Millets and Sorghum
Millets and Sorghum

Biology and Genetic Improvement

J.V. Patil
Contents

List of Contributors  xvii
Preface  xix
Introduction: Millets – The Miracle Grains  xxi
C. Aruna Reddy

1  Sorghum, *Sorghum bicolor* (L.) Moench  1
   P. Sanjana Reddy
   1.1  Introduction  1
   1.2  Origin and Taxonomy  1
   1.3  Germplasm Resources and Utilisation  2
   1.4  Genetics and Cytogenetics  4
      1.4.1  Cytogenetics  5
   1.5  Reproductive Biology  5
   1.6  Production Constraints  7
   1.7  Breeding Objectives  7
      1.7.1  Grain Sorghum  8
      1.7.1.1  Breeding for Yield  8
      1.7.1.2  Breeding for Abiotic Stress Resistance  9
      1.7.1.3  Breeding for Biotic Stress Resistance  15
      1.7.1.4  Breeding for Grain Quality  19
      1.7.2  Forage Sorghum  21
      1.7.3  Sweet Sorghum  23
   1.8  Sorghum Improvement Across Diverse Parts of the World  24
      1.8.1  Sorghums of India  24
         1.8.1.1  Rainy / kharif Sorghum  24
         1.8.1.2  Post-rainy / winter Sorghum  25
         1.8.1.3  International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)  28
      1.8.2  Sub-Saharan Africa  30
      1.8.3  Western and Central Africa (WCA)  30
      1.8.4  Eastern and Southern Africa (ESA)  30
      1.8.5  Latin America  31
      1.8.6  China  32
   1.9  Future Prospects  32
   References  33
2 **Pearl Millet, Pennisetum glaucum (L.) R. Br.** 49

*P. Sanjana Reddy*

2.1 Introduction 49
2.2 Origin and Taxonomy 51
2.2.1 Taxonomy 51
2.2.2 Origin 51
2.3 Genetic Resources 52
2.3.1 Genetic Diversity 53
2.3.2 Germplasm Utilisation 53
2.4 Genetics of Important Traits 55
2.4.1 Quantitative Traits 55
2.4.1.1 Gene Effects 56
2.4.2 Qualitative Traits 57
2.5 Morphology and Reproductive Biology 58
2.6 Selfing and Crossing 59
2.7 Breeding Methods 60
2.8 Cultivar Development 62
2.8.1 Open Pollinated Varieties 62
2.8.2 Hybrids 63
2.9 CMS Systems in Pearl Millet 64
2.10 Production Constraints 65
2.10.1 Breeding for Abiotic Stresses 65
2.10.1.1 Drought 65
2.10.1.2 Heat Tolerance 70
2.10.2 Breeding for Biotic Stress Resistance 71
2.10.2.1 Downy Mildew (DM) 71
2.10.2.2 Other Biotic Constraints 72
2.11 Grain Quality 73
2.12 Alternate Uses of Pearl Millet 73
2.13 Future Research Thrust Areas 74
References 75

3 **Improvement in Finger Millet: Status and Future Prospects** 87

*K.N. Ganapathy*

3.1 Introduction 87
3.2 Area Production and Productivity 87
3.3 Origin and Domestication 88
3.4 Botanical Features and Breeding Behaviour 89
3.4.1 Botanical Classification 89
3.4.2 Botanical Description 89
3.4.3 Floral Biology and Breeding Behaviour 90
3.5 Emasculation and Pollination Techniques 90
3.5.1 Hand Emasculation 90
3.5.2 Hot-water Treatment 91
3.5.3 Gametocide-induced Male Sterility 91
3.5.4 Use of Genetic Male Sterility 91
3.6 Genetics of Traits 91
3.7 Gene Pool of Eleusine coracana 93
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7.2 Recombination Breeding</td>
<td>130</td>
</tr>
<tr>
<td>4.7.3 Heterosis Breeding and Male Sterility</td>
<td>130</td>
</tr>
<tr>
<td>4.7.4 Disease Resistance Breeding</td>
<td>131</td>
</tr>
<tr>
<td>4.8 Breeding Efforts in the United States</td>
<td>131</td>
</tr>
<tr>
<td>4.9 Breeding Efforts in China</td>
<td>132</td>
</tr>
<tr>
<td>4.10 Breeding Efforts in India</td>
<td>133</td>
</tr>
<tr>
<td>4.10.1 Improved Varieties</td>
<td>134</td>
</tr>
<tr>
<td>4.11 New Tools for Genetic Improvement</td>
<td>135</td>
</tr>
<tr>
<td>4.12 Future Prospects</td>
<td>140</td>
</tr>
<tr>
<td>References</td>
<td>140</td>
</tr>
</tbody>
</table>

