Current rate of change is unprecedented

- Digital transformation of the value chain
- Next generation biotechnologies
- Spectroscopy, imaging
- Computational biology
- Cloud computing, smart phone apps

Smart farms and supply chains

- Remote control of operations, robotics, drones
- Digital soil mapping, variable rate technologies
- Real time sensing (soil, water, plants, animals, weather)
- Process control, trace-back systems
- Internet of things
- Social media
  - era of populism
  - everyone can be an expert
Research targets for plant breeders

- Exploring genetic diversity in wild relatives of modern crops
  - Plant breeders need genetic variation (natural, generated mutants, GM)
  - Up to 95% of genetic variation lost through domestication and selective breeding

- Better adaptation to heat and drought
  - Shorter maturity cycles to reduce exposure to abiotic and biotic stress

- Improving water and nutrient use efficiency
  - Root architecture

- Salt tolerance so that more brackish water can be used for irrigation

- Further development of hybrid wheat and rice to increase yield

- Improving photosynthesis - Rubisco, reducing photorespiration, C4 rice

- Compositional changes to improve quality and nutritional value of produce

- Use of genetic engineering to direct discovery of natural variants

- Pharming

Better practices for improved genetics

- Cover crops for increased biodiversity

- Mixed cropping and livestock systems

- Perennials
  - Softer environmental footprint, more efficient N and P use

- Legumes in agricultural systems
  - Increase biological N-fix
  - Animal production in tropical environments
  - Increase legume grains in the human diet

- Subsistence and niche crops
  - Sorghum, cassava, millets, ...

In the pipeline

- Next generation sequencing
- Genome wide association studies
- Genomic prediction
- Gene editing
- Microbiomics
- Epigenetics
- Micro-analytical devices
- Synthetic biology

Next generation sequencing

Enabling technology with many applications

- Assembly of many short-read lengths
- Gigabases of sequence per day, but may have gaps

- DNA sequencing - genotyping, identifying genetic variation, genetic markers associated with QTLs, genomic selection
  - Tens of thousands of markers vs hundreds

- Over 100 plant genomes available, many crop species

- RNA sequencing – transcriptomics
  - Gene expression
  - Single cell (medicine)
    - Tissue specific profiling, plant development, cell differentiation and specialization
    - Cellular variation in stress-induced gene expression
Linking genotype to phenotype is a bottleneck

**Genomics**  DNA sequence, chromosomal location and function of all genes in a species
**Phenotype**  observable characteristics (physical, developmental, biochemical) that characterize an organism

Forward genetics
- Gene → RNA → Proteins → Phenotype

Reverse genetics
- Phenotype → Proteins → RNA → Gene

**Transcriptomics**  genes that are active/inactive under a particular set of conditions
**Proteomics**  abundance of proteins under a particular set of conditions
**Metabolomics**  abundance of small molecules under a particular set of conditions

Major advances in technologies

**Genome wide association studies**
- Determine whether a genetic variant is associated with a phenotype
- DNA from many accessions is sequenced to identify genetic variations between individuals
  - single nucleotide polymorphism (SNPs)
  - basic database for exploration
- Statistical analysis finds SNPs that occur in greater frequency among individuals with a particular phenotype (condition) than among unrelated control individuals
- Identified SNPs can be associated with specific chromosomal regions or quantitative trait loci (QTLs)

Genomic prediction
- breeding value of plants/animals for desired traits predicted from a model population that has been genotyped and phenotyped

**GWAS for arabinoxylan content of tetraploid wheat**
- Arabinxyanol (AX) from cereal grains has important food functionality
- Genetic variability and AX content was investigated in a set of 104 tetraploid wheats
- GWAS identified 19 QTLs associated with AX content


**Gene editing**
- Customizable tools to alter gene expression or silence genes (knockouts)
- Guide system directs a nuclease enzyme to create a double stranded break at a specific site in the DNA
- Natural DNA repair mechanisms can delete (insert) nucleotides as directed by a template
  - changes may be a single nucleotide
- Greatly enhanced by knowledge of the genome
- Protein-based recognition (TALENs, Zn finger nucleases)
- RNA-based recognition (CRISPR)
- No foreign DNA, so not considered transgenic
- Applications with tomatoes, maize, canola, rice, flax, cattle, ...

