1966-2016
CIMMYT

Wheat Genetics and Molecular Genetics: Past and Future

Graham Moore

1960s onwards
Wheat traits genetically dissected

- Chromosome pairing and exchange (Ph1)
- Height (Rht)
- Vernalisation (Vrn1)
- Photoperiodism (Ppd)
- Disease resistance loci
- Crossability (Kr)
- Grain Storage proteins
- Starch composition, Grain Hardness (Ha)
- Several Others……. Exploiting Ernie Sears genetic resources

PBI Cambridge,1979 onwards
Wheat Molecular Genetics established

- 1979: Dick Flavell is the first researcher in the World to successfully clone plant DNA - it was from wheat
- 1979: Peter Payne establishes the link between high molecular weight sub-units of glutenin and the strength of dough made from wheat flour – an important component of bread-making quality.
- 1983: Dick Flavell identifies and partially sequences a cluster of genes which produce the high molecular weight glutenin sub-units. We now have an understanding of the molecular basis of bread making quality
- 1985 First RFLP mapping in wheat, John Snape/Dick Flavell
- 1988 Wheat x maize double haploid production technique, David Laurie

1992 onwards
Marker systems developed to assist wheat breeding

- In 1992, first Wheat RFLP Genetic map (Mike Gale)
- Marker diversification: RAPDs, SSRs, AFLPs, SNPs
- Chip Based SNPs (820K arrays)
- Genotyping by Sequencing established
- Genomic selection implemented

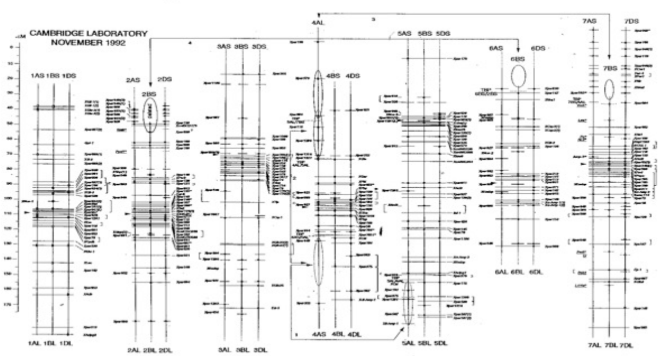
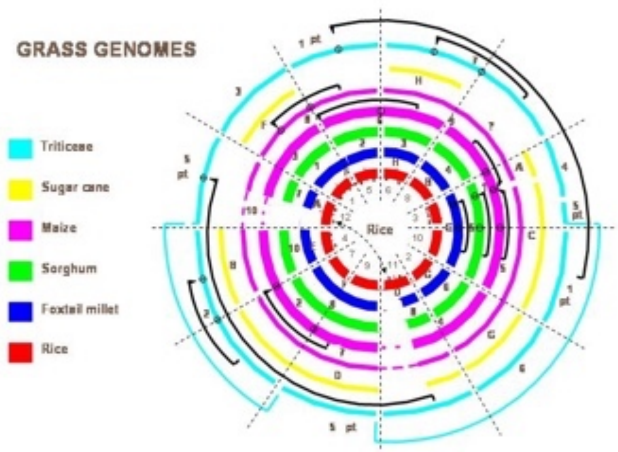


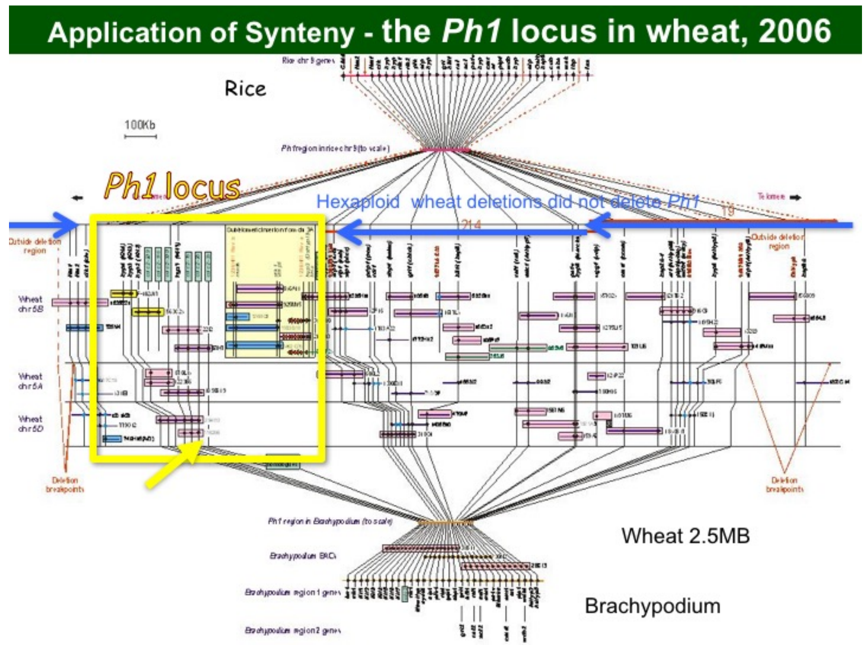
Figure 1 The Cambridge Laboratory genetic map of wheat, showing some 800 loci.