## 5 Proso Millet, *Panicum miliaceum* (L.): Genetic Improvement and Research Needs

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<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Introduction</td>
<td>150</td>
</tr>
<tr>
<td>5.2 Origin and Taxonomy</td>
<td>150</td>
</tr>
<tr>
<td>5.3 Botany and Reproductive Biology</td>
<td>151</td>
</tr>
<tr>
<td>5.3.1 Roots</td>
<td>152</td>
</tr>
<tr>
<td>5.3.2 Stem/Culm</td>
<td>152</td>
</tr>
<tr>
<td>5.3.3 Leaves</td>
<td>152</td>
</tr>
<tr>
<td>5.3.4 Panicle</td>
<td>152</td>
</tr>
<tr>
<td>5.3.5 Seed</td>
<td>152</td>
</tr>
<tr>
<td>5.4 Growth and Development</td>
<td>153</td>
</tr>
<tr>
<td>5.5 Cytogenetics</td>
<td>153</td>
</tr>
<tr>
<td>5.6 Genetic Resources and Utilisation</td>
<td>155</td>
</tr>
<tr>
<td>5.7 Genetic Improvement of Proso Millet: Achievements and Status</td>
<td>158</td>
</tr>
<tr>
<td>5.7.1 India</td>
<td>158</td>
</tr>
<tr>
<td>5.7.2 United States</td>
<td>158</td>
</tr>
<tr>
<td>5.7.3 Russia</td>
<td>158</td>
</tr>
<tr>
<td>5.7.4 China</td>
<td>161</td>
</tr>
<tr>
<td>5.7.5 Kenya</td>
<td>162</td>
</tr>
<tr>
<td>5.8 Breeding Objectives and Research Strategies</td>
<td>163</td>
</tr>
<tr>
<td>5.8.1 Development and Evaluation of Core Sets for Biotic and Abiotic Stresses as well as Quality Traits</td>
<td>163</td>
</tr>
<tr>
<td>5.8.2 DUS Characterisation of Varieties</td>
<td>163</td>
</tr>
<tr>
<td>5.8.3 Identification of Location and Trait-Specific Germplasm for Utilisation in Crop Improvement</td>
<td>163</td>
</tr>
<tr>
<td>5.8.4 Development of Varieties with Abiotic and Biotic Stress Tolerance/ Resistance</td>
<td>163</td>
</tr>
<tr>
<td>5.8.5 Developing Lodging- and Shattering-Resistant Varieties</td>
<td>164</td>
</tr>
<tr>
<td>5.8.6 Development of Varieties with Early Vigour and Short Duration</td>
<td>164</td>
</tr>
<tr>
<td>5.8.7 Identification of Elite Germplasm and Varieties with Superior Nutritional Traits and Bio-Fortification of Existing Elite Lines</td>
<td>164</td>
</tr>
<tr>
<td>5.8.8 Grain Quality Improvement</td>
<td>164</td>
</tr>
<tr>
<td>5.8.9 Protein Content and Quality</td>
<td>165</td>
</tr>
<tr>
<td>5.8.10 Inducing Cytoplasm Genetic Male Sterility</td>
<td>165</td>
</tr>
<tr>
<td>5.8.11 Wide Hybridisation</td>
<td>165</td>
</tr>
</tbody>
</table>
5.8.12 Improved Plant Type with High Harvest Index (HI) 165
5.8.13 Breeding Varieties for Intensive Cultivation and Suitable for Mechanical Harvesting 166
5.9 Future Prospects 166
References 166

6 Genetic Improvement in Little Millet 170
K.N. Ganapathy
6.1 Introduction 170
6.2 Floral Biology 171
6.3 Cytogenetics and Morphological Variation in the Genus 172
6.4 Improvement in Little Millet 173
6.4.1 Genetic Variability 174
6.4.2 Germplasm Variability for Various Economic Traits 174
6.4.3 Varietal Improvement 176
6.4.4 Improvement in Grain Smut Resistance 176
6.4.5 Drought-Tolerance Studies 179
6.4.6 Nutritional Improvement 180
6.4.7 Mutational Approaches 180
6.5 Critical Research Gaps 181
6.6 Strategies for Genetic Improvement 181
References 182

7 Barnyard Millet: Present Status and Future Thrust Areas 184
Sunil Shriram Gomashe
7.1 Introduction 184
7.2 Nutritional Composition and Food Value 184
7.3 Origin and Taxonomy 185
7.4 Reproductive Biology 186
7.4.1 Roots 186
7.4.2 Stem/Culm 186
7.4.3 Leaves 186
7.4.4 Panicle 186
7.4.5 Seed 186
7.4.6 Floral Biology 188
7.5 Cytogenetics 188
7.6 Genetic Resources and Utilisation 189
7.7 Breeding Objectives 191
7.7.1 Development and Evaluation of Core Collections 194
7.7.2 Exploitation of the Wild Relative Gene Pool 194
7.7.3 Breeding for Waxy Endosperm Genotypes 195
7.7.4 Breeding for Pests and Diseases 195
7.7.5 Breeding for Dual-Purpose Genotypes (Grain and Stover) 195
7.7.6 Breeding for Genotypes Suitable for Mechanical Harvesting and Post-Harvest Processing 195
7.8 Future Prospects 196
References 196
8 **Kodo Millet, *Paspalum scrobiculatum* L.** 199

8.1 Introduction 199
8.2 Origin and Taxonomy 201
8.2.1 Origin and Distribution 201
8.2.2 Taxonomy 202
8.2.3 Chromosome Number 203
8.3 Germplasm Resources and Utilisation 204
8.5 Genetics and Cytogenetics 206
8.5.1 Genetic Studies 206
8.5.2 Genetic Diversity 206
8.5.3 Genetic Variability 206
8.5.4 Correlation Studies 207
8.5.5 Cytogenetics 208
8.6 Reproductive Biology 208
8.6.1 Morphology and Floral Biology 208
8.6.2 Flowering Behaviour 210
8.7 Breeding Objectives 211
8.7.1 Agronomic Traits 211
8.7.2 Biotic and Abiotic Factors 211
8.8 Breeding Methods 212
8.8.1 Introduction and Selection 213
8.8.2 Pure-Line Selection 213
8.8.3 Recombination Breeding 213
8.8.3.1 Natural Hybridisation 213
8.8.3.2 Controlled Hybridisation 214
8.8.3.3 Contact Method of Hybridisation 214
8.8.4 Mutation Breeding 214
8.8.5 Improved Varieties 214
8.9 New Tools for Genetic Improvement 215
8.10 Future Prospects 219
References 219