In humans, <10% of disease associations are in protein coding regions of genome
CRISPR technology

- Developed in 2012
- Causing great excitement for potential applications in medicine and agriculture
- Based on natural bacterial defense against viral infection
- Small RNA guide molecules (derived from Clustered Regularly Interspaced Palindromic Repeats) can be custom-made to match a specific site in a specific gene
- Changes in reproductive cells will be heritable
- Capabilities and limitations of CRISPR technology are still to be fully defined
  - off-target mutations, repair mistakes, unmapped genetic variability, few traits controlled by a single gene

Microbiomes

- Most aspects of physiology of organisms are influenced by their associated microbes
  - metagenome (sum of all genomes)
- Human gut microbiome has major influences on health and well being
- Microbes co-evolved with plants and are critical in agro-ecosystems
  - essential in soil fertility, root growth, plant nutrition, plant protection, stress tolerance
- Microbiome is the largest gene pool associated with plants
  - rhizosphere, phyllosphere, endobiome, soil
  - explored using genomics technologies
  - influence on plant improvement strategies, agricultural 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 progeny
- Reversibility, heritability and significance needs to be explored
  - genetic diversity, control of gene expression, gene modification

Micro-analytical devices

SCiO pocket-sized NIR micro-spectrometer

Consumer evaluation of produce and foods for quality, nutrition, compliance

cargill.com

MICHELLE POSSUM NUNGUARRAYI
Indigenous Australian art

www.aboriginal-art-australia.com
**Provenance - consumer interest in production, quality, nutrition**

Humane Choice True Free Range is a whole farm accreditation system for Australian and New Zealand true free range, *pasture raised* pork, beef, lamb, chicken and egg producers.

**Agri-food workforce of the future**

- **Technology capable**
- Many services will be delivered by people without an agri-food background
  - technology, data, communications
- **Larger, consolidated enterprises**
  - demand for specialist advisory services
    - agronomy, soils, water, plant and animal diseases
    - agribusiness, finance, eCommerce, risk management, ...
    - processing, logistics, marketing, regulatory issues, ...
- **Decline in need for unskilled labour**
- **Accreditation**

**Regulation**

- Current regulations on genetic modifications were formulated 30 years ago
  - the science was very different
  - no gene editing tools
  - gene editing changes within natural variation
  - difficult to detect modifications using CRISPR
- Regulation should be based on principle of equivalence of the product, not the process
- Will gene editing will be more acceptable to consumers than transgenics?
  - USA, Canada, Argentina, Germany do not consider such applications subject to regulation if transgenic crop varieties are not involved
  - Europe yet to make a decision
- How will altering DNA methylation in the future be regulated?

**Concluding thoughts (i)**

- Discovery and adoption of new technology are the keys to the future
  - new measurable indicators to observe and assess the status of a system
  - multi-disciplinary research
  - adoption of innovations not targeted to agriculture
  - identify researchable questions to make best use of the new tools
- Our ability to extract knowledge from the vast amount of accumulated information is still limited by a rudimentary understanding of biology and the natural resource base
- Technology opens up possibilities and presents options
  - socioeconomic analysis determines how it is best applied and the benefits
- Science has become too complex and is changing too rapidly for non-specialists
  - asymmetry of knowledge between scientists and the community means that decisions are based increasingly on beliefs, values and attitudes
  - people turn to trusted sources (family, friends) or social media for advice
Concluding thoughts (ii)

- Consumers have lost connection with agriculture
- Scientists need to tell their story accurately and responsibly
  - key messages in simple language but not over-trivialised
  - critique the popular media to dispel myths
  - engage more with social scientists

- Most people are in favour of innovation but fear change
- GM ingredients
  - have been in the food chain for 25 years
  - no more risky than from conventional varieties
  - GM associated with industrial agriculture, unhealthy diet
  - selective application of the precautionary principle
  - understanding hazard and risk

Thank you for your attention