Grand challenges

§ 70% more food by 2050
- increase productivity across agri-food value chain
- environmental stewardship
- adaptation to changing climate

§ Health-promoting foods with consumer acceptance
- cost effective way of managing diet-related illnesses
  - hunger, nutrient deficiencies, over consumption
- modified carbohydrates for glycemic control, prebiotics
- modified oils to reduce saturated fats, increase omega oils
- increased bioavailability of vitamins and minerals
- nutraceuticals
- Agriculture is an instrument of public health

Technological change is the main driver of productivity growth

§ Adoption of research discoveries
- resources, varieties, practices
- exploiting new enabling technologies not specifically targeted to agri-food sector

§ Mostly incremental changes
- integration of existing knowledge across disciplines at the right time and place
- disruptive breakthroughs are rare

§ Green Revolution (1960s)
§ Conservation farming (1970s)
§ Precision agriculture (1980s)
§ GM organisms (1990s)

§ High return on investment, but long lag time
§ Bullish outlook for agri-foods
Agriculture is a complex system

- Making correct decisions is difficult
  - difficult to obtain empirical data
  - long time between action and response
  - link between cause and effect not obvious
  - confounding variables

- Risk management approach for decision making
  - understanding hazard and risk
  - nothing we do is completely safe
  - risk appetite, risk-reward

Current rate of change is unprecedented

- Digital disruption of the agri-food value chain
- Next generation sequencing
- Microbiomics
- Epigenetics
- Computational biology
- Cloud computing, smart phone apps

Digital disruption of agriculture

- GIS, GPS, remote sensing
  - digital soil mapping
  - land use, land use change
  - controlled traffic, variable rate technologies, precision agriculture
- Smart farms
  - robotics, drones
  - real time sensing (soil, plants, animals, weather)
  - tracking animal and plant growth and health, sensing insect pressure, monitoring weeds
  - digitally controlled sowing, watering, fertilisation, crop protection chemicals, harvesting
- Supply chains, process control, trace-back systems

Next generation genome sequencing

- Assembly of many short-read lengths
- Over 100 plant genomes available including many crop species
- Access to genomes greatly speeds up and improves the efficiency of plant breeding
  - genotyping by sequencing
  - identifying genetic variation
  - exploring the gene pool
  - marker assisted selection
  - gene editing
  - genome wide association studies
  - genome prediction
- Human genome
  - 2003: 13 years, $3 billion
  - 2011: 8 days, $10,000
  - 2016: 15 min, $1,000

Plant breeders need genetic variation
- natural
- generated (mutants)
- genetic modification
Linking genotype to phenotype is a boileneck

Phenotype
Combination of observable characteristics (physical, developmental, biochemical) that characterize an organism

Gene
DNA sequence, chromosomal location and function of all genes in a species

Omics

Genomics
Which genes are active/inactive under a particular set of conditions

Transcriptomics
Abundance of all the proteins under a particular set of conditions

Proteomics
Abundance of small molecules under a particular set of conditions

Metabolomics
Abundance of all the proteins and RNA

Forward genetics
Gene
Phenotype
Reverse genetics

Bioinformatics
§ New approaches to answer fundamental questions
- genetic potential of food plants and animals
- quantitative traits – yield, quality, G x E effects, response to stress, ...
- not necessary to grow a plant to maturity to determine whether a characteristic has been transferred from parent to progeny
- genotype by environment interactions
- plant-soil interactions
- explore microbiomes, epigenome

§ Despite the enormous capacity for high-throughput data gathering, extracting knowledge is limited by our rudimentary understanding of biology

Microbiomes
§ Most aspects of physiology of all organisms are influenced by their associated microbes
- critical role in functioning agro-ecosystems
- metagenome (sum of all genomes)
§ Analogous to influence of the gut microbiome on human health
§ Microbes co-evolved with plants and are essential in root formation and growth, plant nutrition, plant protection, stress tolerance
- rhizosphere (root environment)
- phyllosphere (leaf environment)
- soil microbiome is essential in soil fertility
§ Microbiome is the largest gene pool associated with plants
- needs to be considered in plant improvement strategies, practices

Epigenetics
§ Phenotypic variation due to chemical modifications on DNA or associated proteins
- heritable but less stable than nucleotide sequence
§ Can alter gene expression
§ Cause of phenotypic variation between individuals, and between parents and progeny
§ Epimutations may be induced by environmental influences
§ Role in adaptation to environment and transmitting information about ecological niches to future generations
§ Reversibility, heritability and significance needs to be explored
- genetic diversity, control of gene expression, gene modification
Research frontiers for plant breeders

§ Beier adaptation to heat and drought
  - shorter maturity cycles to reduce exposure to abiotic and biotic stress
  - effects of warmer climate on plant and animal diseases and weeds
§ Further development of hybrid wheat and rice to increase yield; rice as a C4 plant
§ Improved water and nutrient use efficiency
  - root architecture
§ Agricultural systems
  - cover crops for increased biodiversity
  - mixed crop and livestock interactions
  - perennials with soper environmental footprint (more efficient N and P use)
  - legumes in agricultural systems
    - increase biological nitrogen fixation, reduce the dependence on industrial N
    - animal production in tropical environments
    - increase legume grains in the human diet for health benefits
  - subsistence and niche crops – sorghum, cassava, millets, ...
§ Compositional changes of grain to improve end use quality and nutritional value
§ Use of genetic engineering to direct discovery of natural variants

GWAS for arabinoxylan content of tetraploid wheat


§ Arabinoxylan (AX) from cereal grains has important food functionality
§ Genetic variability of AX content was investigated in a set of 104 tetraploid wheats
§ The amount of AX in the kernel ranged from 1.8% to 5.5% with a mean value of 4.0%
§ The GWAS identified 19 QTLs associated with AX content

Gene editing

§ Ability to edit genes (make in situ modifications) to alter phenotype has been available since the 1990s
§ New gene-editing tools are customizable
  - allow changes to genes down to the level of a single nucleotide
  - insertions/deletions, silence genes, alter gene expression
  - greatly enhanced by knowledge of the genome
§ Based on a guide system that directs a nuclease enzyme to a specific site in a gene where it creates a break across both DNA strands
§ Stimulates natural DNA repair mechanisms that occur in most cell types
§ Using an added repair template, nucleotide bases may be deleted or inserted to induce gene modifications
§ Protein-based methods (TALENs, Zn finger nucleases)
§ RNA based methods (CRISPR)
CRISPR-Cas9 system

- Small RNA guide molecules (derived from Clustered Regularly Interspaced Palindromic Repeats) are associated with Cas proteins (nucleases) that cut DNA at sites complementary to the RNA
- RNA guide can be custom-made to match a specific site in a specific gene
- Based on natural bacterial defense against viral infection
- Changes made in reproductive cells will be passed on to progeny
- Other nucleases available to expand capability
- Similar principles for alternative gene editing tools

CRISPR technology

- Discovered in 2012
- Causing great excitement for potential applications in medicine and agriculture
- Capabilities and limits of CRISPR technology are still to be fully defined
- Mushrooms modified using gene-editing technology have been released in North America
  - no foreign DNA, so not considered transgenic
- Recognition that current regulations on genetic modifications do not adequately cover the use of the new gene editing tools
  - difficult to establish that an organism has been modified using CRISPR
- The hope is that gene editing will be more acceptable to consumers than transgensics
- Principle of equivalence of the final product, not method of production

Thank you for your attention