1995 onwards
Cereal synteny concept enables wheat genes controlling major traits to be identified



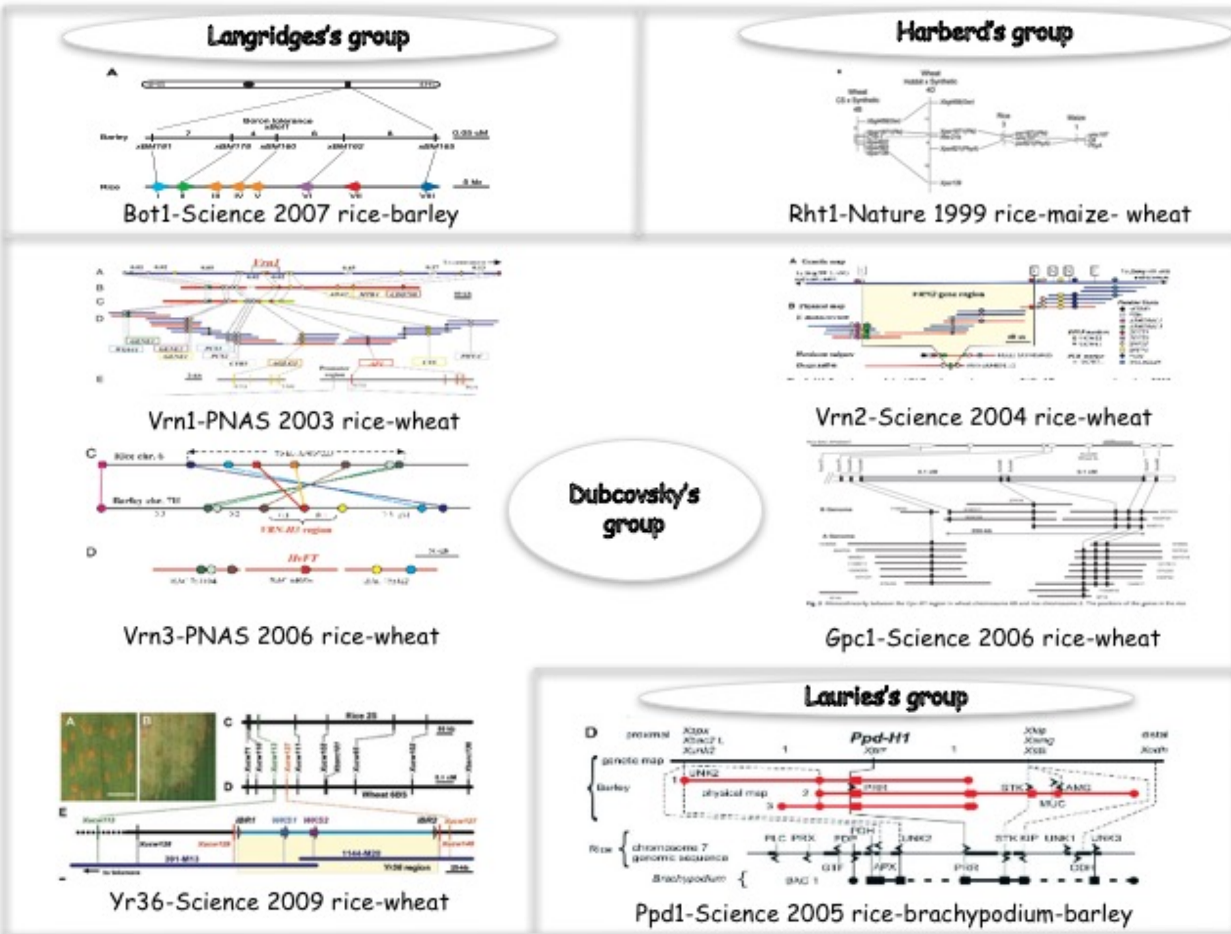
BBSRC
bioscience for the future

Moore et al, 1995
Current Biol



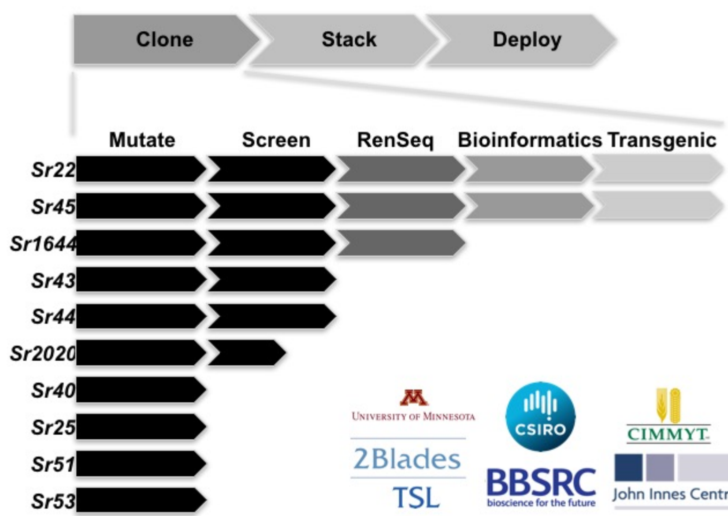
Simon Griffiths et al 2006 Nature

The wheat genes for height (Rht), vernalisation (Vrn), photoperiodism (Ppd) etc, identified exploiting synteny



Disease resistance genes

- In 1979, Roy Johnson (PBI) develops the concept of durable resistance (in wheat)
- In many cases, synteny could not be used to identify resistance genes, therefore their identification has taken longer
- However in 2015 and 2016, two techniques developed (MutRenSeq) and (MutChromSeq), which allow rapid identification of resistance genes



2016
Tools becoming available now to facilitate the rapid identification of genes for traits

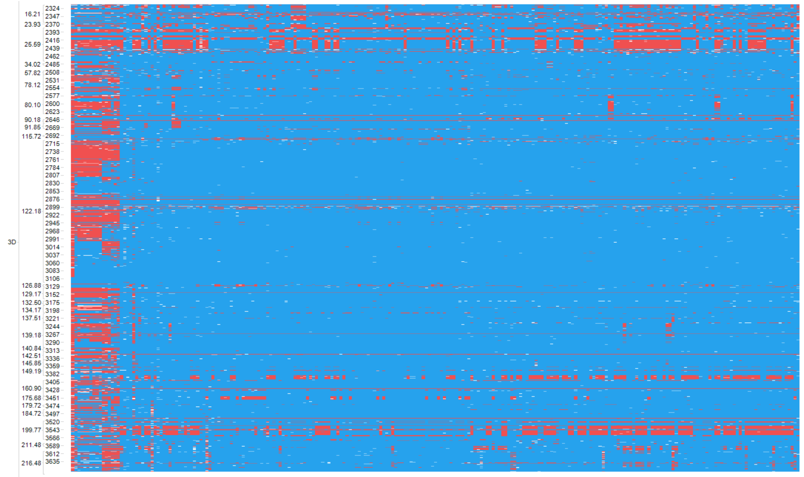
