Friday 24th November 2023

Genomics and Agriculture

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SCIENCE WEEK

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University College Dublin (UCD)
www.ucd.ie

Area:	Urban campus (133 hectares)
Year founded:	1854
Faculty:	1,914
Total students:	38,417
Graduate students:	12,269
Post-Brexit:	Largest native English-speaking university in the European Union

UCD Veterinary Sciences Centre

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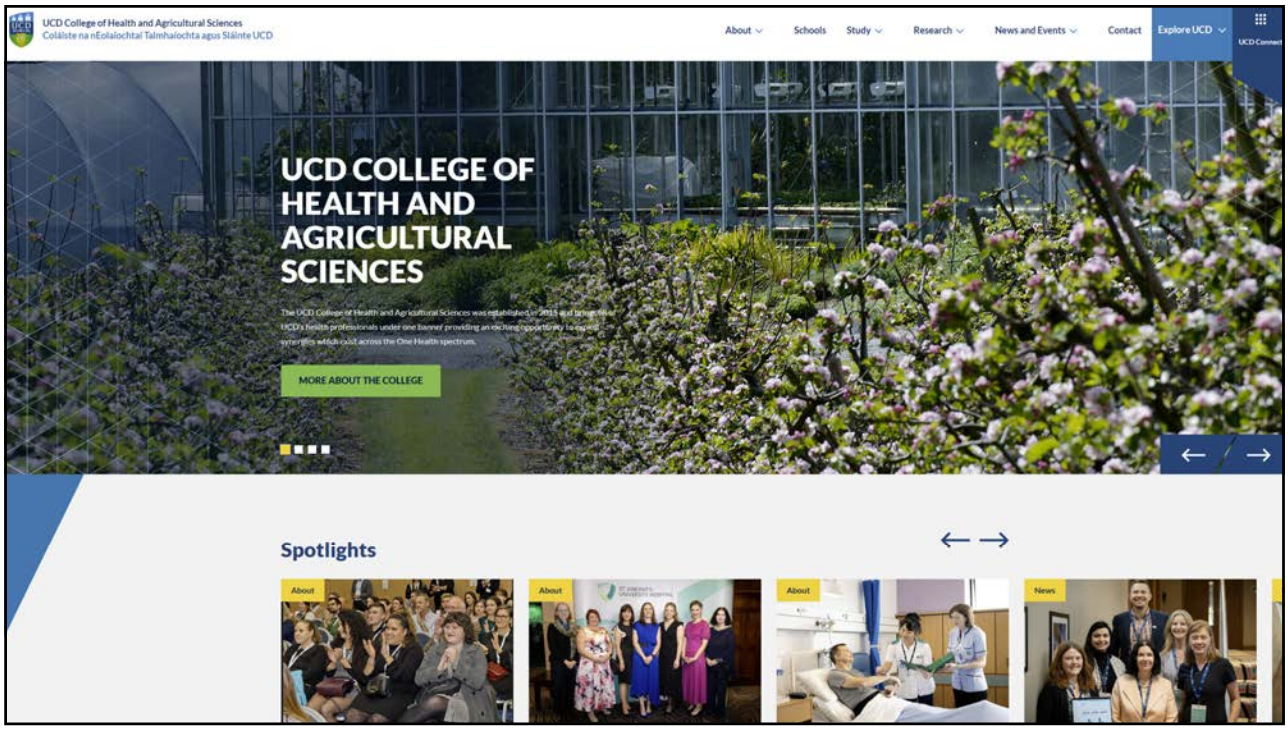

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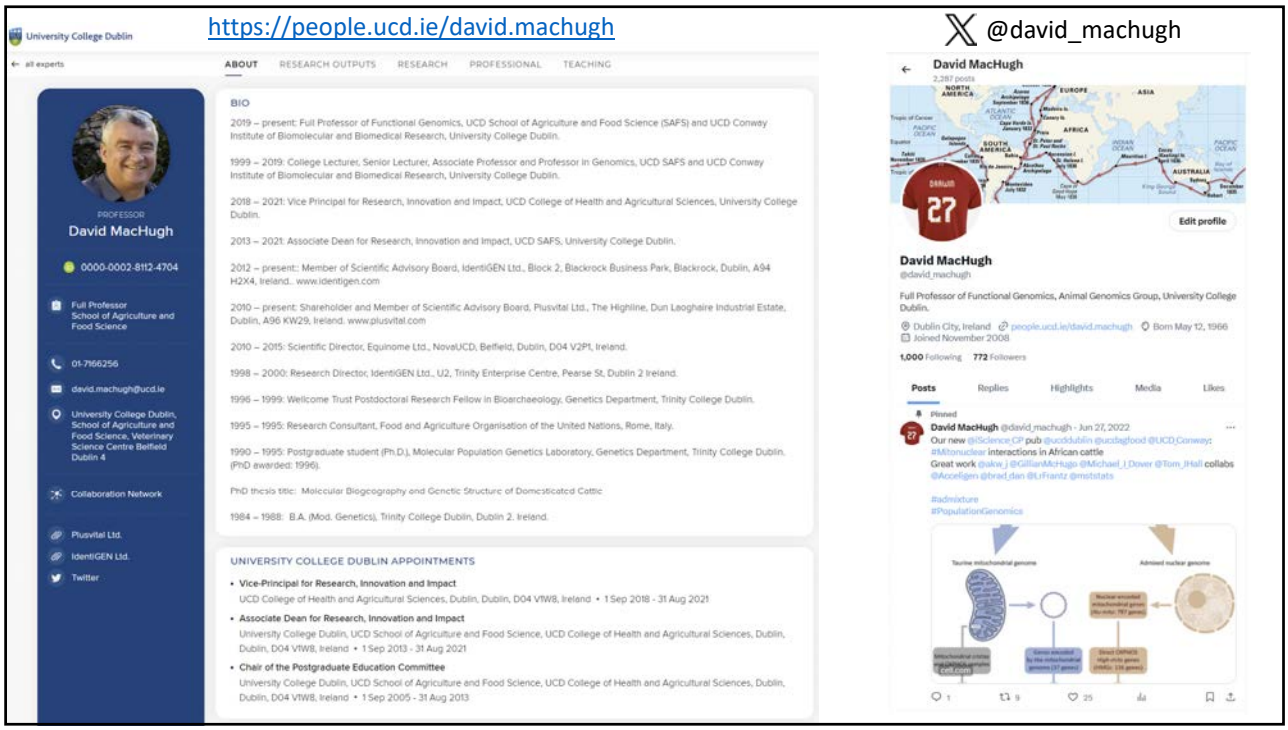
https://people.ucd.ie/david.machugh
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University College Dublin
ABOUT
RESEARCH OUTPUTS
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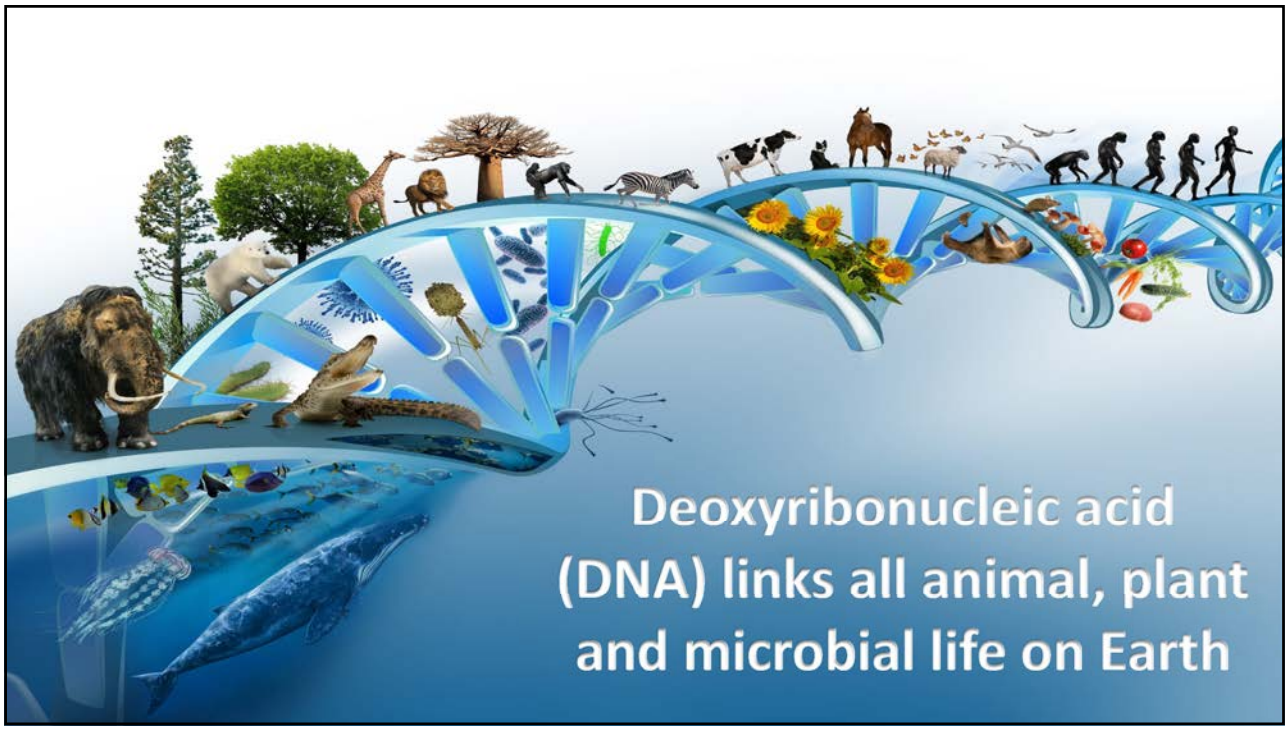
David MacHugh
Edit profile
Full Professor of Functional Genomics, Animal Genomics Group, University College Dublin.
Posts
Replies
Highlights
Media
Likes

