamora and Sjaak van Heusden, Solynta, The Netherlands</i>	99
1	Introduction	99
2	The scientific basis for hybrid potato breeding	101
3	The state of the art of hybrid potato breeding	104
4	Production and commercialization of hybrid seed cultivars	107
5	Inbred lines for genetic research	108
6	Cropping systems based on true seeds	111
7	Case studies	113
8	Conclusion	116
9	Where to look for further information	117
10	Acknowledgements	117
11	References	117
 Part 2 Improving particular traits		
6	Advances in development of potato varieties resistant to abiotic stress <i>Ankush Prashar and Filipe de Jesus Colwell, Newcastle University, UK; and Csaba Hornyik and Glenn J. Bryan, The James Hutton Institute, UK</i>	125
1	Introduction	125
2	Abiotic stress improvement targets for potatoes	126
3	Technological advances to develop abiotic stress resistant/tolerant varieties	130
4	Future trends and conclusion	135
5	References	136
7	Developing early-maturing and stress-resistant potato varieties <i>Prashant G. Kwar, ICAR-Directorate of Floricultural Research, India; Hemant B. Kardile, S. Raja, Som Dutt and Raj Kumar, ICAR-Central Potato Research Institute, India; P. Manivel, ICAR-Directorate of Medicinal & Aromatic Plants</i>	143

<i>Research, India; and Vinay Bhardwaj, B. P. Singh, P. M. Govindakrishnan and S.K. Chakrabarti, ICAR-Central Potato Research Institute, India</i>	
1	Introduction 143
2	Selecting germplasm and traits for breeding early-maturing varieties 145
3	Genetic aspects of earliness and breeding strategy 146
4	Early tuber initiation 148
5	High dry matter partitioning efficiency 150
6	Basic factors in breeding for earliness in the potato 150
7	Breeding strategies for earliness and stress resistance 151
8	Genetic aspects 152
9	Case study: developing an early-maturing, moderately late-blight-resistant Kufri Khyati potato variety for Indian plains 153
10	Future trends and conclusion 163
11	Acknowledgments 163
12	Where to look for further information 164
13	References 164
8	Developing new sweet potato varieties with improved performance 169
<i>Peng Zhang, Weijuan Fan, Hongxia Wang, Yinliang Wu and Wenzhi Zhou, Institute of Plant Physiology and Ecology, Chinese Academy of Sciences, China; and Jun Yang, Shanghai Chenshan Plant Science Research Center, Shanghai Chenshan Botanical Garden, China</i>	
1	Introduction 169
2	Genetic transformation of sweet potato from model cultivars to farmer-preferred cultivars 171
3	Production of disease-resistant sweet potato 174
4	Production of sweet potato resistant to abiotic stresses 177
5	Starch modification for industrial applications 180
6	Increased understanding of storage root development for better yield 181
7	Production of purple sweet potato with increased anthocyanin content 183
8	Conclusion and perspectives 184
9	Where to look for further information 185
10	Acknowledgements 185
11	References 186
9	Nutritional properties and enhancement/biofortification of potatoes 191
<i>Duroy A. Navarre, Washington State University and USDA-ARS, USA; and M. Moehninsi, Sen Lin and Hanjo Hellmann, Washington State University, USA</i>	
1	Introduction 191
2	The vitamin B family 193
3	Vitamin C 199
4	Potassium 201
5	Carotenoids 201
6	Potato phenylpropanoids 202
7	Glycoalkaloids 205
8	Conclusion and future trends 207
9	Where to look for further information 207
10	References 208

10	Improving the breeding, cultivation and use of sweetpotato in Africa <i>Putri Ernawati Abidin and Edward Carey, International Potato Center (CIP), Ghana</i>	223
1	Introduction	223
2	Programmes for improving sweetpotato as a crop	224
3	Developments in breeding and seed dissemination	228
4	Improvements in cultivation and post-harvest handling	235
5	Nutritional quality and its improvement	237
6	Crop diversification for new uses	242
7	Case studies: Malawi	246
8	Case studies: Ghana	248
9	Conclusion and future trends	249
10	Where to look for further information	250
11	Acknowledgements	250
12	References	250

Part 3 Translating research into practice: improving cultivation in the developing world