9 **Tef, *Eragrostis tef* (Zucc.) Trotter** 226

9.1 Introduction 226
9.2 Origin and Taxonomy 227
9.2.1 Origin 227
9.2.2 Taxonomy 230
9.3 Genetic Resources and Utilisation 232
9.3.1 Genetic Resources of Tef 232
9.3.2 Utilisation of Tef Genetic Resources 232
9.4 Genetics and Cytogenetics 236
9.4.1 Genetics of Qualitative Traits 236
9.4.1.1 Lemma Colour 236
9.4.1.2 Seed Colour 236
9.4.1.3 Panicle Form 236
9.4.2 Genetics of Quantitative Traits 236
10.1.2.4 Sucking Pests 274
10.1.2.5 Other Pests 274
10.1.3 Finger Millet 274
10.1.3.1 Root Feeders 274
10.1.3.2 Shoot and Stem Feeders 274
10.1.3.3 Leaf Feeders 275
10.1.4 Foxtail Millet 275
10.1.4.1 Shoot Fly, Atherigona atripalpis 275
10.1.4.2 Other Important Pests 275
10.1.5 Kodo Millet 275
10.1.5.1 Shoot Fly, Atherigona simplex 275
10.1.5.2 Other Pests 275
10.1.6 Proso Millet 275
10.1.6.1 Shoot fly, Atherigona pulla 275
10.1.6.2 Other Pests 276
10.1.7 Little Millet 277
10.1.7.1 Shoot Fly, Atherigona miliaceae 277
10.1.7.2 Other Pests 277
10.1.8 Barnyard Millet 277
10.1.8.1 Shoot Fly, Atherigona falcata 277
10.1.8.2 Other Pests 277
10.2 Host-Plant Selection by Insect Pests 277
10.2.1 Host Preferences 279
10.2.2 Mechanisms of Host Plant Resistance 281
10.2.3 Antixenosis 281
10.2.4 Antibiosis 282
10.2.5 Tolerance 283
10.2.6 Sources of Insect Resistance 283
References 284

11 Millet Diseases: Current Status and Their Management 291
I.K. Das
11.1 Introduction 291
11.2 Sorghum Diseases 291
11.2.1 Grain mould 292
11.2.2 Anthracnose 294
11.2.3 Downy Mildew 295
11.2.4 Ergot or Sugary Disease 297
11.2.5 Rust 298
11.2.6 Leaf Blight 299
11.2.7 Leaf Spots 300
11.2.8 Smuts 301
11.2.9 Charcoal Rot 302
11.2.10 Viral Diseases 303
11.3 Pearl Millet Diseases 305
11.3.1 Downy Mildew 305
11.3.2 Blast 307
11.3.3 Ergot 308
11.3.4 Smut 309
11.3.5 Rust 309
11.4 Small Millet Diseases 310
11.4.1 Blast 310
11.4.2 Leaf Spots 312
11.4.3 Smut 313
11.4.4 Rust 313
11.4.5 Downy Mildew 314
11.4.6 Udbatta 314
References 314

12 Nutritional Qualities & Value Addition of Millets 323
C.V. Ratnavathi
12.1 Introduction 323
12.2 Sorghum 324
12.3 Pearl Millet 326
12.4 Finger Millet 327
12.4.1 Essential Amino Acid Composition (mg/g) and Chemical Score of Sorghum and Millet Proteins 328
12.5 Other Millets 328
12.6 Health Benefits of Millets 336
12.7 Conclusion 337
References 337

13 Molecular Markers for the Genetic Improvement of Millets 341
P. Rajendrakumar
13.1 Introduction 341
13.2 Sorghum 342
13.2.1 Genetic Diversity 342
13.2.1.1 Functional Diversity 343
13.2.1.2 Core and Reference Collections 343
13.2.2 Molecular Marker Resources 343
13.2.3 Genetic Maps 345
13.2.4 QTL Mapping 346
13.2.4.1 Phenology 346
13.2.4.2 Grain Yield and Its Components 348
13.2.4.3 Insect Resistance 349
13.2.4.4 Disease Resistance 349
13.2.4.5 Resistance to Weed 351
13.2.4.6 Drought Tolerance 351
13.2.4.7 Cold Tolerance 351
13.2.5 Marker-Assisted Selection (MAS) 353
13.3 Pearl Millet 354
13.3.1 Genetic Diversity 354
13.3.1.1 Core and Reference Collections 355
13.3.2 Molecular Marker Resources 355
13.3.3 Genetic Maps 356
13.3.4 QTL Mapping 357
13.3.4.1 Phenology and Morphological Traits 357
13.3.5 Marker-Assisted Selection (MAS) 360
13.4 Finger Millet 361
13.4.1 Genetic Diversity 361
13.4.1.1 Core and Reference Collections 362
13.4.2 Molecular Marker Resources 362
13.4.3 Genetic Maps, QTL Mapping and Marker-Assisted Selection (MAS) 363
13.5 Foxtail Millet 364
13.5.1 Genetic Diversity 364
13.5.1.1 Core and Reference collections 365
13.5.2 Molecular Marker Resources 365
13.5.3 Genetic Maps 366
13.5.4 QTL Mapping 368
13.6 Other Small Millets 369
13.6.1 Genetic Diversity 370
13.6.1.1 Core collections 371
13.6.2 Molecular Marker Resources, Mapping and Marker-Assisted Selection 372
13.7 Progress of Molecular Marker Research in Millets 372
13.8 Future Prospects 373