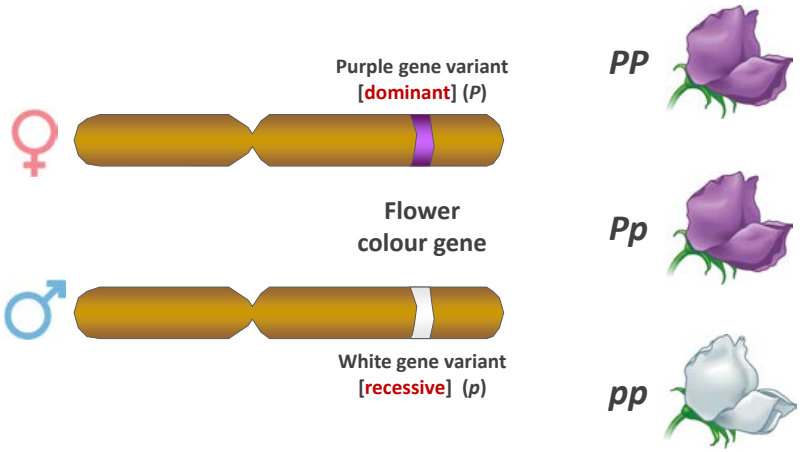
5


Deoxyribonucleic acid (DNA) links all animal, plant and microbial life on Earth

6

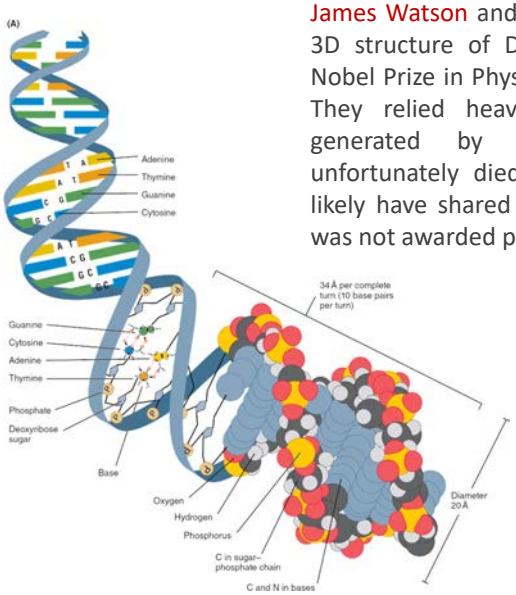
Gregor Mendel and the concept of a gene (1860s)

Pisum sativum (the pea plant)



7

The three-dimensional structure of the DNA double helix (1950s)



James Watson and Francis Crick described the 3D structure of DNA in 1953 and won the Nobel Prize in Physiology or Medicine in 1962. They relied heavily on experimental data generated by Rosalind Franklin, who unfortunately died in 1958 and who would likely have shared the Nobel Prize but that it was not awarded posthumously.

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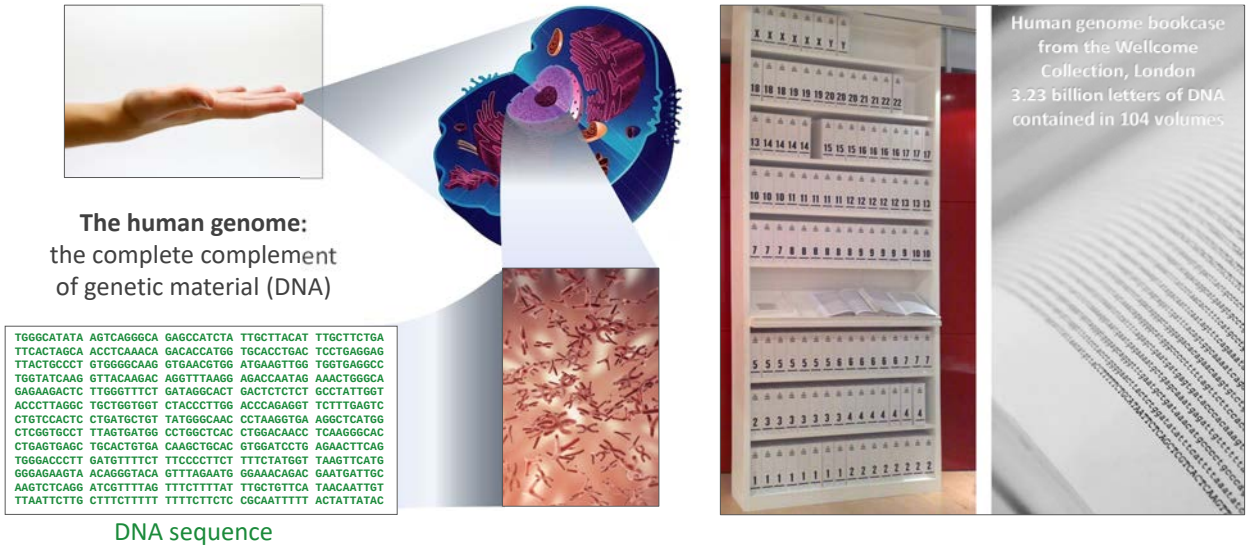
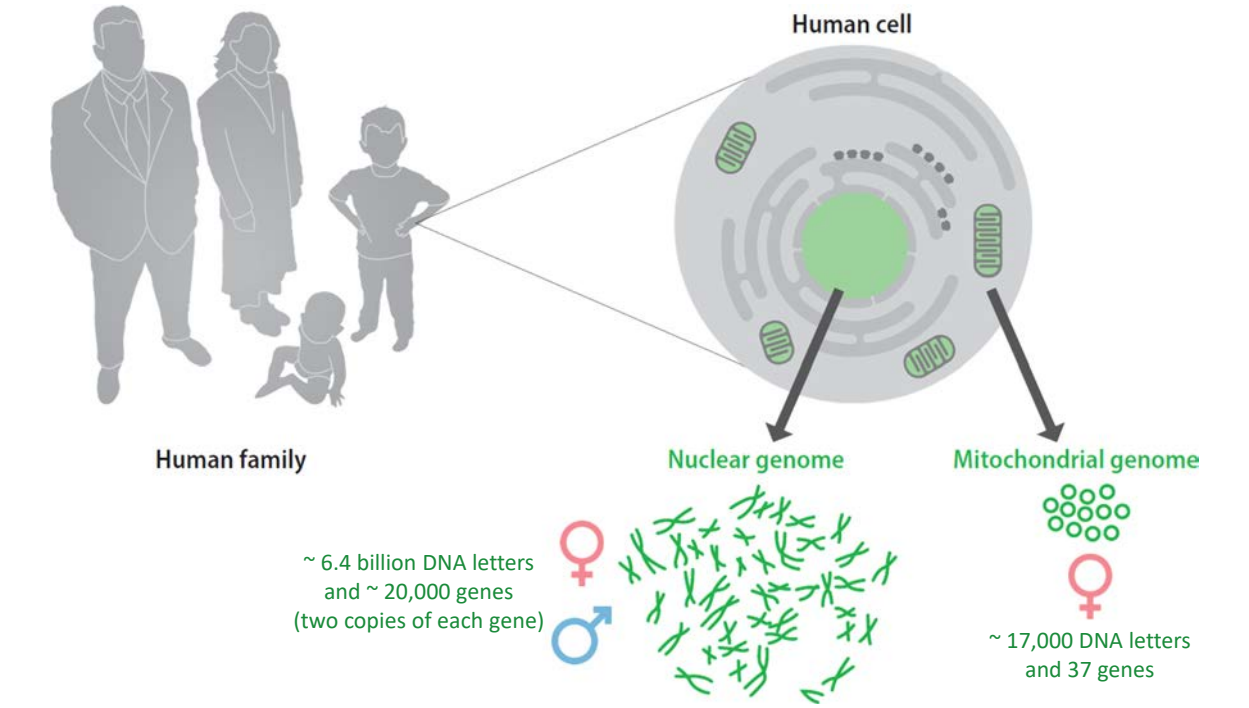
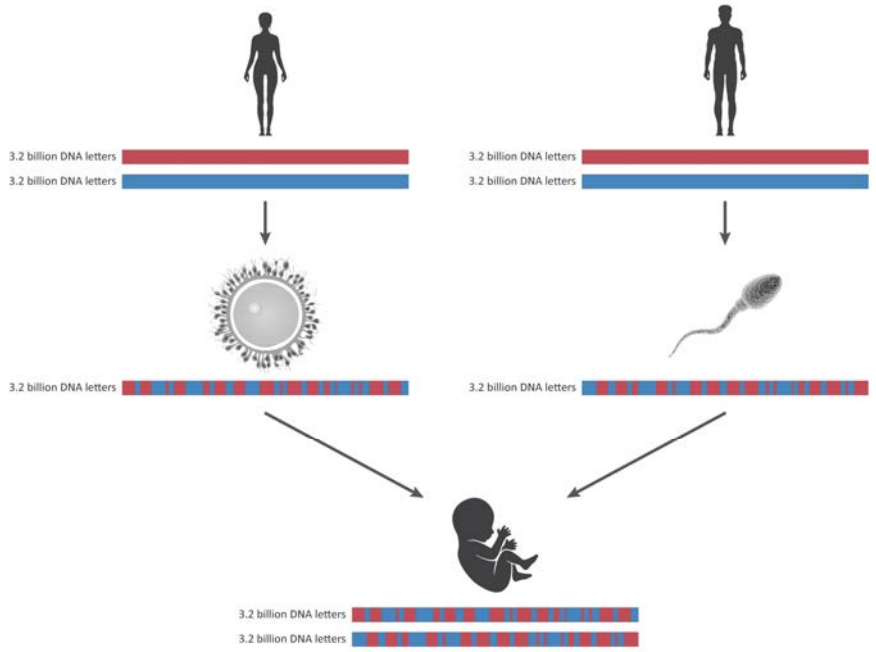