11	Potato production and breeding in China <i>Liping Jin, Chinese Academy of Agricultural Sciences, China</i>	259
1	Introduction	259
2	Current production and consumption	260
3	Key trends and challenges	262
4	Germplasm material	263
5	Breeding objectives and development	264
6	Types of new variety	265
7	Virus-free seed potato production	266
8	Future trends	268
9	Where to look for further information	268
10	References	268
12	Improving potato cultivation to promote food self-sufficiency in Africa <i>Moses Nyongesa and Nancy Ng'ang'a, Kenya Agricultural and Livestock Research Organization, Kenya</i>	271
1	Introduction	271
2	Potato production in Africa and its challenges	272
3	Variety development and promotion	275
4	Systems and programs to support potato production in Africa	278
5	Prospects for development and poverty alleviation: opportunities and challenges	280
6	Future prospects	281
7	Conclusion	281
8	Where to look for further information	282
9	References	282
13	Supporting smallholder women farmers in potato cultivation <i>Linley Chiwona-Karlton, Swedish University of Agricultural Sciences, Sweden; Maryanne Wamahi, Stockholm University, Sweden; Chikondi Chabvuta,</i>	285

Actionaid International Malawi, Malawi; Dianah Ngonyama, Association of African Agricultural Professionals in the Diaspora, USA; and Paul Demo, International Potato Center (CIP), Malawi

1 Introduction	285
2 The importance of potato cultivation to African smallholders	285
3 The role of women in potato cultivation	287
4 Challenges facing women smallholders	288
5 Strategies to support women smallholders	289
6 Conclusion and future trends	291
7 Where to look for further information	291
8 References	292
Index	297

Introduction

Potatoes are one of the world's key food crops. Their nutritional value, and the fact that they can be grown with relatively few inputs in a wide range of environments, makes them an important food security crop. However, yields in developing countries are held back by factors such as poor cultivation practices and the impact of pests and diseases, whilst more intensive systems need to become more 'climate smart' to minimise environmental impact and adapt to climate change. These challenges are addressed in the two volumes of *Achieving sustainable cultivation of potatoes*:

- Volume 1 Breeding improved varieties
- Volume 2 Production, storage and crop protection

Volume 1 reviews general developments in breeding, research on improving particular traits, from stress resistance to nutritional quality, as well the challenges facing potato cultivation in particular regions. The volume reviews the latest research on understanding potato plant physiology and genetic variety. It discusses major advances in conventional, hybrid and marker-assisted breeding as well as their application in improved varieties, before focusing on ways of supporting smallholders in regions such as Africa and Latin America. Although a separate species, the book also includes selective coverage of research on sweet potato. The book is accompanied by a second volume which looks at ways of improving potato cultivation as well as advances in pest and disease management.

Part 1 Plant physiology and breeding

The first part of the volume assesses recent research on plant physiology and genetic diversity and their implications for conventional, hybrid and marker-assisted breeding. The subject of Chapter 1 is advances in understanding potato plant physiology and growth. The chapter looks at what we know about initial crop development and the factors affecting the subsequent development of the potato plant. The chapter examines in particular potato responses to water and heat stresses as well as nutrient availability and other factors.

Given its important implications for shelf-life, Chapter 2 reviews research on understanding ageing processes in seed potatoes. The physiological quality of seed tubers is very important for the performance of the crop grown from them, and interacts strongly with seed tuber size. Physiological quality consists of two components: dormancy and physiological age. The chapter reviews the conditions which influence both dormancy and physiological age, as well as the effects of seed quality on various aspects of crop performance. After considering seed tubers as the main propagules in potato production, the chapter deals with the quality characteristics of seed tubers, dormancy and physiological age, and the importance of seed quality as a yield-limiting and quality-determining factor. The chapter focuses on the importance of understanding dormancy, bud activation, initial sprout growth and apical dominance, as well as understanding aging in sprouts and mother tubers. The chapter provides an analysis of the dynamic development of physiological age and resulting crop performance, as well as assessing the causes of variation in physiological age and options for manipulation.

The subject of Chapter 3 is the importance of ensuring the genetic diversity of potatoes. The opportunities for advances in the potato crop through genetics are significant, since potato has many needs for improvement, and related species with the traits required are available. The chapter discusses the special challenges, opportunities, and recent developments and accomplishments for potato genebanks in the areas of acquisition, classification, preservation, evaluation, and distribution of genetic stocks and information, as well as discussing key issues in access to genetic material.