References 374

14 Strategies to Build Sustainable Millet Seed Systems 395
Vilas A. Tonapi and Ch. Ravinder Reddy
14.1 Introduction 395
14.2 Factors Leading to Sustainable Seed Security 397
14.2.1 Overview of Seed Systems 397
14.2.1.1 Formal Seed Systems 397
14.2.1.2 Informal Seed Systems 398
14.2.2 Seed Sources for Informal and Formal Seed Systems 398
14.2.3 Challenges for Seed Sector in Marginal Environments 399
14.2.4 Indian Scenario 399
14.2.5 Barriers to Seed Dissemination and Socio-Economic Constraints 401
14.2.5.1 Sound Informal Seed Systems: Most Suitable for Dry Land Ecosystems 402
14.2.5.2 Sustaining Viability of Informal Systems with Innovative Seed Delivery Models 402
14.2.5.3 Alternate Village-Based Seed Delivery Models 403
14.2.5.4 Small-Scale Seed Enterprises Models 405
14.3 Developing a Community-Based Millet Seed System 409
14.3.1 Steps for Strengthening Community Seed Production, Seed Saving and Storage 409
14.3.2 Seed Production 410
14.3.3 Seed Certification 410
14.3.4 Seed Storage 411
14.3.5 Developing a Community Seed Programme 412
14.3.6 Steps in Developing a Community Seed-System Module 412
14.3.6.1 Reconnaissance Survey 412
14.3.6.2 Participatory Selection of Crops/Varieties 412
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.3.6.3 Selection of Seed Growers</td>
<td>413</td>
</tr>
<tr>
<td>14.3.6.4 Capacity Building</td>
<td>413</td>
</tr>
<tr>
<td>14.3.6.5 Procurement of the Basic Seed and Distribution</td>
<td>413</td>
</tr>
<tr>
<td>14.3.6.6 Formation of Seed Growers’ Association</td>
<td>414</td>
</tr>
<tr>
<td>14.3.6.7 Seed Marketing</td>
<td>414</td>
</tr>
<tr>
<td>14.4 The Alternative Integrated Seed-System Model</td>
<td>415</td>
</tr>
<tr>
<td>14.4.1 Step 1</td>
<td>415</td>
</tr>
<tr>
<td>14.4.2 Step 2</td>
<td>416</td>
</tr>
<tr>
<td>14.4.3 Sensitising Stakeholders</td>
<td>416</td>
</tr>
<tr>
<td>14.4.4 Formation of Village Seed Bank Committees</td>
<td>416</td>
</tr>
<tr>
<td>14.4.5 Farmer-Participatory Selection of Varieties</td>
<td>418</td>
</tr>
<tr>
<td>14.4.6 Capacity Building</td>
<td>418</td>
</tr>
<tr>
<td>14.4.7 Institutional Linkages</td>
<td>419</td>
</tr>
<tr>
<td>14.4.8 Funding</td>
<td>419</td>
</tr>
<tr>
<td>14.4.9 Advantages of Village Seed Banks</td>
<td>420</td>
</tr>
<tr>
<td>14.4.10 Constraints of Village Seed Banks</td>
<td>421</td>
</tr>
<tr>
<td>14.5 Need for a Policy Framework to Build a Viable Local Seed System</td>
<td>421</td>
</tr>
<tr>
<td>14.5.1 The Role NARS Has to Play in Strengthening the Community Seed</td>
<td>422</td>
</tr>
<tr>
<td>14.5.2 The Role of the State and the Central Agencies</td>
<td>423</td>
</tr>
<tr>
<td>14.5.3 The Role of Public/Private Partnership in Local Seed Availability</td>
<td>423</td>
</tr>
<tr>
<td>14.5.4 Identification of the Components for Village-Based or Community</td>
<td>423</td>
</tr>
<tr>
<td>14.5.5 Strengthening Stakeholders of Community Seed Systems</td>
<td>425</td>
</tr>
<tr>
<td>14.5.6 Interventions Required for Developing Informal Seed Systems</td>
<td>426</td>
</tr>
<tr>
<td>14.6 Conclusion</td>
<td>428</td>
</tr>
<tr>
<td>References</td>
<td>429</td>
</tr>
</tbody>
</table>

**Index** 431
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Preface

Sorghum and millets – pearl millet, finger millet, foxtail millet, kodo millet, proso millet, barnyard millet, little millet, teff millet, etc. – are the main sources of food and fodder for millions of people living in the semi-arid and arid regions of the world. They are the primary sources of dietary fibre, energy, protein, vitamins and minerals for the poor people inhabiting these regions. The growing environments of these crops are characterized by low and erratic rainfall, poor soil fertility, poor agronomic practices, disease and insect pressure and abiotic stress factors such as heat, drought and soil salinity. These crops are grown under marginal conditions unsuitable for various other high-input commercial crops.

The research and development in sorghum and pearl millet is much more advanced as compared to other millets. With the cytoplasmic–nuclear male sterility (CMS) system in place, successful development and spread of hybrids have occurred in both these crops. Small millets in India are a group of six crops such as finger millet, foxtail millet, kodo millet, proso millet, barnyard millet and little millet. After years of neglect, small millets are finding a place in agricultural research agendas in many institutions in India. Doctors and nutritionists are increasingly recommending them as important in health management. Germplasm availability has vastly improved with the launch of the All India Coordinated Small Millets Improvement Project. More than 15,000 accessions of various small millets are now conserved. However, the rate of genetic advancement being made now, barring in finger millet, is slow in all small millets. Demand-driven crop improvement is the current thrust area. Also, millets, being climate-smart crops, have a significant role to play in the current climate change scenario to provide food, feed, fodder and nutritional security to the dryland poor. Teff is a very important millet grown in Ethiopia, accounting for 30% of acreage. Crop improvement has been very slow, and most of the area is under landraces.

