Organic crop production utilizes different approaches and growing environments compared to conventionally raised crops to achieve production in growing systems that mimic natural ecosystems. These systems seek to employ fewer direct inputs and innovative agronomic methods to achieve this goal. This alternative approach has attracted great interest in this rapidly expanding method of crop production. Organic Crop Breeding brings together the latest research on the development of new varieties and cultivars best suited to thrive under organic production. It will also be of interest to those breeding in conventional systems who wish to adapt their breeding goals to sustainable low input agriculture.

Organic Crop Breeding will be a useful tool to helping meet the increasing global demand for organically produced grains, vegetables, and fruits. The book is divided into two sections that logically cover the topic from foundational principles to crop-specific examples of organic breeding efforts. The opening section looks at general topics related to organic crop breeding ranging from nutrient management to disease and pest resistance. The second section looks at the applications of these principles to economically important crops such as wheat, maize, rice, potatoes, legumes, and tomatoes.

Written by a global team of the leading experts in the field, Organic Crop Breeding is a field-defining reference that will be of both academic and practical use.

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Organic Crop Breeding
Organic Crop Breeding

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Dedication

We dedicate this book to all organic growers whose knowledge, vision, and wisdom has helped us to see the marvellous complexities of organic plant breeding through farmers’ eyes.
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Foreword

This book is a long overdue addition to the plant breeding literature. Until now, what has been written on the subject of breeding for organic production systems has been scattered among many journals and conference proceedings. These other sources seldom, if ever, combine both philosophy and practical experience, and often the older sources have focused on one species or a group of allied species. This volume overcomes both weaknesses. It is rich in both practical knowledge and philosophy of breeding plants for organic systems. Field and vegetable crops and self-pollinated and cross-pollinated species are thoroughly discussed.

While many will seek out this volume in their desire to become practitioners of breeding for organic agriculture, all those interested in plant breeding should read it to understand the theory and philosophy as well as the legal and structural aspects that underlie breeding for organic systems. Undoubtedly some readers will question some ideas, but many will be exposed to new perspectives. And this is precisely why this book is so important.

Increasingly, breeding for organic agriculture is gaining attention in the public and private sectors in both Europe and in the United States. This has come about through the realization that organic production systems usually represent a different environment from conventional systems, and due to potential genotype × system interactions, varieties not adapted to a specific production system may not be the best performers in that system. Many of the methods used in organic plant breeding have been developed in poorer countries under low-input conditions without a seed production infrastructure. The sharing of innovative methods among these different areas has opened an exciting time in the breeding for organic and sustainable systems.

The editors have organized a thoughtful review on the topic of organic plant breeding and tapped as authors the leaders in the field. The book is split into two sections: Section 1, General topics related to organic plant breeding and Section 2 Organic plant breeding in specific crops. The first section will be of interest to all those interested in plant breeding. After an introductory chapter, the next three chapters cover the unique environmental challenges presented by organic systems and various ways plant breeders have risen to meet those challenges. The next four chapters are perhaps the most provocative of the book and are sure to generate discussion among students of plant breeding. Chapters 5 and 6 deal with technical challenges that should be of interest to all breeders and those are the development of genetically diverse cultivars that can respond to evolutionary pressures and the dichotomy of centralized versus decentralized research and extension systems. Chapter 7 tackles values and principles in organic breeding and will be eye-opening to many. Chapter 8 discusses intellectual property (IP), germplasm ownership, and commercialization issues that constrain organic plant breeding. Given the much smaller and decentralized nature of organic plant breeding efforts the IP and distribution mechanisms that have been developed for large commercial ventures don’t fit, often constrain, and sometimes eliminate the ability of organic plant breeding to be successful.
Section 2 with nine chapters on organic breeding of specific crops will be a valuable resource to breeders of these and other allied crops.

The editors hailing from Europe and the United States represent the two regions where organic plant breeding has shown the greatest advances. They have assembled a team of authors that reflects this diversity, and in the process of writing these chapters have fostered cross pollination among the regions. The result is a cosmopolitan approach to the subject.

The field is rather new, and we are seeing an exponential increase in the literature as the first round of studies is completed. This book establishes the baseline for a growing discipline within plant breeding and is designed to contribute to furthering knowledge and innovation in the field of organic plant breeding.

William F. Tracy

Madison, Wisconsin
Preface

Organic crop breeding is a relatively young and growing discipline described as either plant breeding for organic agriculture or plant breeding under organic conditions, acknowledging the organic principles that underlie this field. Both approaches are captured in this book as “organic crop breeding.”