The human genome:
the complete complement
of genetic material (DNA)
TGGGCATATA AGTCAGGGCA GAGCCATCTA TTGCTTACAT TTGCTTCTGA
TTCACTAGCA ACCTCAAACA GACACCATGG TGCACCTGAC TCCTGAGGAG
TTACTGCCCT GTGGGGCAAG GTGAACGTGG ATGAAGTTGG TGGTGAGGCC
TGGTATCAAG GTTACAAGAC AGGTTTAAGG AGACCAATAG AAACTGGGCA
GAGAAGACTC TTGGGTTTCT GATAGGCACT GACTCTCTCT GCCTATTGGT
ACCCTTAGGC TGCTGGTGGT CTACCCTTGG ACCCAGAGGT TCTTTGAGTC
CTGTCCACTC CTGATGCTGT TATGGGCAAC CCTAAGGTGA AGGCTCATGG
CTCGGTGCCT TTAGTGATGG CCTGGCTCAC CTGGACAACC TCAAGGGCAC
CTGAGTGAGC TGCACTGTGA CAAGCTGCAC GTGGATCCTG AGAACTTCAG
TGGGACCCTT GATGTTTTCT TTCCCCTTCT TTTCTATGGT TAAGTTCATG
GGGAGAAGTA ACAGGGTACA GTTTAGAATG GGAAACAGAC GAATGATTGC
AAGTCTCAGG ATCGTTTTAG TTTCTTTTAT TTGCTGTTCA TAACAATTGT
TTAATTCTTG CTTTCTTTTT TTTTCTTCTC CGCAATTTTT ACTATTATAC
DNA sequence
Human genome bookcase
from the Wellcome
Collection, London
3.23 billion letters of DNA
contained in 104 volumes

9


Human cell
Human family
Nuclear genome
Mitochondrial genome
~ 6.4 billion DNA letters
and ~ 20,000 genes
(two copies of each gene)
~ 17,000 DNA letters
and 37 genes

10



11

Holstein-Friesian (European)	Holstein-Friesian (European)	Jersey (European)	Adamawa Gudali (African)
CCATGAACTCCCAACGGTATTGCA	CCATGAACTCCCAACGGTATTGCA	CCATGAACTCCCAACGGTATTGCA	CCATGAACTCTCAACGGTATTGCA
ACGACAGGGATGCCGGCCGCGCTT	ACGACAGGGATGCCGGCCGCGCTT	ACGACAGGGATGCCGGCCGCGCTT	ACGACAGGGATGCCGGCCGCGCTT
TCCTCTGCTTTCTACCTCCGGACG	TCCTCTGCTTTCTACCTCCGGACG	TCCTCTGCTTTCTACCTCTGGACG	TCCTCTGCTTTCTACCTCCGGACG
TGCGTTTGACCCAAGCAGTATAGA	TGCGTTTGACCCAAGCAGTATAGA	TGCGTTTGACCCAAGCAGTATAGA	TGCGTTTGACCCAAGCAGTATAGA
GCACCCGTCCATTTTTCAGACTTA	GCACCCGTCCATTTTTCAGACTTA	GCACCCGTCCATTTTTCAGACTTA	GCACCCGTCCATTTTTCAGACTTA
GGTAGACATTGGAGTATCTCCAAA	GGTAGGCATTGGAGTATCTCCAAA	GGTAGACATTGGAGTATCTCCAAA	GGTAGGCATTGGAGTATCTTCAAA
CCAGAACACACGAATGCTATTCCT	CCAGAACACACGAATGCTATTCCT	CCAGAACACACGAATGCTATTCCT	CCAGAACACACGAATGCTATTCCT
ACTTAGGTTCTCTAAATCCGGAAG	ACTTAGGTTCTCTAAATCCGGAAG	ACTTAGGTTCTCTAAATCCGGAAG	ACTTAGGTTCTCTAAATCCGGAAG
TGCTTACCTTAAAAATCGCGGAGT	TGCTTACCTTAAAAATCGCGGAGT	TGCTTATCTTAAAAATCGCGGAGT	TGCTTACCTTAAAAATCGCGGAGT
CGTACATCTATCTAACTTACGTGA	CGTACATCTATCTAACTTACGTGA	CGTACATCTATCTAACTTACGTGA	CGTACATCTATCTAACTTACGTGA
TTTGTTGCAACTGTTCCTGCTAGA	TTTGTTGCAACTGTTCCTGCTAGA	TTTGTTGCAACTGTTCCTGCTAGA	TTTGTTGCAGCTGTTCCTGCTAGA
ACCAGAGGCCGATGGTACTTCCCT	ACCAGAGGCCGATGGTACTTCCCT	ACCAGAGGCCGATGGTACTTCCCT	ACCAGAGGCCGATGGTACTTCCCT
ACGGACATCTCGACTAAGGAGCTC	ACGGACATCTCGACTAAGGAGCTC	ACGGACATCTCGACTAAGGAGCTC	ACGGACATCTCGACTAAGGAGCTC
CTTAGGTACGCAGTATCTGCCCGG	CTTAGGTACGCAGTATCTGCCCGG	CTTAGGTACGCAGTATCTGCCCGG	CTTAGGTACGCAGTATCTGCCCGA
TAGTCGTCTACTTGTATATGACGA	TAGTCGTCTACTTGTATATGACGA	TAGTCGTCTACTTGTATATGACGA	TAGTCGTCTACTTGTATATGACGA
TTAATAACCAAATACATCTATGAT	TTAATAACCAAATACATCTATGAT	TTAATAACCAAATACATCTATGAT	TTAATAACCAAACACATCTATGAT
GGGAAGGCTGGAGATCACGTTTGC	GGGAAGGCTGGAGATCACGTTTGC	GGGAAGGCTGGAGATCACGTTTGC	GGGAAGGCTGGAGATCACGTTTGC
TCAGGACTCCACTTCCTCTTCGTC	TCAGGACTCCACTTCCTCTTCGTC	TCAGGACTCCACTTCCTCTTCGTC	TCAGGACTCCACTTCCTCTTCGTC
ATCGCCCTACCCGAGCTGCCCCTA	ATCGCCCTACCCGAGCTGCCCCTA	ATCGCCCTACCCGAGCTGCTCCTA	ATCGCCCTACCCGAGCTGCCCCTA
GAGGATGAGAAGGGTCGAGTTGCA	GAGGACGAGAAGGGTCGAGTTGCA	GAGGATGAGAAGGGTCGAGTTGCA	GAGGATGAGAAGGGTCGAGTTGCG
TCTTGACGGCGGCCGACCGTGAGT	TCTTGACGGCGGCCGACCGTGAGT	TCTTGACGACGGCCGACCGTGAGT	TCTCGACGGCGGCCGACCGTGAGT
TATAAGAAGGTATACAGCAGAAAT	TATAAGAAGGTATACAGCAGAAAT	TATAAGAAGGTATACAGCAGAAAT	TATAAGAAGGTGTACAGCAGAAAT

The technical term for a DNA "spelling" difference in a genome sequence is **single-nucleotide polymorphism (SNP)**

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Genome
DNA sequence information

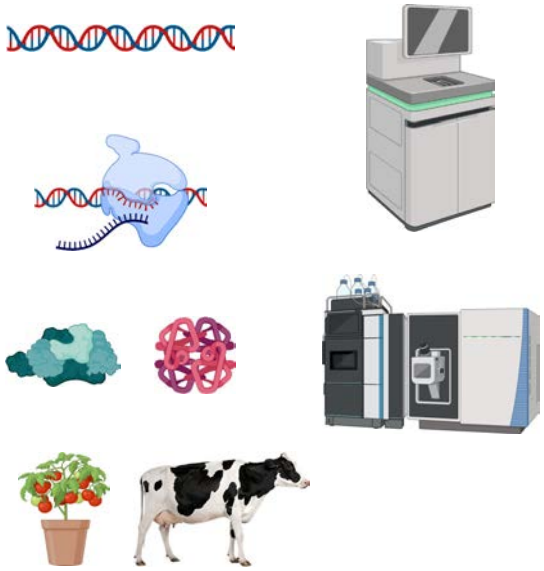
Transcription

Transcriptome
RNA copies of active genes

Translation

Proteome
Cell and tissue protein repertoires

Phenome
Phenotype of a complex organism



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The cost to sequence a mammalian genome in 2001 versus 2022

Mammalian genome sequence cost (2001)

Super Yacht (> €100,000,000)

Mammalian genome sequence cost (2022)

Inflatable dinghy (€400)
[note: soon to be ~ €200 (2023)]

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Genetic (genomic) modification of plants and animals since the dawn of agriculture

Genetic (genomic) modification of plants and animals using modern biotechnologies

Genome-enabled breeding (genomic selection)