It is felt that a review of research in sorghum and millets would help identify the focus areas of research for the reorientation of millets – from a forgotten crop to a smart and nutritious crop. Millets and Sorghum is designed to fulfil this requirement. The book has 14 chapters. The first chapter gives an overview of all the crops. The next nine chapters on individual crops – sorghum, pearl millet, finger millet, foxtail millet, proso millet, little millet, barnyard millet, kodo millet and teff millet – deals with the origins, available genetic resources, genetics, reproduction biology, production constraints, improvement techniques and achievements in each of these crops. Diseases – especially grain mould in sorghum, downy mildew in pearl millet and blast in other millets – play an important role in reducing yield in millets. The research that has been undertaken in enhancing resistance is discussed in a separate chapter on diseases. Except sorghum,
insect pests are not a major problem in millets, though incidences of few of them are reported on a small scale. Several pests – such as shoot fly, stem borer, aphids, shoot bug, midge, head bugs, etc. – cause yield losses in sorghum. The chapter on insect pests covers the research that has taken place in deploying insect resistance. Sorghum and millets are renowned for their nutritional benefits. Their nutritional profile and marketing aspects are discussed in a separate chapter. Biotechnology has emerged as a new tool for increasing the precision of plant breeding. Chapter 13 deals with the progress of biotechnology in sorghum and pearl millet, and its initiation in small millets. The success of plant breeding will not make any difference to the average yields of the region unless it is backed by an efficient seed production program. The private seed industry in sorghum and pearl millet is a success story in India mainly due to the availability of hybrid technology. However, there are still several issues to be addressed in these two crops and new strategies to be developed for sustainable seed systems in small millets. These are discussed in Chapter 14 on seed systems.

I am extremely grateful to all the authors and take this opportunity to sincerely thank them for their active cooperation and contribution in this book. I also extend my gratitude to several others who played important roles in the completion of this assignment and for their encouragement – noteworthy among these are T. Mohapatra (DG, ICAR), S. K. Datta (former DDG, Crop Science, ICAR) and J. S. Sandhu (DDG, Crop Science, ICAR). I also gratefully acknowledge the help received from Harshal Gawali in photography, and the secretarial assistance received from N. Kanak Durga, Sanath Kumar and Raghendra Rao. I hope the book will create better awareness of the research and development needs and explore the potential of sorghum and millets for the future. I also hope that Millets and Sorghum will prove to be a valuable reference book for students, teachers and researchers interested in the research and development of these smart crops.

J. V. Patil
Introduction

Millets – The Miracle Grains
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Sorghum and millets are among the important sources of staple diet in the semi-arid tropic regions of Asia and Africa. Millets comprise of an important group of cereal crops known for their nutritional values. They are gaining importance in a world that is increasingly becoming populous and facing large climatic uncertainties. About 500 million people in more than 30 countries rely on sorghum as staple diet, and more than 90 million people in Africa and Asia depend on millets as staple diet. Sorghum and millets are very hardy and climate-smart crops suitable for environments prone to drought and extreme heat. These crops are adapted to a range of temperatures, moisture-regimes and input conditions supplying food and feed to millions of dryland farmers, particularly in the developing world. These are the major crops successfully cultivated in dry regions where fine cereals such as rice and wheat cannot be grown. The most important characteristic of sorghum and millets is their ability to tolerate and survive under conditions of continuous or intermittent drought periods that result from low or uncertain rainfall. Millets are perhaps the only cereal crop that can grow in arid lands, requiring only 350–400 mm annual rain.

The millet group includes the great millet sorghum (Sorghum bicolor (L.) Moench) and pearl millet (Pennisetum glaucum); and the small millets including finger millet (Eleusine coracana), Italian or foxtail millet (Setaria italica), common or proso millet (Panicum miliaceum), kodo millet (Paspalum scrobiculatum), little millet (Panicum miliare), barnyard millet (Echinochloa frumentacea), fonio (Digitaria exilis) and teff (Eragrostis tef). Of these, fonio and teff are confined to Africa. Other crops are important both in Asia and Africa. Millets are one of the oldest foods known to man and possibly the first cereal grain to be used as food. Millets are also unique due to their short growing season. They can develop from planted seeds to mature, ready to harvest plants in as little as 65 days.

Millets have always been the crops that can be banked upon during situations where there is a risk of famine. They offer a low but more reliable harvest relative to other crops in low-rainfall areas. Small millets are considered as coarse grains and are used as food in situations where other food grains generally cannot be raised, or purchased at economic prices. Therefore, small millets have largely remained as the food of the poor and the less privileged section of the population. The outer tough seed coat and the characteristic flavour of these millets are the main reasons for their reduced popularity among rice- and wheat eaters (Malleshi, 1989). Except finger millet, all the small millet seeds have a slight resemblance with paddy (rough rice) in their morphological features.
and have an outer husk, bran and starchy endosperm whereas the finger millet seed coat is tightly bound with soft endosperm.

Sorghum and millets have good potential as livestock feed also in the dry zones. With modest water requirements, they have the potential to yield good grain for the farming community and substantial quantities of palatable fodder for cattle. They can make good use of any irrigation water available after the main crops have been harvested, and hence may be fitted in to more productive crop patterns. Almost all the grain produced is used as food in India and in other developing countries, whereas in the United States and other developed countries these are used mainly as feed for calves and birds. Sorghum and millets constitute a major source of energy and protein for millions of people in Asia and Africa. Millets, being nutritionally superior to rice and wheat, provide cheap proteins, minerals and vitamins to the poorest of the poor where the need for such ingredients is the maximum. Practically devoid of any grain storage pests, these small millets have indefinite storage life. The untapped grain yield coupled with nutritional superiority makes small millets the potential future food crop, particularly in the more difficult rainfed areas.

