

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable cultivation of bananas

Volume 1: Cultivation techniques

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Introduction

Bananas are produced in over 135 tropical and subtropical countries and, according to the Food and Agriculture Organization (FAO), represented an estimated combined economic value of US \$52 Billion in 2017. Each year more than 100 billion bananas are consumed globally and over 400 million people rely on bananas for their staple food or as a source of income. A large portion (85%) of the 113 million tons of bananas are consumed locally while the remaining 15% is exported, mainly to countries in temperate regions. Banana is the world's most exported and valuable fruit and was, according to figures from the FAO, the sixth most valuable food crop after rice, maize, wheat, potato and soybean in 2016.

Despite their importance as a food crop, bananas are often considered an orphan crop when it comes to investment into making production more efficient and sustainable. Funds invested in research on bananas, in areas such as genetics, breeding, variety evaluation trials, physiology, pathology and entomology, have always been far less than the resources available to those researching major crops of comparable economic importance grown in temperate climates. Investment in interdisciplinary research involving environmental and social aspects of banana production is even further behind. Since no contemporary book exists on banana cultivation, we had no hesitation in agreeing to edit a three-volume book series on bananas. Volume 1 is focussed on the cultivation of bananas, Volume 2 on genetics and breeding, and Volume 3 on banana diseases. Each volume stands on its own but together, we hope, the three books will provide a comprehensive review of all the key aspects of research into making cultivation more sustainable in the long term.

Bananas were among the first crops cultivated by man. Their wide utility as building and packing material, fibre for making rope and string, and cooked food in the form of starch from the corm and pseudostem, male flowers and the seeded bananas, preceded eating the seedless fruit we are familiar with today. Early farmers cultivated seeded bananas for these purposes in Asia, from which they identified seedless parthenocarpic plants which they subsequently propagated vegetatively. Movement of these plants by man in Southeast Asia also facilitated hybridisation between different *Musa* species, giving rise to novel interspecific hybrids. It is interesting to note that almost all varieties of banana we use today were selected by farmers in antiquity. Thousands of such varieties were selected in the past and brought into cultivation through vegetative propagation, giving rise to our current global suite of germplasm of seedless bananas. Since many seedless bananas are intra- and inter-specific hybrids which vary in ploidy level, they are expected to have high levels of heterozygosity which is maintained by man through ongoing vegetative propagation. Selections of Cavendish for example can, under ideal growing conditions and best agricultural practice, produce up to 80 tons of fruit per ha. Although modern plant breeding has played no role in generating the current varieties, the genetic yield potential of these early farmer selections compares very favourably to modern breeding efforts in other fruit crops.

On the one hand, continuous vegetative propagation and high levels of sterility in banana varieties locks in high genetic potential but, on the other, they also hamper significant genetic improvement of bananas. After discovering a new sterile hybrid in the wild, any advance in productivity solely relies on improving cultivation methods. Therefore the first book of the banana trilogy deals with development of sustainable cultivation techniques as outlined in more detail below.

Favourable clones, especially those of the Cavendish subgroup, which show very high levels of productivity, are widely used, giving rise to the contemporary global monoculture in banana production. The downside of the lack of genetic improvement and diversification is extreme genetic vulnerability, exacerbated by the need for uniformity in the transport and ripening process. This lack of diversity can only be overcome through much wider utilisation of available germplasm and by generating new varieties that meet consumer demands and sustainability targets. Genetics is the key to achieve that goal and therefore the second book is focussed on the current state of knowledge with regard to genetic improvement and diversification of bananas.

The spread of bananas around the globe over the last century has instigated the spread of a range of important plant diseases such as yellow and black Sigatoka, Fusarium wilt and banana bunchy top virus. Simultaneously, new diseases were encountered such as Xanthomonas wilt in Africa and Moko disease in Latin America. Increases in travel and trade have enabled pathogens which originated in different parts of the world to spread rapidly to new areas and the lack of resistance against some of these pathogens has caused some of the most damaging plant disease epidemics. Therefore the third book in the series focuses on the latest research into the myriad of pathogens affecting bananas and how to improve disease management in a sustainable manner.

Our hope is that the contributions of leading experts will combine into an integrative state-of-art banana trilogy that provides a springboard for a new generation of banana stakeholders to develop a sustainable banana sector.

As noted, Volume 1 consists of three parts which review key research on improving the efficiency and sustainability of global banana production:

- Part 1 reviews current challenges in banana production
- Part 2 surveys ways of improving cultivation practice across the value chain, from propagation to harvesting and ripening
- Part 3 assesses ways of measuring and improving the environmental impact of banana cultivation

Each of these three parts is discussed in more detail below.