Moving on the subject of breeding techniques, the subject of Chapter 4 is advances in conventional potato-breeding techniques. Potato is highly heterozygous and, in order to maintain productivity, improved potato varieties must be developed by inter-mating desired parental lines and selecting superior clones from the progeny. Since potato is vegetatively propagated, any selected genotype can be fixed with all its intra- and inter-locus interactions responsible for phenotypic expression, and multiplied for commercial cultivation if desired. Recent advances in molecular breeding provide opportunities for rapid genetic gain. Nevertheless, phenotypic selection remains the common practice in conventional potato breeding programmes. Nearly all new varieties of potato still emerge from a process free from use of molecular technologies. The chapter reviews the progress and advances made in phenotypic selection techniques of conventional potato breeding. The chapter describes the role of molecular approaches in improving phenotypic selection.

Complementing the preceding chapter's theme of potato breeding, Chapter 5 looks at hybrid potato breeding for improved varieties. Hybrid potato breeding promises to create new cultivars within a few years. This would facilitate the introgression of genes by marker assisted selection, and hybrid cultivars could then be made available as true seeds, free of soil-borne pathogens, quick to multiply and easy to transport and store. What were previously thought to be prohibiting factors for hybrid potato breeding have recently been overcome: nearly homozygous inbred lines have been created and the first experimental hybrids have been evaluated in the field. The chapter reviews the scientific basis for hybrid potato breeding and highlights the key features of a strategy for creating an inbred, line-based, hybrid potato crop that can be propagated through seed. The chapter discusses the recent progress made towards the development of useful hybrid varieties, and considers how the hybrid potato breeding technology platform will need to be adapted and optimized for different production systems.

Part 2 Improving particular traits

Building on Part 1, the second part of the book looks at ways developments in breeding have been used to improve particular traits. The focus of Chapter 6 is on advances in the development of potato varieties resistant to abiotic stress. Abiotic stresses such as drought, high or low temperature, salinity, submergence and nutrient deficiency can significantly impact potato yields. These suboptimal conditions restrict potato plant performance so that the plants do not reach their full genetic potential. The chapter examines different abiotic stress improvement targets in the potato as well as the variety of tools and techniques being developed and used for crop improvement for abiotic stresses. The chapter reviews technological advances to develop abiotic stress resistance in potatoes and tolerant varieties, especially through genetic engineering.

Chapter 7 examines the challenge of developing early-maturing, stress-resistant potato varieties. The chapter describes the selection of germplasm and traits for breeding early maturing varieties of potato, exploring genetic aspects of earliness as a trait. The chapter looks at early tuber initiation, high dry matter partitioning efficiency and basic factors that need to be taken into account when breeding for earliness in potato. The chapter includes a detailed case study of developing an early-maturing, late blight-resistant Kufri Khyati potato variety for cultivation in India.

As a point of comparison, Chapter 8 deals with developing new sweet potato varieties with improved performance. Novel sweet potato varieties with improved traits are needed, especially for marginal lands and disease-prone regions. However, the high degree of heterozygosity, high male sterility, and self- and interspecific incompatibility of the sweet potato plant results in strong segregation of hybrid progenies. Molecular breeding provides a promising approach for the development of new varieties with value-added traits. The chapter reviews the development and application of genetic transformation and trait improvement to sweet potato, including the development of sweet potato plants which are resistant to disease and abiotic stress, and sweet potatoes with improved starch quality and higher anthocyanin content.

Chapter 9 begins by considering the nutritional properties and enhancement and bio-fortification of potatoes. There are a number of factors that make potatoes a logical focus for nutritional breeding efforts. As one of the world's staple foods, they have a key role to play in improving global food security, largely due to their nutritional value, storability, affordability and high yield. Recent years have also witnessed greatly increased consumer concern for healthy food choices, leading to high demand for an increase in the nutritional value of foods that have previously been subject to negative health publicity. The chapter reviews the nutritional composition of potatoes from diverse germplasm including vitamin C, B vitamins, potassium, carotenoids, phenylpropanoids and glycoalkaloids. In each case, the chapter discusses the feasibility and health benefits of increasing these nutrients through traditional and precision breeding programmes.

Chapter 10 deals with improving the breeding, cultivation and use of sweet potato in Africa. Sweet potato is a low input crop with significant potential for improving public health and nutrition and developing food security in Sub-Saharan Africa. The chapter examines the nutritional contribution made by OFSP (orange-fleshed sweet potato) in poor rural communities in Malawi, Ghana, Nigeria and Burkina Faso, sustainable breeding and seed systems and effective commercialisation and marketing to benefit the communities concerned. The chapter includes detailed case studies from Ghana and Malawi.