Similar to maize, sorghum and millets also offer opportunities for industrial utilisation. They form an important raw material for potable alcohol and starch production in industrialised countries. The food, fodder, feed and industrial uses of these crops make them important in the agrarian economy of the developing regions of Africa and Asia having low rainfall and limited irrigation resources. Though these cereals have been important staples in the semi-arid tropics for many centuries, there appears to be no reliable historical record of their origin or pattern of dispersion. Since they have been cultivated for so long in so many countries, mainly by smallholder cultivators, they are known by many common and vernacular names (Table 1). In some records, no distinction is made between sorghum and millets; production statistics quoted, even by international authorities, often group the cereals together.

Origin and History of Sorghum and Millets

Sorghum, *Sorghum bicolor* (L.) Moench, which is also known as great millet, belongs to the tribe Andropogonae of the grass family Poaceae. Sorghum is mainly an annual crop, although some have perennial nature in the tropics and can be harvested many times. The greatest variation in the genus Sorghum is observed in the region of the northeast quadrant of Africa comprising Ethiopia, Sudan and East Africa (Doggett, 1988). It appears that sorghum moved into Eastern Africa from Ethiopia around 200 AD or earlier, and was probably taken to India during the first millennium BC. Grain sorghum appears to have arrived in America as ‘guinea corn’ from West Africa with the slave traders about the middle of the nineteenth century.

Pearl millet, *Pennisetum glaucum*, has many names viz., spiked millet, bajra and bulrush millet (Purseglove, 1972). Pearl millet includes a number of cultivated races. It originated in the tropical Western Africa, where the greatest number of both wild and cultivated forms are found. About 2000 years ago the crop was carried to eastern and central Africa and to India, where due to its excellent tolerance to drought it became established in the drier environments.

Finger millet, *Eleusine coracana* L., is an important staple food in parts of eastern and central Africa and India. It is an old tropical cereal widely grown in eastern Africa and south Asia. It first occurs in the archaeological records of early African agriculture
dating back to around 3000 years, and was introduced to India at least 3000 years ago. It can be stored for long periods without insect damage (Purseglove, 1972) and thus important during famine. In India and Africa, two groups are recognised: African highland types with grains enclosed within the florets; and Afro-Asiatic types with mature grains exposed outside the florets. Uganda is the centre of origin of this crop.

Foxtail millet, *Setaria italica* L., is also known as Italian millet. Its origin is considered to be in eastern Asia, where it has been cultivated since ancient times. The main cultivation areas are China, Japan and India (Purseglove, 1972). Foxtail millet was also found in the early agricultural sites in Switzerland and Austria dating back to around 3000 years.

Kodo millet, *Paspalum scrobiculatum* L., is another indigenous cultivated cereal especially of India. The species is widely distributed in damp habitats across the tropics and subtropics of the world. The species could have been domesticated anywhere across its natural range extending from Europe to Japan. It has been grown in China for at least 5000 years (Ho, 1975).

Common millet, *Panicum miliaceum* L., also known as proso millet, hog millet, broomcorn millet, Russian millet and brown corn, is of ancient cultivation, and is believed to have been domesticated in central and eastern Asia. The progenitor of broomcorn millet

<table>
<thead>
<tr>
<th>Crop</th>
<th>Scientific name</th>
<th>Common names</th>
<th>Place of origin</th>
<th>Chromosome no.</th>
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<tr>
<td>Sorghum</td>
<td><em>Sorghum bicolor</em></td>
<td>Great millet, guinea corn, kafir corn, aura, mtama, jowar, cholam, kaoliang, milo, milo-maize</td>
<td>Northeast Africa (Ethiopia–Sudan border)</td>
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</tr>
<tr>
<td>Pearl millet</td>
<td><em>Pennisetum glaucum</em></td>
<td>Cumbu, spiked millet, bajra, bulrush millet, candle millet, dark millet</td>
<td>West Africa</td>
<td>2n=14 (2x)</td>
</tr>
<tr>
<td>Finger millet</td>
<td><em>Eleusine coracana</em></td>
<td>African millet, koracan, ragi, wimbi, bulo, telebun</td>
<td>East Africa, India</td>
<td>2n=36 (4x)</td>
</tr>
<tr>
<td>Foxtail millet</td>
<td><em>Setaria italica</em></td>
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<td>Proso millet</td>
<td><em>Panicum miliaceum</em></td>
<td>common millet, hog millet, broomcorn millet, Russian millet, brown corn</td>
<td>Central and eastern Asia</td>
<td>2n=36 (4x)</td>
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<tr>
<td>Barnyard millet</td>
<td><em>Echinochloa frumentacea</em></td>
<td>Indian barnyard millet, sawa millet, Japanese barnyard millet</td>
<td>India, Japan</td>
<td>2n=54 (6x)</td>
</tr>
<tr>
<td>Kodo millet</td>
<td><em>Paspalum scrobiculatum</em></td>
<td>Kodo millet</td>
<td>India</td>
<td>2n=40 (4x)</td>
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<tr>
<td>Little millet</td>
<td><em>Panicum sumatrense</em></td>
<td>Little millet</td>
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<td>Teff</td>
<td><em>Eragrostis tef</em></td>
<td>Teff, lovegrass, annual bunch grass, Ethiopia warm season annual bunch grass</td>
<td>Ethiopia</td>
<td>2n=40 (4x)</td>
</tr>
<tr>
<td>Fonio</td>
<td><em>Digitaria exilis</em></td>
<td>Fonio, hungry rice, white fonio (En.), fonio blanc, petit mil</td>
<td>West Africa</td>
<td>2n=54</td>
</tr>
</tbody>
</table>

*Source: Sorghum and millets in human nutrition, FAO 1995.*
is native to Manchuria. The species was introduced into Europe as a cereal at least 3000 years ago. Spikelets and florets of broomcorn millet were found together with remains of foxtail millet in the early farming sites of the European Neolithic.