Discussion and Q&A

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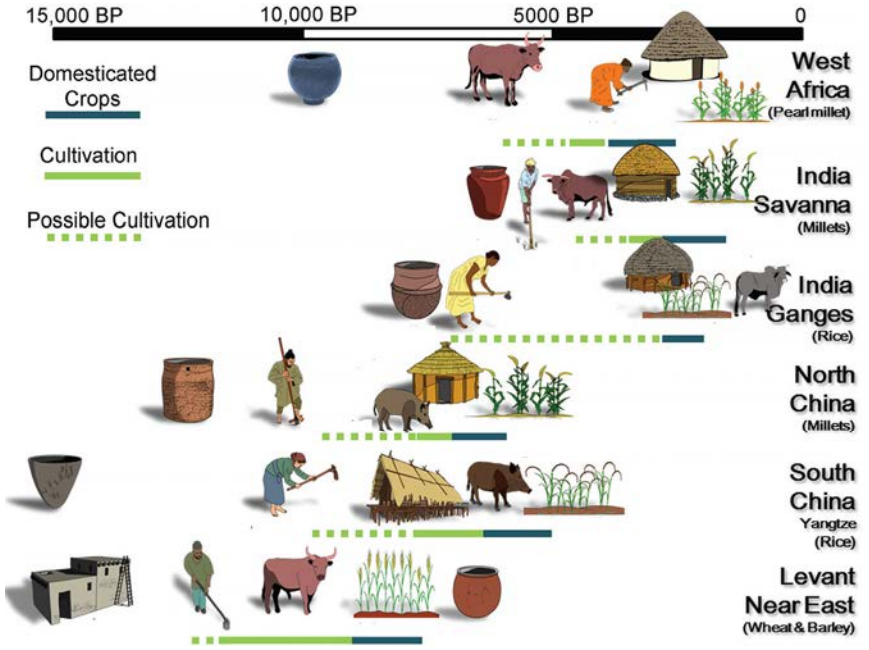

Fuller D.Q., *et al.* (2015) Comparing pathways to agriculture. *Archaeology International* **18**, 61-6, doi: 10.5334/ai.1808.

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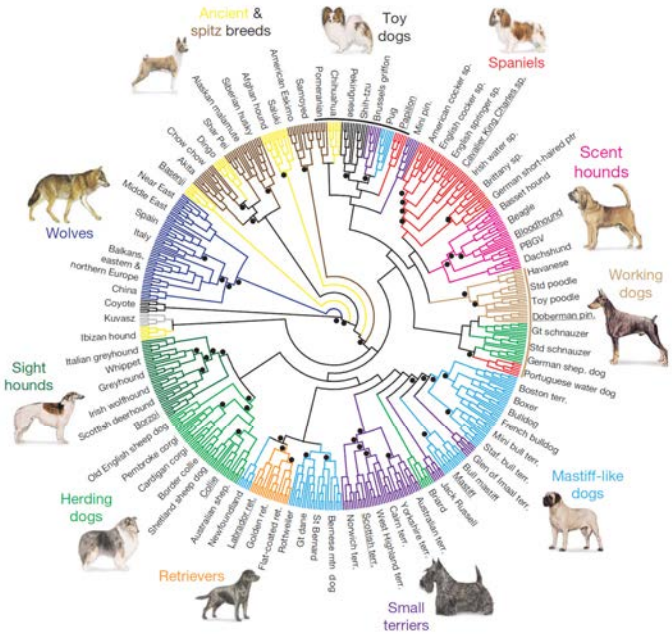
Canis lupus lupus (Eurasian wolf)

Canis lupus familiaris (domestic dog)



Vonholdt B.M., *et al.* (2010) Genome-wide SNP and haplotype analyses reveal a rich history underlying dog domestication. *Nature 464*, 898-902. DOI: 10.1038/nature08837.

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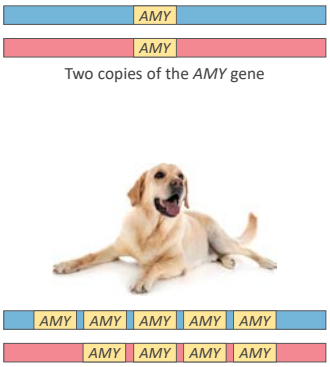
Salivary amylase enzyme produced by the amylase gene (*AMY*) (digests starch)



Axelsson E., *et al.* (2013) The genomic signature of dog domestication reveals adaptation to a starch-rich diet. *Nature* **495**, 360-4. DOI: 10.1038/nature08837

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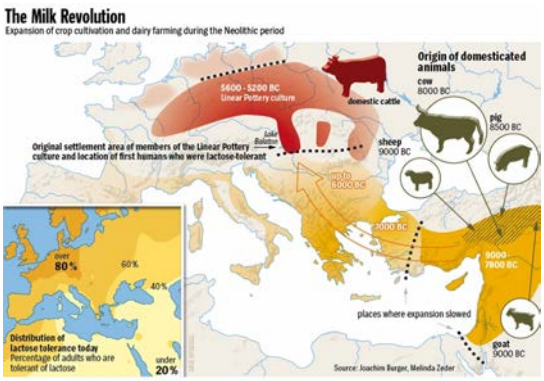
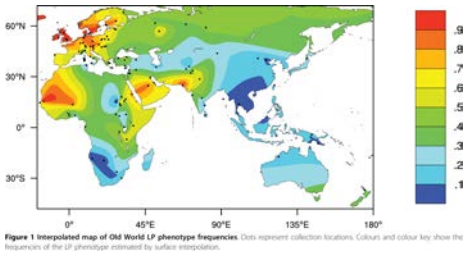
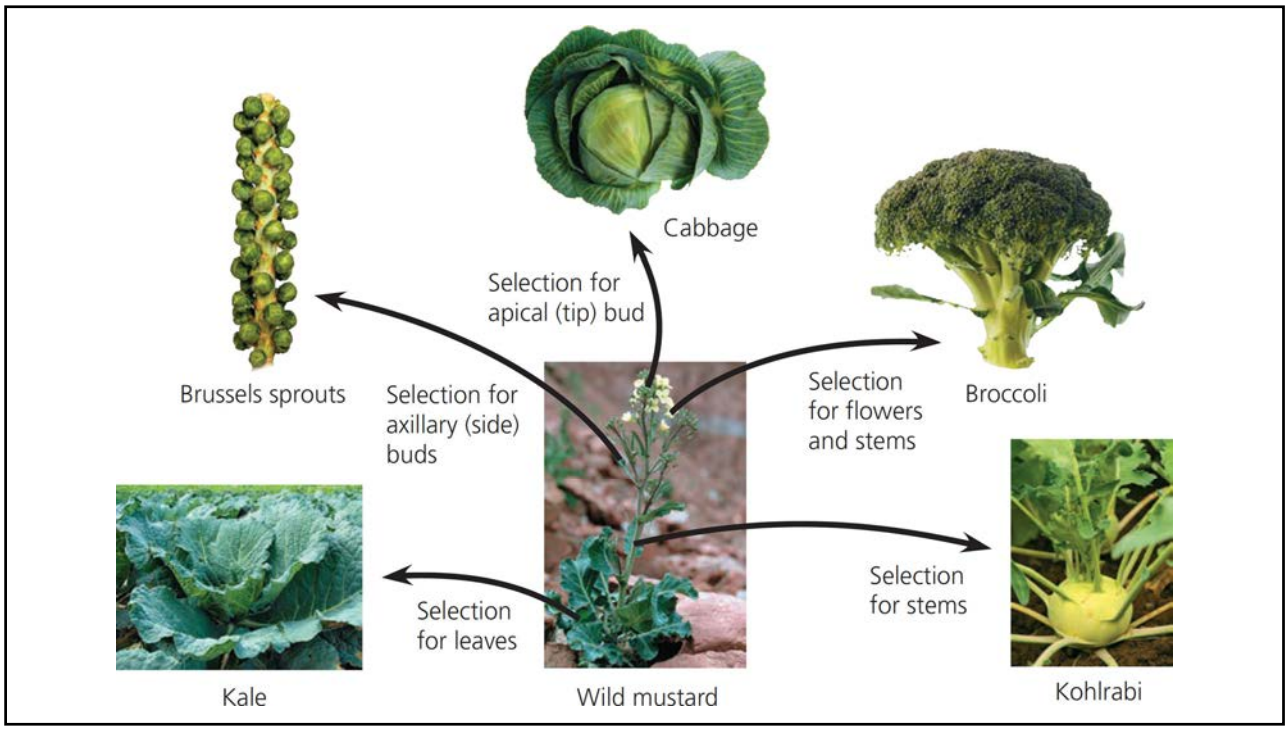


Lactase enzyme digests the sugar lactose in dairy foods



Itan Y., *et al.* (2010) A worldwide correlation of lactase persistence phenotype and genotypes. BMC Evol. Biol. 10, 36. DOI: 10.1186/1471-2148-10-36.