Part 3 Translating research into practice: improving cultivation in the developing world

The book's third section looks at ways of supporting smallholders in regions such as Asia, Africa and Latin America to improve potato cultivation. Chapter 11 offers an overview of potato production and breeding in China. The chapter outlines current potato production and consumption, identifying key trends and challenges. The chapter explores challenges associated with germplasm material, breeding objectives and development of new varieties, and the types of new variety available. The chapter considers the possibility of virus-free seed potato production.

The subject of Chapter 12 is the challenge of improving potato cultivation to promote food self-sufficiency in Africa. Demand for potato in sub-Saharan Africa is growing, but the projected growth in demand is not matched by the projected growth rate in local potato production. An interplay of factors ensures the production gains achieved are small and slow. The chapter reviews the current state of potato production in Africa, and the challenges it faces. The chapter describes the development and promotion of suitable potato varieties, considers crop improvement initiatives and programs, and emphasises the potential of potato to contribute to food security and poverty reduction.

The volume's final chapter, Chapter 13, addresses the importance of supporting smallholder women farmers in potato cultivation. It is clear that women farmers have a vital role to play in shaping and maximising this growth, safeguarding potatoes as a primary food security crop. The chapter offers a summary of the current state of potato cultivation and the role of women, with a focus on sub-Saharan Africa. The chapter highlights the enormous potential of women farmers in promoting the broader goals of development and food security in these areas, before examining some of the challenges women face in making their voices count. The chapter presents different strategies for supporting women smallholders, with a particular emphasis on ensuring that women benefit from agricultural training and have the opportunity to apply their knowledge and resources.

Index

- Abiotic stress improvement
 - drought stress 126–128
 - heat stress 128–129
 - salinity stress 129–130
- Ageing process in seed potatoes
 - apical dominance 41–43
 - bud activation 41
 - causes of variation in physiological age 49–50
 - crop performance result 46–49
 - dormancy 35–37, 40–41
 - importance of seed quality 38–40
 - initial sprout growth 41
 - manipulation options 49–50
 - overview 33–34
 - physiological age 37–38
 - dynamic development 46–49
 - quality characteristics 34–35
 - sprouts and mother tubers 43–46
 - difference and interaction 43–44
 - relationship between mother tuber size and physiological age 44–46
- Breeding and cultivation of sweet potato
 - breeding and seed dissemination 228–235
 - linking for sustainability 228–231
 - nutritious orange-fleshed 231–235
 - case studies 246–249
 - Ghana 248–249
 - Malawi 246–248
 - crop diversification 242–246
 - commercialisation of vines 242–243
 - markets in Ghana, Nigeria and Burkina Faso 244–246
 - cultivation and post-harvest handling 235–237
 - intercropping OFSP with maize, soya beans and onions 235–237
 - storage facilities 237
 - nutrition quality and improvement 237–242
 - OFSP storage roots 237–239
 - leaves 239
 - vitamin A content and market development 239–242
 - overview 223–224
 - programmes for improvement 224–226
 - breeding and crop development 224–225
 - farmer-participatory selection 226
 - key research developments 225–226
 - provitamin A-rich OFSP 227–228
 - utilization and culinary attributes 226
- Conventional potato-breeding techniques
 - overview 81–82
 - parental line selection 82–85
 - breeding values 84
 - combining ability 82
 - mid-parent and mid-self values 84–85
 - progeny test 82–84
 - progeny selection 85–89
 - diploid progenies and use of 4x × 2x test crosses 86
 - genetic divergence 85–86
 - individual clone selection 87–88
 - in vitro selection 88–89
 - speed and success rate of selection 89–92
 - microtubers 89
 - molecular markers in aid of phenotypic selection 91–92
 - multi-location testing 89–91
- Crop rotation and planting
 - early growth of crop 5–6
 - production system 4–5
 - tuber initiation 6–7
- Early-maturing and stress-resistant potato varieties
 - breeding strategies 151
 - case study 153–163
 - adaptability 159–160
 - clonal selection 157–158
 - disease reaction 158–159
 - late-blight-resistant Kufri Khyati 153–157
 - multilocation trials 158
 - parental selection 157
 - quality 160
 - release 160–163
 - yield performance 158
 - dry matter partition efficiency 150
 - early tuber initiation 148–150
 - factors 150–151
 - cultivar maturity/growing degree days (GDDs) 150–151
 - heat stress level 151
 - genetic aspects 152–153
 - germplasm and traits selection 145–146
 - overview 143–145
- Food self-sufficiency in Africa
 - development and poverty alleviation 280
 - overview 271–272
 - production and challenges 272–275
 - system and programs to support production 278–280
 - National Agricultural Research Programmes and Support 279–280
 - supply and delivery systems 278–279
 - variety development and promotion 275–278