Little millet, *Panicum sumatrense* Roth, is grown throughout India to a limited extent up to altitudes of 2100 m. The seeds of little millet are smaller than those of common millet. Barnyard, Japanese barnyard or sawa millet (*Echinochloa frumentacea* (L.) Link) is the fastest growing of all millets and produces a crop in six weeks. It is mainly grown in India, Japan and China.

**Millets – the Climate-Smart Crops**

Most of the small millets, particularly little-, proso- and foxtail millets mature early and, therefore, provide one first harvest for human consumption. These are traditionally the indispensable components of the dryland farming system.

The climate change reports from across the globe have raised the threat of climate change to a whole new level, warning of sweeping consequences to life and livelihood, particularly to the world’s food supply. Most climate scenarios depict a world warmer by 2 degrees or more by 2100, predicting sharp declines in crop yield for major grains such as wheat and maize. The anticipated climate change makes the drylands a tougher environment to develop and survive in. It has been predicted that there will be a 10% increase in the world’s dryland areas with the climate change, with more variability and occurrences of short periods of extreme stresses (drought and heat) during the crop growing seasons. Some estimates suggest that with global warming, 40% of the land now used to grow maize in sub-Saharan Africa will no longer be able to support that crop by the 2030s (The World Bank, 2013). This will have hugely disruptive implications for livelihoods and lives in the semi-arid regions. In the light of changing climate, millets are considered as future crops for farming in the arid and semi-arid tropical regions.

Millets have a wide adaptation. They can withstand a certain degree of soil acidity and alkalinity, stress due to moisture and temperature, and variations in soils from heavy to sandy infertile soils. These crops are grown from sea level to an altitude of 3000 metres and with consequent variation in photoperiod from short to long days. The most attractive feature of sorghum and several of the millets is their capacity to survive and yield grain during continuous or intermittent drought stress. Sorghum can remain dormant during the periods of stress and renew growth when conditions are favourable. Sorghum is more tolerant of flooding than maize but does not grow at its best under prolonged wet conditions. Grain sorghum grows successfully on many soil types but best on medium textured, light textured or sandy soils, and less satisfactorily on clay or heavy textured soils. It tolerates medium to high pH conditions in the soil (Ross and Webster, 1970). Sorghums tolerant to low temperatures and high altitudes are gradually finding a place in Mexico, Brazil and other Latin American countries, in addition to their natural habitat in Ethiopia.

**Millet Area and Production Statistics**

Detailed area and production data of individual millets are either scanty or currently unavailable. Several kinds of millets are grown in the world, but Food and Agricultural Organization (FAO) data on area, yield and production of all millets are placed together
under the general heading of millet. Pearl millet, finger millet and proso millet account for a large proportion of the world production. Sorghum is the world’s fifth most important cereal, in terms of both production and area cultivated. All other small millets together are considered the seventh most important cereal grains. All these crops are primarily grown in agro-ecologies subjected to low rainfall and drought. Some cultivars of finger millet are adapted to high altitude conditions in Asia, largely in the foothills of the Himalayas, and in Africa (Purseglove, 1972).

**Trends in Area, Production and Productivity of Sorghum and Millets**

Sorghum is one of the main staple foods for the world’s poorest and most food-insecure people across the semi-arid tropics. Globally sorghum is cultivated on 42 million hectares (ha) to produce 62.3 million tonnes, with productivity hovering around 1.5 tonnes per hectare (FAO stat, 2014). Table 2 provides data on area, yield and production of sorghum in various regions of the world, which shows that Africa followed by Asia and America are the largest producers of sorghum, while 95% of world’s millet area lie in

<table>
<thead>
<tr>
<th>Region</th>
<th>Sorghum</th>
<th>Millet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (m ha)</td>
<td>Production (m tonnes)</td>
</tr>
<tr>
<td>Africa</td>
<td>26.52</td>
<td>25.64</td>
</tr>
<tr>
<td>Eastern Africa</td>
<td>4.75</td>
<td>6.47</td>
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<td>Central Africa</td>
<td>1.89</td>
<td>1.99</td>
</tr>
<tr>
<td>Northern Africa</td>
<td>7.28</td>
<td>5.28</td>
</tr>
<tr>
<td>Southern Africa</td>
<td>0.14</td>
<td>0.19</td>
</tr>
<tr>
<td>Western Africa</td>
<td>12.46</td>
<td>11.71</td>
</tr>
<tr>
<td>Americas</td>
<td>6.84</td>
<td>23.58</td>
</tr>
<tr>
<td>Northern America</td>
<td>2.64</td>
<td>9.88</td>
</tr>
<tr>
<td>Central America</td>
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</tr>
<tr>
<td>South America</td>
<td>2.18</td>
<td>6.95</td>
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<td>Asia</td>
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</tr>
<tr>
<td>Central Asia</td>
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<td>0.0075</td>
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<td>Eastern Asia</td>
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</tr>
<tr>
<td>Oceania</td>
<td>0.60</td>
<td>2.23</td>
</tr>
<tr>
<td>World</td>
<td>42.2</td>
<td>62.30</td>
</tr>
</tbody>
</table>

*Source: FAO database 2014.*
Africa and Asia. The region-wise distribution of area for millets is 15.4 million ha in Western Africa and 10 million ha in South Asia. Finger millet is the principal small millet species grown in South Asia followed by kodo millet, foxtail millet, little millet, proso millet and barnyard millet in that order. Foxtail millet and proso millet are important in China. In Africa, finger millet, teff and fonio have local importance. Some small millets are grown in the United States and Europe on a very limited scale.