Part 1 Banana production and its challenges

The themes of chapters in the first part of the volume range from the origin, domestication, dispersal and production of bananas to the role of monoculture in banana cultivation, and challenges and opportunities for smallholders in banana value chains. Chapter 1 details the search for the origins of edible bananas, which probably began soon after European explorers returned home with stories of a fruit they had discovered in Africa. Currently, about 40 seeded species of the genus *Musa* have been recognised. This chapter describes the morphological and molecular evidence for the origin of bananas and the role of *Musa balbisiana* in the domestication and early cultivation of bananas. The chapter also reviews the archaeological evidence for early banana cultivation before considering the dispersal of bananas to Oceania, Africa, South and Southeast Asia.

Chapter 2 provides an overview of how the dominance of monoculture in banana cultivation has produced numerous agricultural, social and political problems. The chapter reviews the evolution of the banana industry and the advent of the dominance of the

Cavendish variety, before considering the crisis in Cavendish cultivation and a proposed new paradigm for future banana production. The chapter also examines the search for new banana varieties and looks ahead to future developments in the area.

Chapter 3 highlights the importance of banana in Africa as a food, cash and climate-resilient crop. However, average productivity in the region has declined dramatically to below 10t/ha compared with a potential of 60t/ha or more, whilst plantation longevity has also been drastically reduced. This chapter examines the composition and distribution of banana cultivars and assesses banana production systems, focusing particularly on banana production in Uganda as a case study of the problems faced by farmers in the region. The chapter reviews the range of challenges in banana production, including nutrient deficiencies, moisture stress and the impact of pests and diseases, as well as problems of market access. It examines solutions to these challenges such as the ways in which banana varieties might be improved to provide better resistance to pests and diseases.

The topic of Chapter 4 is the major role of bananas and plantains in global food security and household incomes in producing countries. As noted in Chapter 3, banana production and yields are affected by a variety of challenges, including availability of labour, soil degradation, access to clean planting material, management of pests and diseases, post-harvest losses and market access. This chapter reviews the range of research exploring constraints in relation to pre-production, production, post-harvest management and marketing in domestic value chains of cooking bananas and plantains from the perspective of smallholders. The chapter identifies opportunities for smallholders and other value chain actors for addressing these constraints and concludes with recommendations for future research.

Part 2 Improving practices across the banana value chain

The chapters in the second part of the volume review how to improve cultivation practices throughout the banana value chain. Chapter 5 addresses the fact that the sustainable management of bananas in farming systems requires knowledge of plant physiology, especially the pivotal processes of bunch formation. The chapter reviews what we know about formation of the inflorescence up to flowering (bunch emergence) emphasising interaction of the plant with the environment. The role of cool temperature in shortening the juvenile phase and long photoperiod in shortening the mid-vegetative phase of development is also discussed. By interpreting the bunch as a *thyrses* and hand as a *cincinnus*, the differentiation of functionally female flowers that form fruit and subsequently male flowers that do not form fruit is examined. In addition, this chapter highlights that hand formation and fruit number per hand are independent but coordinated processes. Genotype and environment determine the relationship between the number of hands/bunch and flowers/hand along the female peduncle. The chapter highlights the need to quantify the relationships that underpin new genotypes and management practices for sustainable banana production. A case study focusing on photosynthate availability and bunch formation in bananas is also presented.

The theme of Chapter 6 is how the process of propagating bananas, by taking a sucker, has allowed farmers to multiply their banana selections and share them. The banana sucker is a resilient form of planting material as the growing point is protected within the sucker, which contains a corm with a starchy store that allows the plant to readily

re-establish. This chapter briefly describes the basic anatomy of the banana plant required to understand the part of the plant used for propagation. The chapter then describes the various practical aspects of banana propagation using either conventional planting material or tissue culture plants and the benefits and disadvantages of each method. The chapter looks ahead to future research trends in the area of banana tissue culture.

Chapter 7 reviews how the availability of pest- and disease-free planting material is fundamental for successful banana cultivation. This chapter examines the key issues in the selection, establishment and management of a field germplasm collection, with a focus on how best to provide a reliable source of quality banana planting stock. The chapter discusses characterisation strategies for variety selection and includes a case study of banana cultivation in Queensland, Australia. The chapter addresses the sourcing of material for the germplasm collection and strategies to ensure freedom from pests and disease, and suggests future directions for research.