20


Cabbage
Selection for apical (tip) bud
Brussels sprouts
Selection for axillary (side) buds
Selection for flowers and stems
Broccoli
Selection for stems
Selection for leaves
Kale
Wild mustard
Kohlrabi

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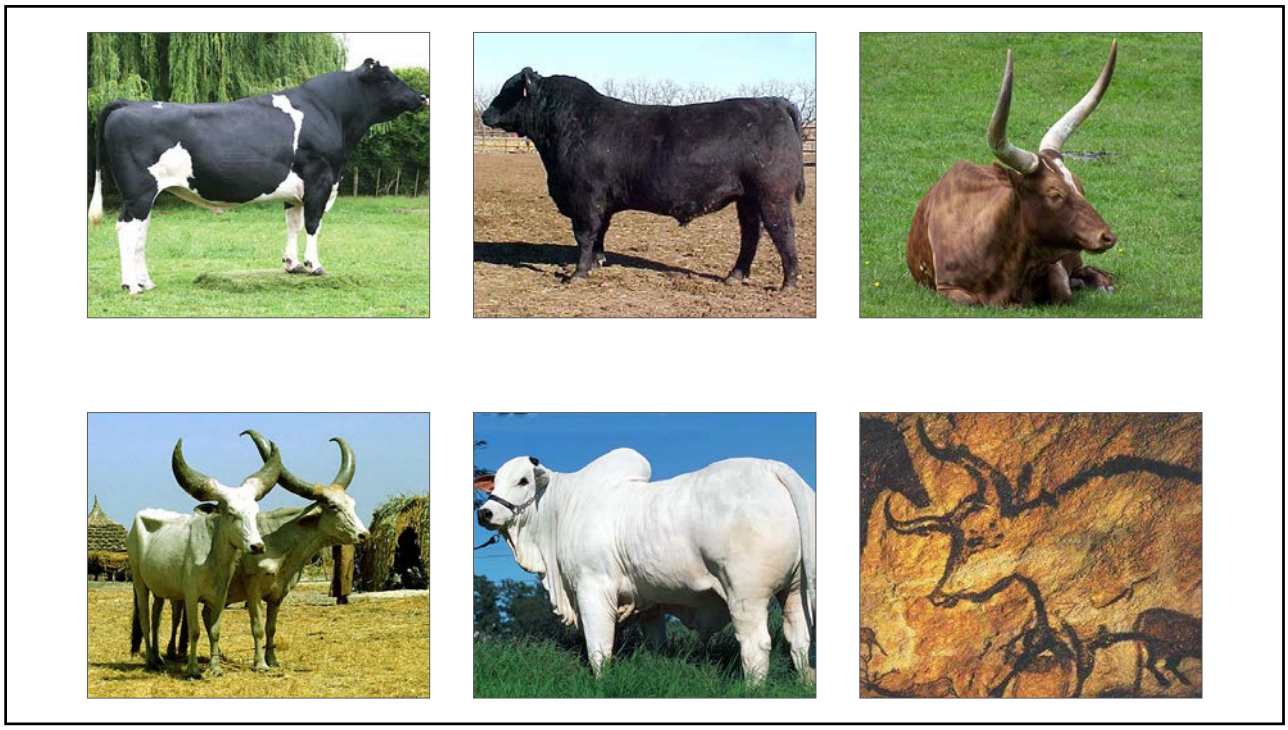

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Park *et al. Genome Biology* (2015) 16:234
DOI 10.1186/s13059-015-0790-2

Genome Biology

RESEARCH Open Access

Genome sequencing of the extinct Eurasian wild aurochs, *Bos primigenius*, illuminates the phylogeography and evolution of cattle

Stephen D E Park[1], David A. Magee[2,3], Paul A. McGettigan[2], Matthew D. Teasdale[4], Ceiridwen J. Edwards[5], Amanda J. Lohan[6], Alison Murphy[6], Martin Braud[7], Mark T. Donoghue[7], Yuan Liu[8], Andrew T. Chamberlain[9], Kévin Rue-Albrecht[7], Steven Schroeder[10], Charles Spillane[7], Shuaishuai Tai[8], Daniel G. Bradley[9], Tad S. Sonstegard[10,11], Brendan J. Loftus[6,12] and David E. MacHugh[2,6*]

Abstract

Background: Domestication of the now-extinct wild aurochs, *Bos primigenius*, gave rise to the two major domestic extant cattle taxa, *B. taurus* and *B. indicus*. While previous genetic studies have shed some light on the evolutionary relationships between European aurochs and modern cattle, important questions remain unanswered, including the phylogenetic status of aurochs, whether gene flow from aurochs into early domestic populations occurred, and which genomic regions were subject to selection processes during and after domestication. Here, we address these questions using whole-genome sequencing data generated from an approximately 6,750-year-old British aurochs bone and genome sequence data from 81 additional cattle plus genome-wide single nucleotide polymorphism data from a diverse panel of 1,225 modern animals.

Results: Phylogenomic analyses place the aurochs as a distinct outgroup to the domestic *B. taurus* lineage, supporting the predominant Near Eastern origin of European cattle. Conversely, traditional British and Irish breeds share more genetic variants with this aurochs specimen than other European populations, supporting localized gene flow from aurochs into the ancestors of modern British and Irish cattle, perhaps through purposeful restocking by early herders in Britain. Finally, the functions of genes showing evidence for positive selection in *B. taurus* are enriched for neurobiology, growth, metabolism and immunobiology, suggesting that these biological processes have been important in the domestication of cattle.

Conclusions: This work provides important new information regarding the origins and functional evolution of modern cattle, revealing that the interface between early European domestic populations and wild aurochs was significantly more complex than previously thought.

Keywords: Ancient DNA, Aurochs, *Bos primigenius*, Cattle, Domestication, Evolution, Genome, Hybridization

Park S.D., *et al.* (2015) Genome sequencing of the extinct Eurasian wild aurochs, *Bos primigenius*, illuminates the phylogeography and evolution of cattle. *Genome Biol.* **16**, 234, doi: 10.1186/s13059-015-0790-2.

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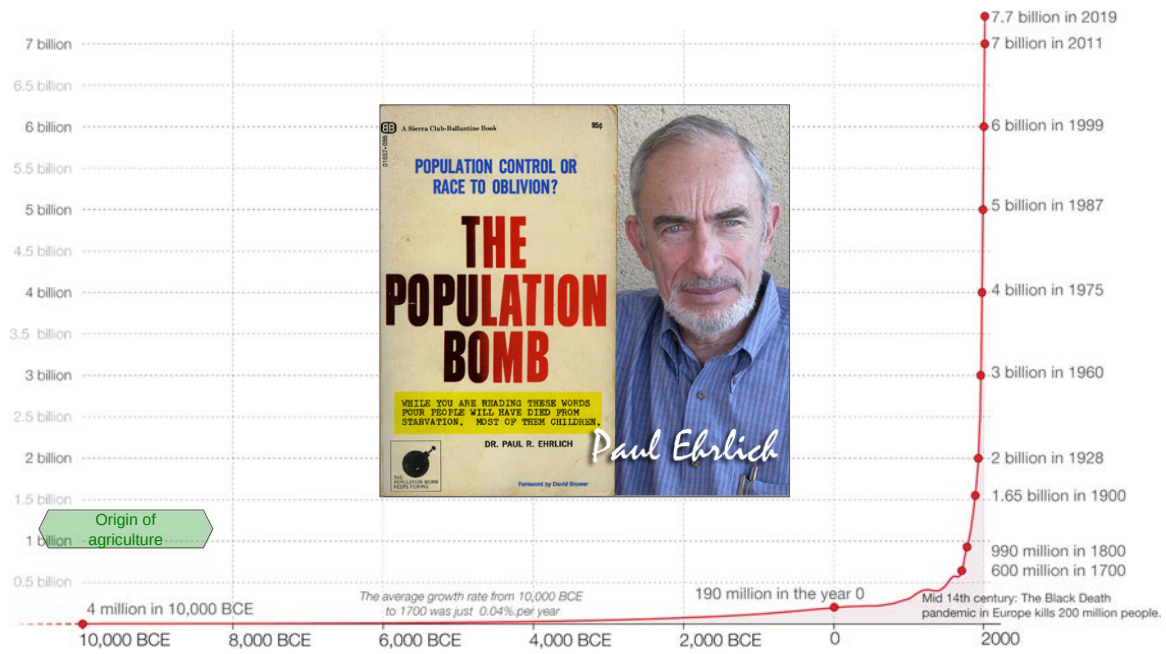
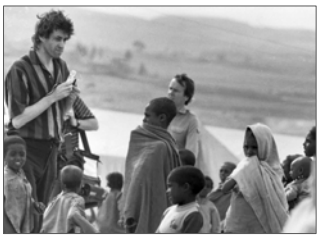


Source: Our World in Data – ourworldindata.org

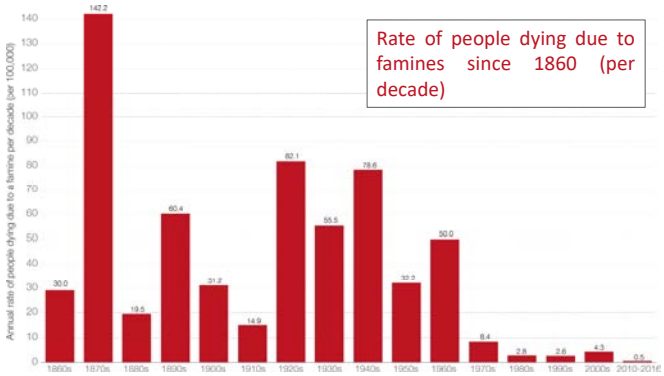
25

Bengal (1943) ~ 3 million deaths

China (1959-61) ~ 25 million deaths



Ethiopia (1983-85) ~ 1.2 million deaths



Source: Our World in Data – ourworldindata.org

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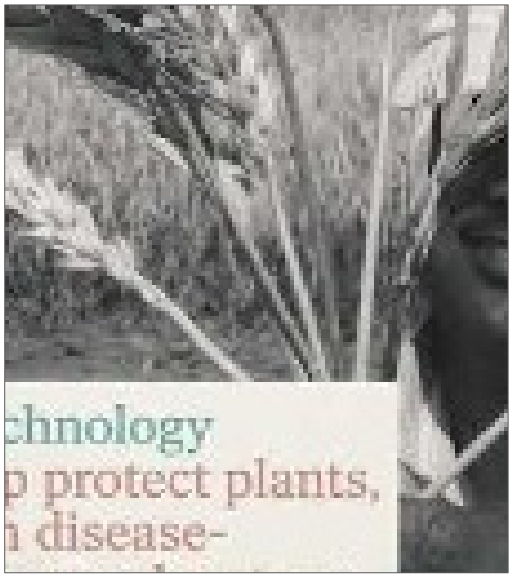
Norman Borlaug: "Father" of the Green Revolution
Winner of the Nobel Peace Prize in 1970



