Achieving sustainable cultivation of potatoes

Volume 1: Breeding improved varieties

Edited by Professor Gefu Wang-Pruski
Dalhousie University, Canada
# Contents

Series list 
Acknowledgement
Introduction

## Part 1  Plant physiology and breeding

1  Advances in understanding potato plant physiology and growth  
   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  
   1  Introduction  
   2  Crop rotation, planting and initial crop development  
   3  Development of the potato plant  
   4  Potato responses to water and heat stresses  
   5  Potato responses to nutrient availability  
   6  Additional factors affecting sustainable production  
   7  Summary  
   8  Future trends  
   9  Where to look for further information  
  10  References

2  Understanding ageing processes in seed potatoes  
   Paul C. Struik, Wageningen University and Research, The Netherlands  
   1  Introduction: seed tubers as the main propagules in potato production  
   2  Quality characteristics of seed tubers  
   3  Dormancy and physiological age  
   4  The importance of seed quality as a yield-limiting and quality-determining factor  
   5  Understanding dormancy, bud activation, initial sprout growth and apical dominance  
   6  Understanding ageing in sprouts and mother tubers  
   7  Analysis of the dynamic development of physiological age and resulting crop performance  
   8  Causes of variation in physiological age and options for manipulation  
   9  Summary and future trends  
  10  Where to look for further information  
  11  References

3  Ensuring the genetic diversity of potatoes  
   John Bamberg and Shelley Jansky, USDA-ARS, USA; Alfonso del Rio, University of Wisconsin-Madison, USA; and Dave Ellis, International Potato Center (CIP), Peru  
   1  Introduction  
   2  Acquisition of potato genetic material
### Part 2 Improving particular traits

6 Advances in development of potato varieties resistant to abiotic stress  
**Ankush Prashar and Filipe de Jesus Colwell, Newcastle University, UK; and Csaba Hornyik and Glenn J. Bryan, The James Hutton Institute, UK**  
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  
**Prashant G. Kawar, 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**  
1 Classification of potato genetic material 65  
2 Preservation of potato genetic material 67  
3 Evaluation and enhancement of potato genetic material 69  
4 Legal custody and access to potato genetic material 71  
5 Conclusion and future trends 73  
6 Where to look for further information 75  
7 References 75

### Contents

- Advances in conventional potato-breeding techniques  
  **Jai Gopal, ICAR-Central Potato Research Institute, India**  
  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

- Hybrid potato breeding for improved varieties  
  **Pim Lindhout, Michiel de Vries, Menno ter Maat, Su Ying, Marcela Viquez-Zamora and Sjaak van Heusden, Solynta, The Netherlands**  
  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

© Burleigh Dodds Science Publishing Limited, 2018. All rights reserved.
Research, India; and Vinay Bhardwaj, B. P. Singh, P. M. Govindakrishnan and S.K. Chakrabarti, ICAR-Central Potato Research Institute, India

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
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

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
Duroy A. Navarre, Washington State University and USDA-ARS, USA; and M. Moehninsi, Sen Lin and Hanjo Hellmann, Washington State University, USA

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

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

| 11 | Potato production and breeding in China                             | 259 |
| Liping Jin, Chinese Academy of Agricultural Sciences, China |
| 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 | 271 |
| Moses Nyongesa and Nancy Ng’ang’a, Kenya Agricultural and Livestock Research Organization, Kenya |
| 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           | 285 |
| Linley Chiwona-Karlton, Swedish University of Agricultural Sciences, Sweden; Maryanne Wamahi, Stockholm University, Sweden; Chikondi Chabvuta, |
Contents

	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
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 F2 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 B12) 198–199
niacin (vitamin B3) 195–196
pantothenic acid (vitamin B5) 196
pyridoxine (vitamin B6) 197–198
thiamine/thiamin (vitamin B1) 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
eye 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