The five largest producers of sorghum in the world (Table 3) are the United States (16%), Nigeria (11%), Mexico (10%), India (8.5%) and Ethiopia (7%). Together these five countries account for 52.5% of the total world production. India (36.5%) is the largest producer of millets, followed by Nigeria (16.7%), Niger (10%), China (5.9%) and Mali (4.4%). All these countries together contribute to 73.5% of world millet production.

Because of the higher yield per unit area, North and Central America produce the highest quantity of sorghum (16% of total production). In Asia, sorghum is extensively cultivated in India, China, Yemen, Pakistan and Thailand. Production in Europe is limited to a few areas in France, Italy, Spain and the southeastern countries. In Oceania, Australia is the only producer of significance.

World sorghum production expanded from 40 million tonnes at the beginning of the 1960s to 62 million tonnes during 2012–2013, even though there was a decline in sorghum growing area from 46 million ha in 1961 to 42 million ha in 2013. Millet production increased from 25 million tonnes in 1961 to 30 million tonnes in 2013, and the area was decreased from 43 million ha in 1961 to 33 million ha in 2013.

Sorghum is grown in two contrasting situations in different parts of the world based on production and utilisation patterns. In the developed world there is intensive, commercialised production, mainly for livestock feed. Hybrid seed, fertiliser and improved water management technologies are used fairly widely, and yields average 3–5 t/ha.
In most of the developing world, there is sharp contrast with the low-input, extensive production systems, where sorghum is grown mainly for food. While improved varieties are being adopted in such systems, particularly in Asia, management practices generally remain less intensive than in the commercialised systems. Fertiliser application rates are low and the adoption of improved moisture conservation technologies is limited. As a result, average yields remained low between 0.5 and 1.0 t/ha in many areas but gradually increasing in spite of area decline in some regions.

Millet production systems in Africa and Asia are generally characterised by extensive production practices and limited adoption of improved varieties. Yield average is still only 0.3–1.0 t/ha. While hybrids are being adopted in parts of Asia, most of the world’s millet area remains under traditional varieties. Few farmers apply fertilisers or use improved moisture conservation practices. Therefore, the yield levels remain low for long but increase wherever improved hybrids and management practices are increasingly adopted as in India.

Trends in Area, Production and Productivity of Sorghum and Millets in India

Sorghum
India contributes to about 16% of the world’s sorghum production. It is the fourth most important cereal crop in the country. In India, this crop was one of the major cereal staples during the 1950s and occupied an area of more than 18 million ha but has come down to 6.61 million ha in 2013. The decline has serious concern on the cropping systems and the food security of these dry land regions of the country. The increased productivity of sorghum has not been able to compensate the loss in area turning the production to be negative.

Pearl Millet
Pearl millet is a major warm-season cereal grown largely in the arid and semi-arid tropical regions of Africa and Asia with India accounting for the largest area (7.2 million ha). The diversification of cultivar base with mostly dual-purpose hybrids has led to 24 kg/ha/year of grain yield increase during the last few decades as compared to only 5.2 kg/ha/year of yield increase during the pre-hybrid phase of 1950–1965. Development of improved crop cultivars is just one major component of technological interventions to enhance food and nutritional security. Improved crop management technologies with potential to substantially increase pearl millet grain yield have been developed.

Small Millets
The crop-wise data on area, production and yield for individual small millets are not available, except for finger millet. Therefore, the statistical data are given separately for finger millet; other small millets are grouped together. The area where small millets are cultivated in India during the last 6 decades has significantly reduced from 8 million ha during 1949–1950 to around 2.3 million ha during 2012–2013. This is also reflected in the diminishing production, from around 4 million tonnes produced in late 1940s to around 2.5 million tonnes during 2011–2012. The loss of area is very severe in all small millets other than finger millet. However, in the last 15 years, the finger millet also has lost ground and its area has come down from 2.4 million to 1.2 million ha.

Despite the reduction in area, the total production is not much affected. By and large, the low productivity of these crops is largely due to the meagre attention received in
<table>
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<tbody>
<tr>
<td>Sorghum</td>
<td>Area</td>
<td>17.36</td>
<td>17.68</td>
<td>16.09</td>
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<tr>
<td></td>
<td>Production</td>
<td>6.73</td>
<td>7.58</td>
<td>9.50</td>
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<td>7.63</td>
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<tr>
<td></td>
<td>Productivity</td>
<td>387</td>
<td>429</td>
<td>591</td>
<td>633</td>
<td>823</td>
<td>880</td>
<td>863</td>
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<td>Pearl millet</td>
<td>Area</td>
<td>11.34</td>
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<td>9.32</td>
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<tr>
<td></td>
<td>Production</td>
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<td>3.75</td>
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<td>5.38</td>
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<tr>
<td></td>
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<td>302</td>
<td>314</td>
<td>496</td>
<td>344</td>
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<tr>
<td>Finger millet</td>
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<td></td>
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<tr>
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<td>388</td>
<td>341</td>
<td>412</td>
<td>386</td>
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Source: Agricultural Census, Directorate of Economics and Statistics, Department of Agriculture & Cooperation, Government of India.