PART 2

REDESIGNING CROP PLANTS

Domestication of crop plants by our hunter-gatherer ancestors was likely a hit and miss affair. Once gatherers learned to keep some seed and scatter it with the onset of the rains, domestication began. Keen-eyed protofarmers kept seed from plants with unusual but obviously beneficial traits, such as grasses that did not readily shed their seeds as they matured. Single mutations very occasionally caused dramatic changes that farmers appreciated, such as reduced branching of the maize ancestor teosinte and increased grain number and size. Continued crossing with wild relatives could occur early in the domestication process, but eventually the genetic differences were so great that many crops became genetically isolated from their ancestors. Other extremely rare events such as the cross species hybridisation, as described in Chapter 2, created strikingly different, and presumably very attractive, harvests, but completely isolated all subsequent generations from further crosses, and therefore transfer of traits through natural means. So, at some point after crops were domesticated and until modern breeding, the only source of significant changes was random mutation.

While farmers have been excellent stewards of the crops they domesticated, they had no way of knowing which plants carried subtle differences in important traits such as vitamins and minerals (micronutrients). These could easily be lost through random processes (genetic drift) during seed preservation over many generations, if they initially had been carried over from their ancestors at all. Until the last century or so, the primary food concern of most people was simply getting enough calories. The staple cereals (rice, wheat, maize and sorghum) and root and tuber crops (potato, cassava, sweet potato and plantains) were selected to meet the ever-present caloric demand of growing populations. Over its 10 000 year history, agriculture had a simple primary mandate: produce enough calories. With the advent of the Industrial Revolution, that began to change. Machines driven by fossil fuels and hydropower began to replace the work humans did and the caloric needs of individuals began to decline. For relatively wealthier segments of society, sedentary life styles so common today combined with unmatched diets have led to worldwide problems of obesity, type 2 diabetes, heart disease and colorectal cancers.

Global diets, particularly for the poor, have been transformed by industrialisation of agriculture and the emergence of global supply chains for staple foods. Fewer crop species are now being grown at ever-larger scale, with over half of the global calorie demand now met by rice, wheat and maize. While prices of staples have been steadily declining since mid-20th century, other food prices generally have not. So, in today's world outright starvation from calorie shortages have become limited to areas of conflict. The relative unaffordability of nutrient-dense foods such as fruits, vegetables and animal products has led to nutritional imbalances, or 'hidden hunger', for the poor.

Diversification of diets to secure micronutrients, while an obvious strategy to tackle deficiencies, is nearly impossible for most of the world's very poor. Chapters 5 and 6 outline the serious problems of micronutrient deficiencies in developing countries. Recognising that direct dietary supplements and enriching processed foods can reach some populations, it is pointed out that these are imperfect solutions in that some populations are very difficult to reach. Distribution of supplements can be costly and any breakdown of distribution systems will again expose target populations to deficiencies. Adding micronutrients to processed foods depends on participation of food processors to add to their production costs, which may not yield a financial return. The chapters describe a complementary approach in which the world's staple crops are being modified to contain significant quantities of dietary micronutrients through plant breeding. These programs seek to tap existing variation in nutrient content by identifying high-content accession of germplasm collections and systematically transferring them to cultivars of interest to farmers using conventional plant breeding techniques. This avoids the regulatory and public perception problems of GMOs that can seriously delay deployment of improved crop varieties. The challenges of this undertaking should not be underestimated, though, because again the technological investments needed to accomplish this are significant.

A number of improvements in the nutritional value of crops cannot be accomplished using natural variation in the species that may be found in genetic resource collections. Chapter 7 delves into the importance of plant oils in human nutrition and the difficulty in improving plants to change their oil composition to a healthier profile. It presents a number of examples of successful modification of plant oil composition using genetic engineering. It also illustrates how other important changes can be made in secondary metabolites such as morphine to render products that, because of reduced processing requirements, may be safer and more environmentally benign. The case of provitamin A enriched rice ('Golden Rice') summarised in Chapter 6 is a sobering example of the difficulties facing the public sector in developing a source of vitamin A for populations dependent on rice. The enormous technical challenges of creating varieties that farmers are willing to grow, combined with vociferous opposition by some to genetically modified crops, raise the question of how feasible it is for public sector institutions to develop such crops. Considering that there may be little appetite or profit incentive for the private sector to engage in this work, the question again emerges as to what role the public sector should play in resolving issues impacting the common good.

The emerging understanding of the role of dietary fibre, or plant products that resist digestion in the small intestine, is explored in Chapter 8 in a fascinating historical context. As is so often the case, investigation into underlying processes reveals new layers of subtle complexity. Our understanding of the role of dietary fibre is changing from simply adding bulk for regularity to how it is digested by our gut microbial populations and the uptake of the short chain fatty acids produced by their fermentation.

As in the need to conserve, understand and use crop genetic diversity, changing the nutritional profile or basic productivity levels of our crops requires large investments that will not yield short-term or proprietary returns. Obvious public policy imperatives are to develop frameworks within which the private sector component of our food systems have the incentives to produce more nutritious foods. Governments concerned about the nutritional wellbeing and long-term health of their populations need to develop policies that provide incentives at a number of steps in the food supply chain from the composition of our staples through process and distribution of final food products. The conflicts around the use of genetically modified crops are viewed in the context of the development of rice enriched for iron and in particular provitamin A.

As we look to make major gains in yield potential of our crops to meet expected global food demand, we are not only constrained by the limitations imposed on farmers limited to selecting obvious traits such as crop performance and yield. The forces determining the outcome of natural selection – reproductive success in the wild – resulted in trade-offs among metabolic processes such that inefficiencies in some contributed to better overall plant survival in natural systems. However, in modern agricultural systems in which plants are relatively coddled, these inefficiencies reduce yield potential. The extreme complexity of the fundamental plant processes that control plant performance and yield placed them well beyond the reach not only of our ancestors, but also of modern plant breeders. Chapter 9 takes the readers into the areas today's plant scientists are working to understand and profoundly transform that most elemental of plant processes: photosynthesis.