Research into organic plant breeding has, to a large extent, been focused on cereal crops, but for many other crops this field is still in its infancy. This book brings some balance, in that it includes several crop-specific book chapters, of which cereals are part, but other groups representing legumes, cole crops and various vegetable crops are also covered.

While it is well established that organic production systems represent different growing environments compared to conventional systems, and that genotype x production system interaction is an important consideration, we do not have adequate knowledge of what components of an organic system are most important and what varietal traits allow optimal adaptation to such a system. The first section of the book provides some illumination on this subject in its coverage of general topics of organic plant breeding.

This book will be able to be read independently by those with some background in plant breeding; however, in general, this book will not discuss basic breeding principles, but will focus on the specific issues that are of importance when considering breeding for the organic sector. The book is divided into two sections covering (1) general topics related to organic crop breeding and (2) crop-specific topics. The general topics section discusses the basic organic principles and their consequences for plant breeding, and reviews the state-of-the-art of current breeding research.

Chapter 1 is an introductory chapter showing how organic breeding is a cross between organic agricultural approaches and traditional and modern plant breeding techniques and discusses the basic differences between organic, conventional high- and low-input agriculture, and the history of organic plant breeding in the United States and Europe.

Chapter 2 discusses the consequences of nutrient management in organic farming systems for crop improvement and includes complex issues such as breeding for nutrient efficiency and root system improvement.

Chapter 3 focuses on the fact that organic farming refrains from chemical pest management. Although resistance breeding is a familiar topic to most breeders, this chapter describes where and in which way organic management can reduce pressure of pest and diseases, where crop breeding needs to contribute, and in which ways innovative approaches should be further explored.

Chapter 4 deals with a relatively new topic for breeders on approaches to breed for improved weed suppression – departing from the experience in organically grown cereals, but with application to other crops. Chapter 5 addresses the central issue of biodiversity in organic agriculture. Biodiversity is considered a vital tool in creating higher levels of resilience in farming systems. The chapter
PREFACE

describes strategies to exploit genetic diversity using cultivar mixtures and evolutionary breeding approaches.

Chapter 6 discusses the potentials of participatory approaches for low-input and organic agriculture in Western contexts, and arises from the fact that organic plant breeding is an economic niche for the commercial breeding industry that can profit from the experience of organic growers.

Chapter 7 describes the “Values and principles in organic farming and consequences for breeding approaches and techniques.” It underscores the importance of understanding the origins of organic agriculture, its world-view, and the rationale for the rejection of certain modern plant breeding techniques. Overall, it provides a framework in which organic plant breeding can develop. Chapter 8 discusses the consequences of the current “Laws and policies that govern plant breeding and seed supply” and recommends modifications that support the emerging organic breeding sector.

The second half of the book provides applied examples of the general approaches discussed in chapters 1 through 8 in specific crops. Research groups and breeders were invited to describe the most relevant traits for their crop species, including their experience in breeding for organic farming systems and perspectives on traits required for better adapted cultivars. For this book, crops were selected based on whether experience in breeding for organic systems was available. The crops included: Wheat, maize, rice, soybean, faba bean, potato, tomato, crucifers, and onion. They each give either a general review of the state-of-the-art and breeding perspectives, and/or emphasize a specific breeding approach, and included some examples of current organic breeding programs.

With this compilation, we seek to provide subject matter of interest to students, researchers, and other professionals from universities and institutes related to breeding research and those in plant breeding and seed companies. It is our hope and expectation that this book will be relevant to organic and conventional agriculture alike, and that it will facilitate the search for more sustainable farming systems for the twenty-first century and beyond.

Edith T. Lammerts van Bueren
James R. Myers
Acknowledgments

The idea for this book came from Justin Jeffryes, executive editor at Wiley-Blackwell. The editors of this book gratefully took up his invitation and are thankful for his valuable and expert assistance during preparation of the book.

This book was an opportunity to bring the European and U.S. research and breeding networks together, as well as include some authors from the southern latitudes. Most of the chapters have mixed U.S. and European authorship, and the authors have worked with great inspiration, together sharing knowledge and experience. The editors are most grateful to the various author groups, because without their commitment, this book would not have achieved a high level of quality!

We would like to individually thank those who patiently assisted us in the finalization of the book. Laurie McKenzie read and provided feedback on a number of chapters as they came in, and Berend-Jan Dobma assisted with the exacting process of finally formatting and assembly of the chapters.