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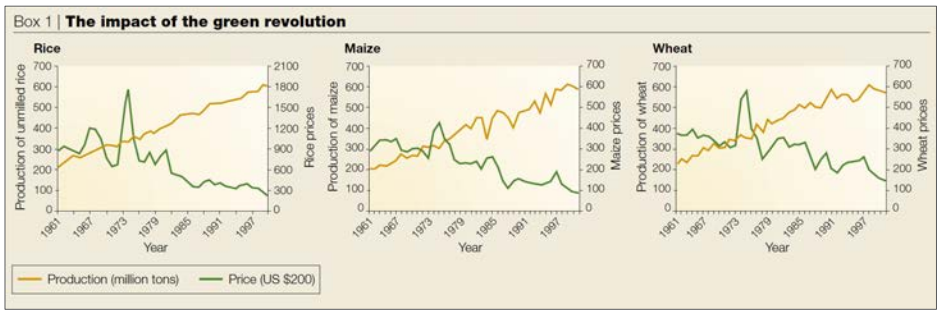

Figure 1 | **Sketches of different plant types of rice.** Left, tall conventional plant type. Centre, improved high-yielding, high-tillering plant type. Right, new plant type ('Super Rice') with low tillering but sturdier stems, and with a larger number of grains per panicle. (Reproduced with permission from IRRI. Ie.)

Khush G.S. (2001) Green revolution: the way forward. *Nat. Rev. Genet.* **2**, 815-22. DOI: 10.1038/35093585.

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Mutation breeding to rapidly generate new crop and horticultural plant varieties

'Gamma field' at the Institute of Radiation Breeding in Japan. 100 m radius. Radioactive cobalt source in the middle - 88.8 TBq

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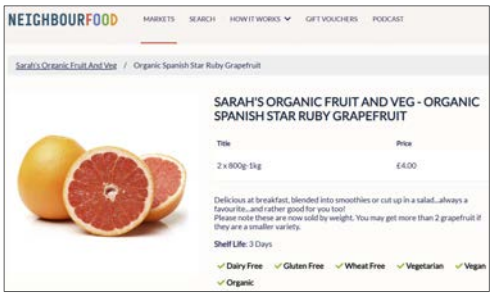
Examples of crops and fruit varieties bred using radiation–mutation breeding

"*Creso*" Durum pasta wheat (1974)

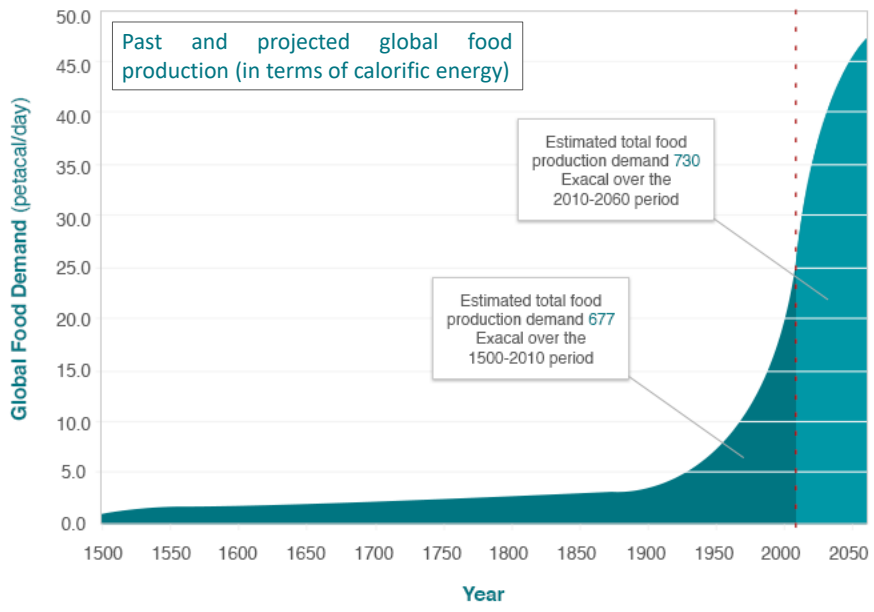
"*Golden Promise*" spring barley (1950s)

"*Osa Gold*" pear (1990s)



"*Star Ruby*" red/pink grapefruit (1960s)

30



Source – CSIRO: www.csiro.au (exacal = 10^{18} calories [10^{15} kilocalories])

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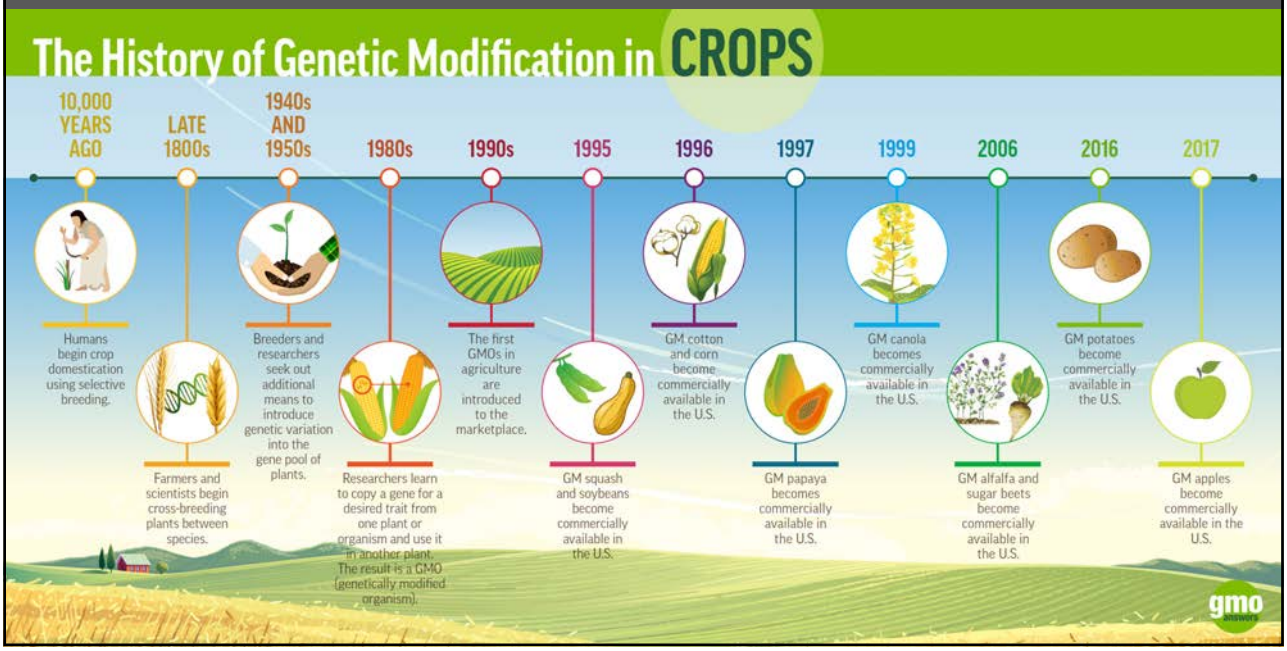
Genetic engineering: The *Gene Revolution*?



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How are GMO plants made?

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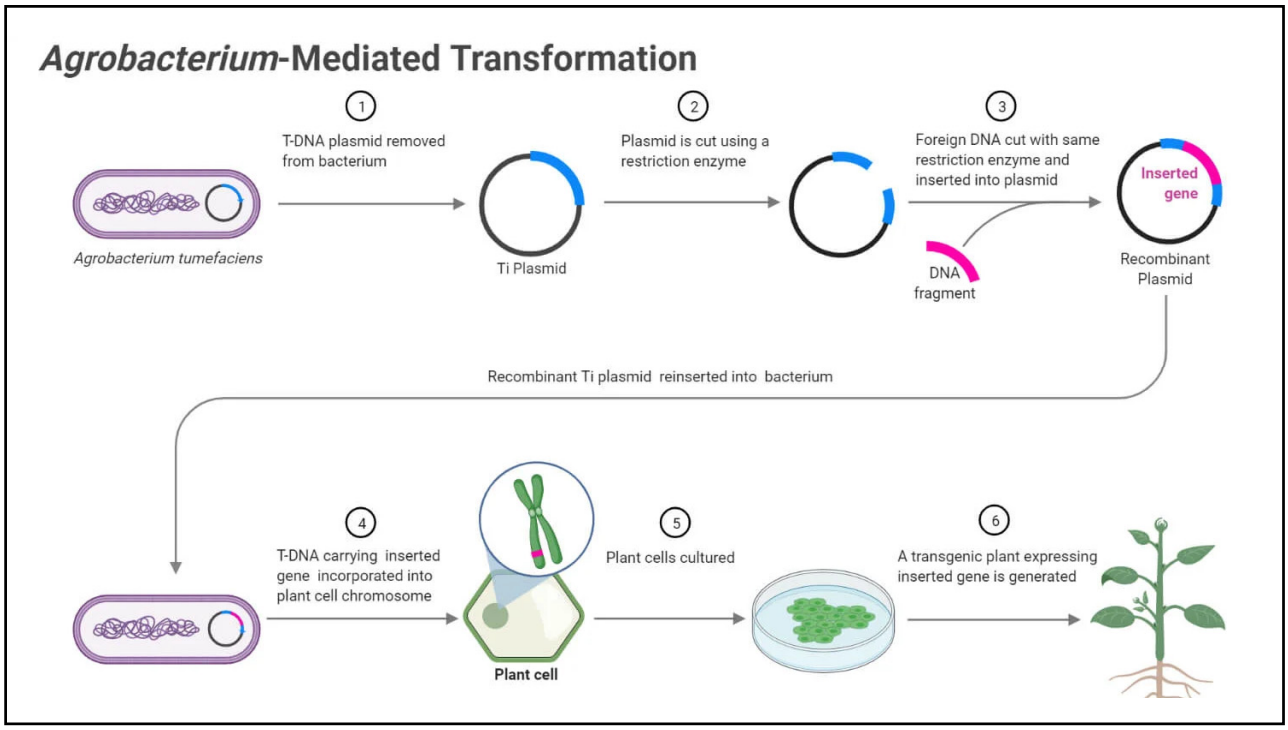
Agrobacterium-Mediated Transformation
1
T-DNA plasmid removed from bacterium
Agrobacterium tumefaciens
Ti Plasmid
2
Plasmid is cut using a restriction enzyme
3
Foreign DNA cut with same restriction enzyme and inserted into plasmid
DNA fragment
Inserted gene
Recombinant Plasmid
Recombinant Ti plasmid reinserted into bacterium
4
T-DNA carrying inserted gene incorporated into plant cell chromosome
Plant cell
5
Plant cells cultured
6
A transgenic plant expressing inserted gene is generated