- In 2016, mutations in most wheat genes (Jorge Dubcovsky UC Davis and Cristobal Uauy JIC)
- Targeted mutations CRISPR Cas9
- In 2016, the sequence of the whole wheat genome (IWGSC Jun 2016 Jun Press release)

Wheat breeding only exploits 10% of the diversity available

now being addressed, for example UK pre-breeding programme (WISP)

- **Wild relatives** (20,000 crosses made with wild relatives)
- **Synthetics** (over 50 new synthetics made, and CIMMYT ones exploited)
- **Landraces** (over 100 loci controlling biomass and nitrogen use efficiency identified)

SNP arrays
Identify introgressions etc
+ KASP- *used in later generations*



Winfield *et al.* (2015) *Plant Biotechnology Journal*

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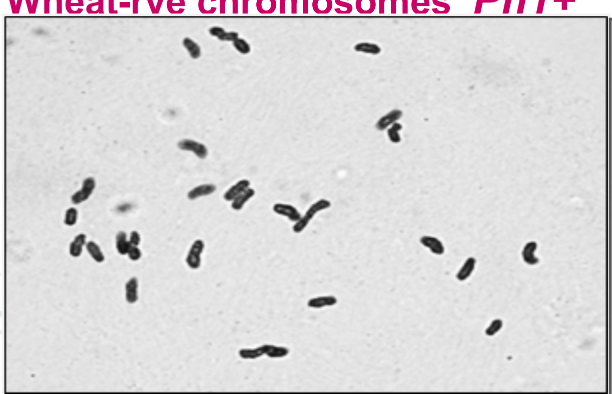
Enhanced chromosome exchange between wheat and wild relatives in wheat breeding