Finally, we send thanks to our families for their patience and support as we burned the midnight oil in bringing this task to fruition.
Section 1
General Topics Related to Organic Plant Breeding
1 Organic Crop Breeding: Integrating Organic Agricultural Approaches and Traditional and Modern Plant Breeding Methods

Edith T. Lammerts van Bueren and James R. Myers

Introduction

Organic agriculture is continuously growing worldwide on land and farms in more than 160 countries as well as in the global marketplace (Willer and Kilcher, 2011). Globally, there are 37.2 million hectares of organic agricultural land (including in-conversion or transition hectarage), which is about 0.9% of all arable lands. Of the total organic area in 2009, most (24.9%) is in Europe, followed by Latin America (23.0%), Asia (9.6%), North America (7.1%), and Africa (2.8%). Some individual countries (mainly those in Europe) had higher percentages due to support by national policies, e.g., Austria (18.5%), Sweden (12.6%), and Italy (9.0%; Willer and Kilcher, 2011).

Organic agriculture has its origins in the early 1900s with individuals advocating that “living soil” was a fundamental value of sound agriculture (Balfour, 1943; Howard, 1940; Pfeiffer, 1947; Steiner, 1958; Rodale, 1961). It was not until the 1970s that the organic movement grew substantially, however. Growth of the movement coincided with consumers’ and farmers’ reactions against the unsustainable environmental impact of the agriculture of that time. In the 1990s, organic agriculture became large enough to attract the interest of major food suppliers. In 2008–2009 organic products occupied about 5% of the market and were worth 55 billion US dollars, or 40 billion euros (Willer and Kilcher, 2011). To date, increasing development in the organic sector is influenced by three main drivers: Values (see four basic principles of the International Federation for Organic Agricultural Movements in Chapter 7), protest (promoting organic agriculture as an alternative strategy) and market (an economic interesting niche market). Alrøe and Noe, 2008.

Regulations translating the values and principles of the organic sector into rules and standards (IFOAM, 2005; Luttikholt, 2007) have been harmonized to promote global trade. The four basic principles of the organic movements as described by the world umbrella organization IFOAM, include (a) the principle of health: Expressing the concept of wholeness and integrity of living systems and supporting their immunity, resilience, and sustainability; (b) the principle of ecology: Promoting diversity in site-specific ecological production systems; (c) the principle of fairness: Serving equity, respect, justice, and stewardship of the shared world; and (d) the principle
of care: Enhancing efficiency and productivity in a precautionary and responsible way (IFOAM, 2005; Luttikholt, 2007).

These principles have been codified in governmental regulations such as the National Organic Program (NOP) in the United States (USDA, 2002) and in Europe by the European Commission (EC, 2007).

It was only in the early 1990s that crop breeding and seed production came to the fore as an issue for organic growers and consumers in response to the emerging field of genetic engineering (GE) and strengthening of intellectual property rights. The organic sector began to discuss ways to actively stimulate crop improvement to meet organic principles.

In this chapter we will describe how organic management differs from conventional agricultural management, what plant traits are required for optimal adaptation to organic farming systems, and ways to acquire such adaptation via cultivar selection, seed production, and breeding. We also summarize the history and future perspectives for organic crop breeding in the United States and Europe.

How Different Are Organic Farming Systems?

When the U.S. National Organic Standards Board convened to advise the USDA on developing organic regulations, they described organic agriculture as:

“...an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain, and enhance ecological harmony” (USDA, 2002).

Organic farming is more than merely replacing chemical pesticides and fertilizers with organic ones. Emanating from the principles of health and ecology, the aim has been to move away from curative measures and to amplify agro-ecological system resilience by developing preventative strategies at the system level (e.g., Kristiansen et al., 2006; see table 1.1). The goal is to stimulate a high level of internal system self-regulation through functional diversity in and above the soil, as opposed to depending on external inputs for regulation (Østergård et al., 2009).

In considering differences among current farming systems in Western societies (e.g., conventional with high-external inputs systems, conventional systems reducing external inputs to become more sustainable, and organic farming systems) organic farming systems are the most extreme of the three types in refraining from chemical-synthetic inputs and in using preventative rather than curative measures. Although conventional low-external input farming seeking sustainability can be considered an intermediate between high-external input farming and organic farming, there is still a critical difference. It aims to reduce the input levels through precision farming methods and integrated pest management but still relies on chemical inputs to quickly correct during crop growth. In contrast, organic farming systems that cannot (easily) “escape” by applying curative methods rely on indirect, long-term strategies of fostering systems resilience. Organic farming systems focus on soil building through increasing organic matter, which increases water holding capacity and buffers against perturbations to the system. Such systems generally lack short-term controls (e.g., by applying mineral fertilizers with ready water-soluble nutrients or pesticides) to modify the growing environment during the season. Because organic farmers have fewer means to mitigate environmental variation, the varieties grown in organic agriculture will exhibit larger genotype by