- Genetic diversity of potatoes
 - enhancement of potato genetic material 70–71
 - evaluation of potato genetic material 69–70
 - legal custody and access 71–73
 - overview 57–62
 - basic genebank mission 58–59
 - comprehensive genebank services 62
 - genebank services 61
 - germplasm consideration 60–61
 - special consideration 59–60
 - potato genetic material 65–67
 - cogs 67
 - core collections 67
 - taxonomic classification 65–66
 - preservation of potato genetic material 67–69
 - DNA markers for assessing diversity 68–69
- Hybrid potato breeding
 - case studies 113–116
 - East Africa 114–116
 - Phytophthora infestans* 113–114
 - cropping system based on true seeds 111–113
 - production of seedling for commercial crop 112
 - production of seedling tubers in greenhouse 111–112
 - production of seed tubers 112–113
 - seedling tubers as starting materials 112
 - inbred lines of genetic research 108–111
 - genetic studies in segregating diploid F_2 population 110–111
 - homozygous self-compatible diploid 109–110
 - market-assisted backcrossing 111
 - overview 99–101
 - production and commercialization 107–108
 - scientific basis 101–104
 - crossable diploid species 103
 - diploid potatoes perform equal to tetraploids 103–104
 - diploids more efficient than tetraploids 101
 - genetic reservoir for diploid breeding 103
 - genetic variation causes inbreed depression 102–103
 - homozygous diploid potato genotypes 102
 - principle 101
 - state of art 104–107
- Nutritional properties of potatoes
 - carotenoids 201–202
 - glycoalkaloids 205–207
 - biosynthesis and regulation 206–207
 - overview 191–193
 - potassium 201
 - potato phenylpropanoids 202–205
 - biosynthesis and regulation 204–205
 - environmental effects 205
 - tuber 203–204
 - vitamin B family 193–199
 - folic acid (vitamin B_9) 198–199
 - niacin (vitamin B_3) 195–196
 - pantothenic acid (vitamin B_5) 196
 - pyridoxine (vitamin B_6) 197–198
 - thiamine/thiamin (vitamin B_1) 193–195
 - vitamin C 199–201
- Potato plant physiology and growth
 - additional factors affecting sustainable production 18–20
 - physiological tolerance of pests and pathogens 18
 - post-harvest storage 18–19
 - yield stability 19–20
 - crop rotation, planting, initial crop development 4–7
 - early growth of crop 5–6
 - production system 4–5
 - tuber initiation 6–7
 - development 7–12
 - architecture of shoot system 8–9
 - canopy growth period 9–11
 - carbon assimilation and distribution 7–8
 - light interception and tuber yield 8
 - root architecture 11–12
 - overview 3
 - responses to nutrient availability 16–18
 - nitrogen use efficiency 16–17
 - potassium, phosphorous and calcium 17–18
 - responses to water and heat stress 13–16
 - heat stress 15–16
 - tuber quality defects 14–15
 - water deficits 12–14
- Potato production and breeding in China
 - germplasm material 263–264
 - key trends and challenges 262–263
 - objectives and development 264–265
 - overview 259–260
 - production and consumption 260–262
 - types of new variety 265–266
 - virus-free seed potato 266–268
- Potato varieties resistant
 - abiotic stress improvement 126–130
 - drought stress 126–128
 - heat stress 128–129
 - salinity stress 129–130
 - overview 125–126
 - technological advances 130–135
 - gene expression regulators 133–135

- genetic engineering approaches 132–133
- genomic tools and techniques 130–131
- phenotyping 132
- Smallholder women farmers
 - challenges 288–289
 - importance 285–287
 - overview 285
 - role of women 287–288
 - strategies 289–291
- Sweet potato
 - in Africa
 - breeding and seed dissemination 228–235
 - case studies 246–249
 - crop diversification 242–246
 - cultivation and post-harvest handling 235–237
 - nutrition quality and improvement 237–242
 - overview 223–224
 - programmes for improvement 224–226
 - varieties development
 - genetic transformation from model to farmer-preferred cultivars 171–174
 - overview 169–171
 - production of disease-resistant 174–177
 - purple sweet potato with increased anthocyanin content 183–184
 - resistant to abiotic stresses 177–180
 - starch modification for industrial application 180–181
 - storage root development for better yield 181–183