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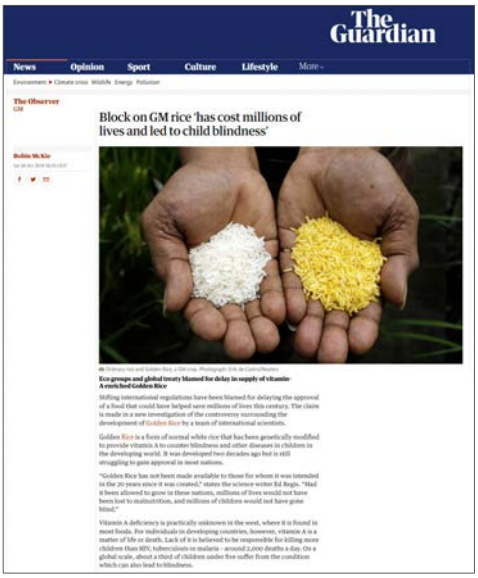

GREENPEACE

NON GMO Project

Friends of the Earth

Soil Association

www.theguardian.com/environment/2019/oct/26/gm-golden-rice-delay-cost-millions-of-lives-child-blindness

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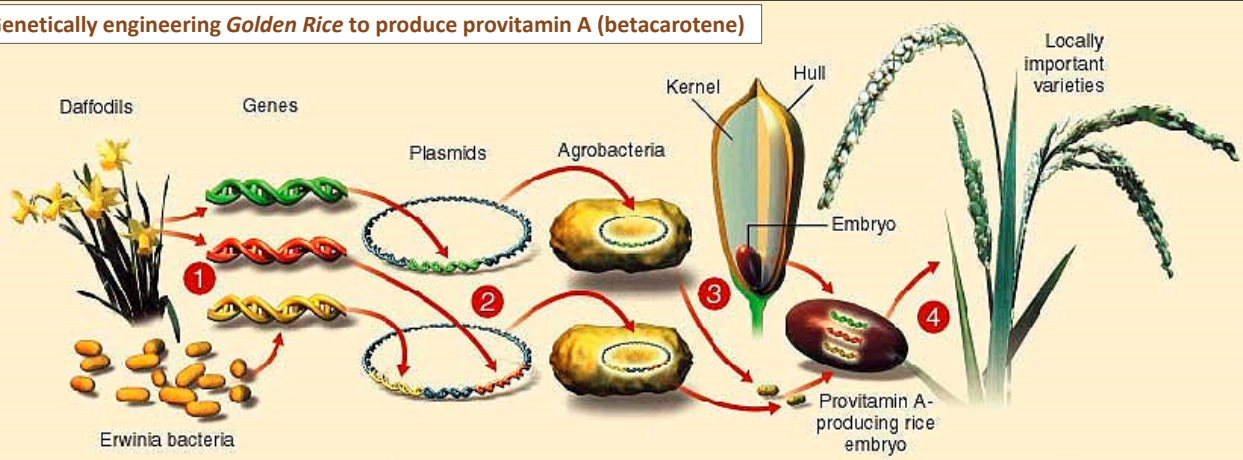
Genetically engineering *Golden Rice* to produce provitamin A (betacarotene)



1 The genes that give golden rice its ability to make beta-carotene in its endosperm (the interior of the kernel) come from daffodils and a bacterium called Erwinia uredovora

2 These genes, along with promoters (segments of DNA that activate genes), are inserted into plasmids (small loops of DNA) that occur inside a species of bacterium known as Agrobacterium tumefaciens

3 These agrobacteria are then added to a Petri dish containing rice embryos. As they "infect" the embryos, they also transfer the genes that encode the instructions for making beta-carotene

4 The transgenic rice plants must now be crossed with strains of rice that are grown locally and are suited to a particular region's climate and growing conditions

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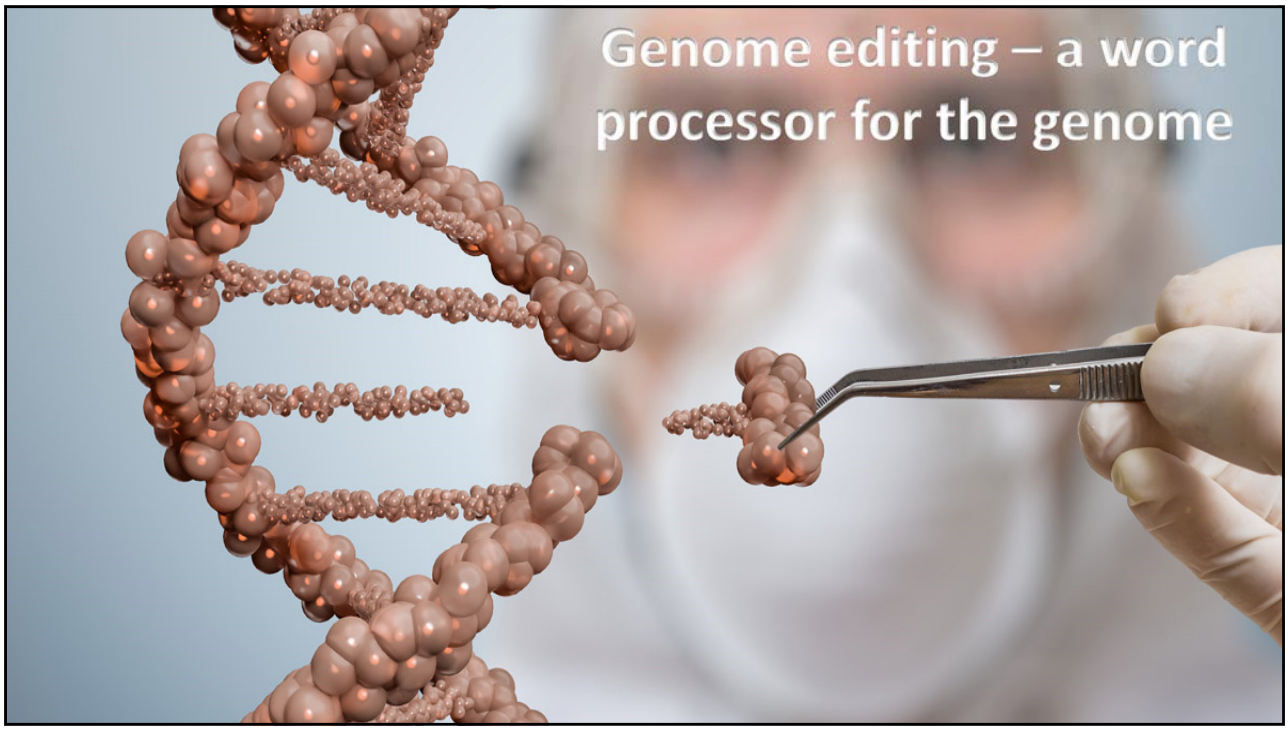

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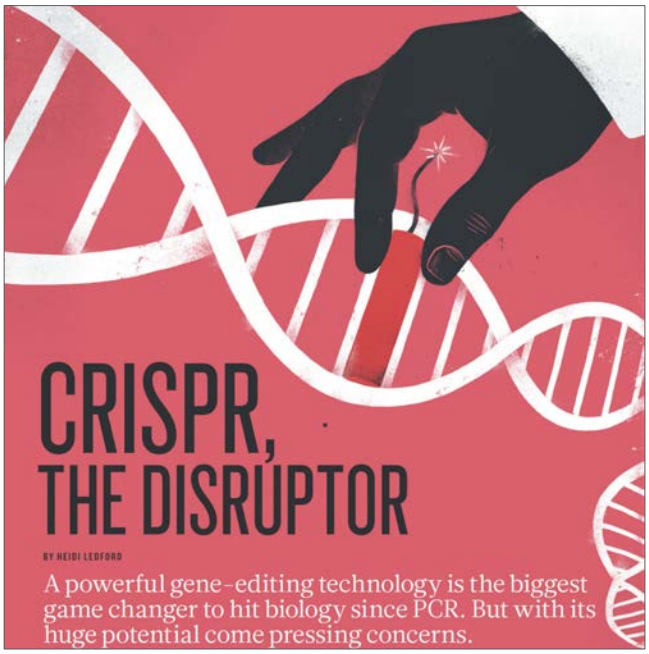

Ledford H. (2015) CRISPR, the disruptor. *Nature* **522**, 20-4.