Chapter 8 reviews the main GAP-related certification schemes used in the sector: GlobalGap, Rainforest, EU Organic, Fair Trade and SA8000. While these schemes have made important improvements, growers have also seen them as a significant and growing bureaucratic burden. Some versions of standards risk being the certification of business as usual. The chapter shows how GAP certification procedures can be re-oriented to become more useful in benchmarking and improving productivity. It also argues that certification criteria should focus not just on specific inputs, but on broader ecological processes (such as soil ecosystem services). The chapter suggests using certification schemes to promote practices such as the use of cover crops and plant residues to protect soil, stimulate root activity and soil biology. As the chapter argues, a more holistic approach will help to achieve true sustainable intensification.

Chapter 9 highlights that fact that although a tropical climate is commonly thought to be more suited to banana production than a subtropical climate, banana yields obtained in the subtropics are excellent and, with good cultural practices, can be considered among the highest in the world. The relatively cool climate of the subtropics causes undesirable physiological phenomena and a long cropping cycle, but it has advantages as well. This chapter describes appropriate cultural practices designed to solve or minimize the climatic constraints on cultivation of bananas in the subtropics, including cultivation under greenhouse conditions.

Moving the focus onto a specific aspect of banana cultivation, Chapter 10 details the significant variation in banana production systems across the world, particularly at the level of soil management. However, as stated at the beginning of the Introduction, research into plant nutrition and soil management in relation to bananas has been limited. Bananas are unusual in their physiology and management, and the characteristics of the crop make it difficult to carry out standard fertilizer response experiments. The current scarcity of fertilization studies in bananas is perhaps surprising, given the significant economic consequences of fertilization costs. This chapter provides an overview of general aspects of soil management and then looks in more detail at crop nutrition. Focusing mostly on intensively managed systems where fertilizer use is highest, the chapter discusses a number of strategies for soil nutrition as well as advantages and disadvantages of each approach.

Chapter 11 highlights that bananas are one of the most widely traded crops globally, and with appropriate management, can be produced on a continuous basis. However, the journey from field to retail destination is a delicate, finely-tuned process which must be closely managed at every stage to ensure product safety and quality. This chapter

describes each stage of this journey, evaluating different strategies and challenges. The chapter reviews criteria for determining when to harvest a bunch, followed by a description of different harvesting and transport techniques to avoid crop damage. Post-harvest losses can be reduced through effective techniques of dehanding, washing, sorting and packaging. The chapter concludes with a discussion of future trends in banana cultivation, balancing the need to minimise production costs with increasing consumer concern for the environmental and human impact of banana production.

Complementing the previous chapter's focus on harvesting, Chapter 12 highlights the importance of correct ripening for optimum taste, appearance, shelf life and consumer satisfaction. This chapter reviews the skills and technologies needed for successful ripening, together with innovations and recent developments. Advice on procedures and best practice throughout the supply chain is presented from the author's unique experience in this sector.

Part 3 Assessing and improving sustainability

The themes of chapters in the third part of the volume address how to assess and improve the sustainability of banana production. As one of the world's most traded fruits, bananas have attracted considerable attention for their social and environmental impact throughout the whole value chain. Chapter 13 describes concepts and tools for life cycle assessment (LCA) and carbon footprint (CFP) analysis as applied to the banana value chain. The chapter examines how LCA and CFP methods can be applied to analyse the environmental impact and sustainability of banana cultivation, and how it can inform banana labelling. It includes case studies of Ecuadorian and Peruvian banana value chains and looks ahead to future tools and practices that may be developed in this area.

The last two chapters of the book focus on ways of making cultivation of bananas more sustainable, with Chapter 14 highlighting that there is no single strategy for sustainable banana cultivation. Echoing Chapter 8, the chapter addresses the gap between implementation of global sustainability standards in the export industry based on a single banana variety, i.e., Cavendish, and the diversity of varieties, uses and production environments related to local food security and rural livelihoods. The gap between ecologically and socially-diverse production systems and management strategies relying on standardisation of agronomic practices complicates coordinated action working towards multiple solutions needed to improve sustainability. This chapter includes a case study of a major banana-producing region in the Philippines, representing a variety of banana production systems, which shows the importance of working towards a territorial approach that has the capacity to accommodate and connect multiple solutions to make banana cultivation more sustainable in the long term.

The last chapter of the volume, Chapter 15, addresses the fact that the cultivation of conventional bananas of the commercial Cavendish variety for export markets in the wet tropics requires a substantial amount of synthetic agrochemical input. Over the last 25 years organic banana production has soared in Latin America. This chapter describes organic banana production, identifying the key requirements for success, including location, soil quality and the use of rotations. The chapter also examines the importance of soil fertility and fertilization, disease management, weed management, and managing nematode and insect pests within organic systems.

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