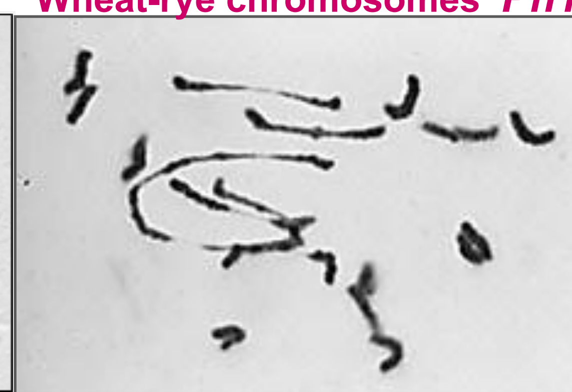
Wheat would not exist without the *Ph1* locus – it stabilises wheat as a polyploid ensuring correct chromosome pairing and exchange at meiosis

But negatively
***Ph1* also blocks chromosome exchange between wheat and wild relative chromosomes**

Wheat-rye chromosomes *Ph1+*

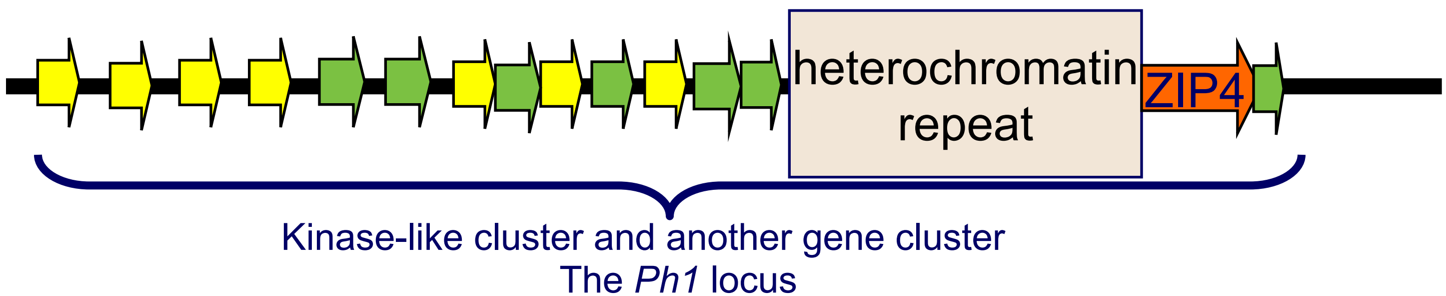


Wheat-rye chromosomes *Ph1-*



Enhanced chromosome exchange between wheat and wild relatives in wheat breeding

The *Ph1* locus is the major meiotic gene ZIP4 controlling chromosome exchange, inserted into a kinase cluster controlling chromosome pairing



In the future, enhanced exchange through either chemical treatment or manipulation of ZIP4 activity

Next 10 years in wheat

- Genome assisted 'traditional' breeding
- Manipulation of chromosome exchange for breeding
- Smart phenotyping technologies
- Basic science-understanding of key traits and the genes involved in them: yield/biomass; water usage, N , K and P use efficiency, photosynthesis; durable disease resistance; abiotic stress (heat and drought); nutritional traits including control of allergens .. To name a few…

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Next 10 years in wheat continued…

- Improved nitrogen/water use efficiency possibly through use of genes from wild relatives
- Understanding soils and rhizosphere (plant-microbe interactions) using visualisation and sequencing technologies- mixed cropping and rotation systems
- Better understanding of key processes such as flowering time
- Understanding of yield: maximizing potential in different environments, genotype x environment interactions defined
- Ability to better model and predict behaviour of wheat traits in different eco-geographies
- More consideration of nutritional quality in wheat

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What is possible in 10-20 years in wheat?

- Hybrid wheat systems and apomixis, especially for low yielding systems
- Perennial wheat crops
- Greater resource efficiency in commercial varieties (water/N/P/K)
- Manipulation of rhizosphere to improve yields and sustainability
- Take-all resistance
- More use of wheat bio-products and harvest wastes

Beyond 20 years

- Partial N fixation through transformation (in low yielding systems)
- Enhanced photosynthesis
- Improvement of wheat relatives with orphan crop characteristics