National Geographic, August 2016

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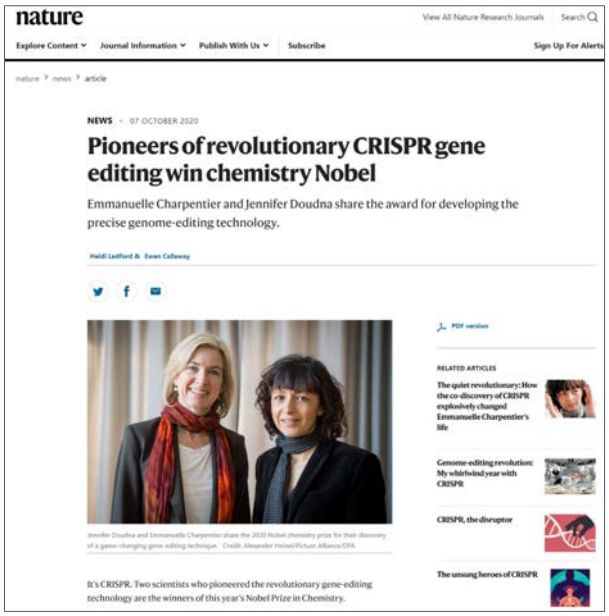

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NEWS · 07 OCTOBER 2020

Pioneers of revolutionary CRISPR gene editing win chemistry Nobel

Emmanuelle Charpentier and Jennifer Doudna share the award for developing the precise genome-editing technology.

Heidi Ledford & Ewen Callaway

PDF version

Jennifer Doudna and Emmanuelle Charpentier share the 2020 Nobel chemistry prize for their discovery of a game-changing gene-editing technique. Credit: Alexander Heinel/Picture Alliance/DPA

It's CRISPR. Two scientists who pioneered the revolutionary gene-editing technology are the winners of this year's Nobel Prize in Chemistry.

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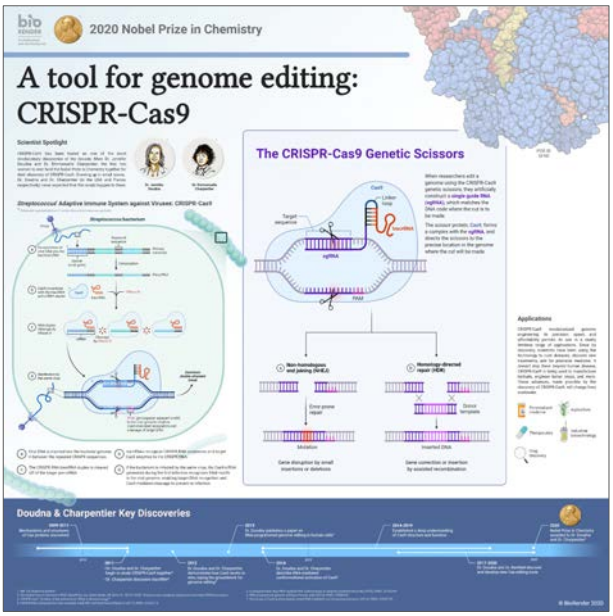

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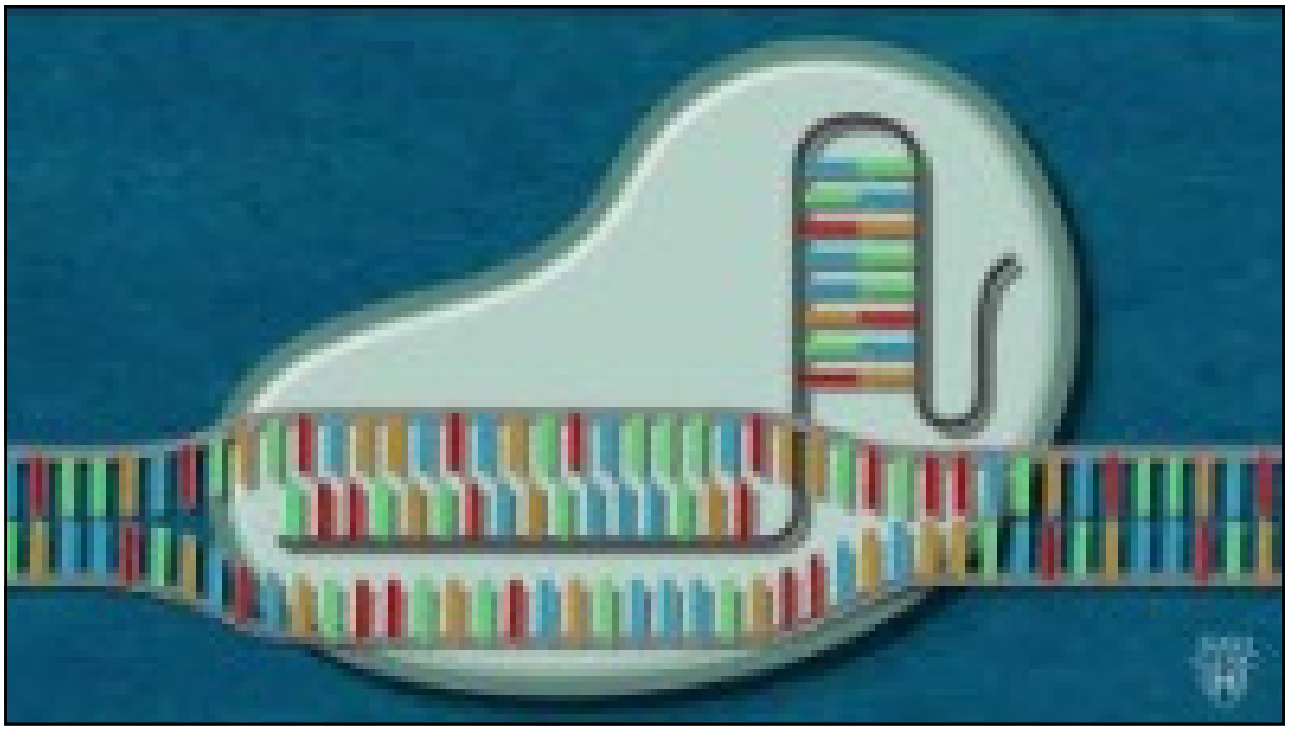

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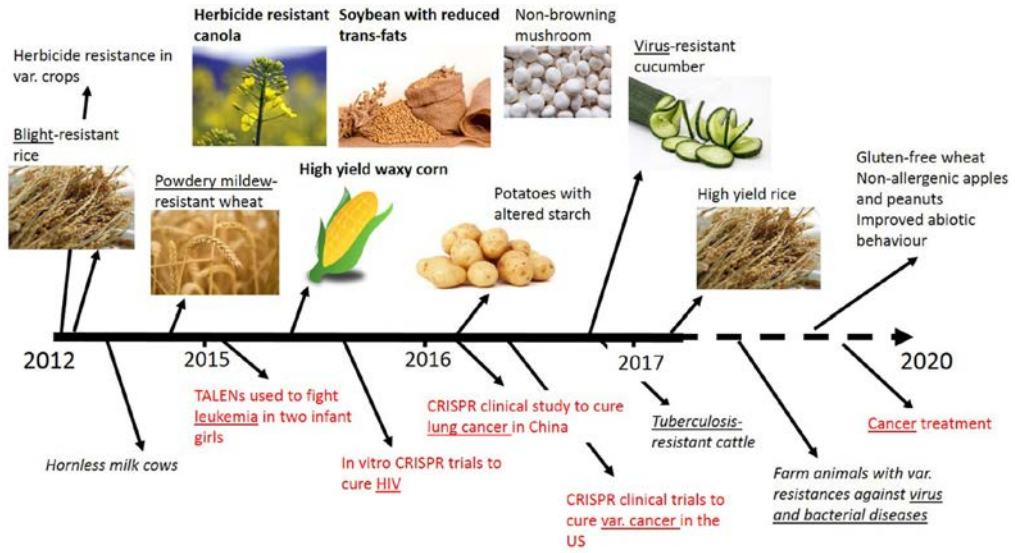

FIGURE 3 | Timeline of selected traits modified by genome editing in plants, animals and for medical applications (red). Addressed diseases are underlined. Bold front: Applied for non-regulated status in the USA. No permissions were required for the use of the images[7].

Duensing N., *et al.* (2018) Novel features and considerations for ERA and regulation of crops produced by genome editing. *Front Bioeng Biotechnol* **6**, 79, DOI: 10.3389/fbioe.2018.00079.

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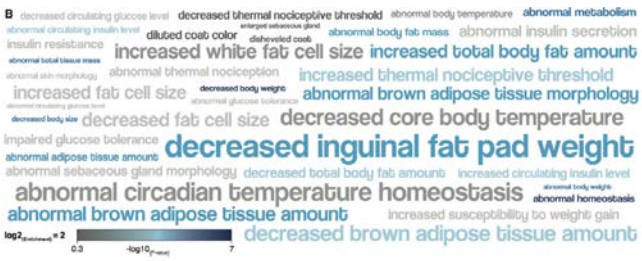
The woolly mammoth paleogenome is fully sequenced: Harvard University has plans to use genome editing to resurrect this extinct species

Mammuthus primigenius

Asian elephant
Elephas maximus

George Church (Harvard)



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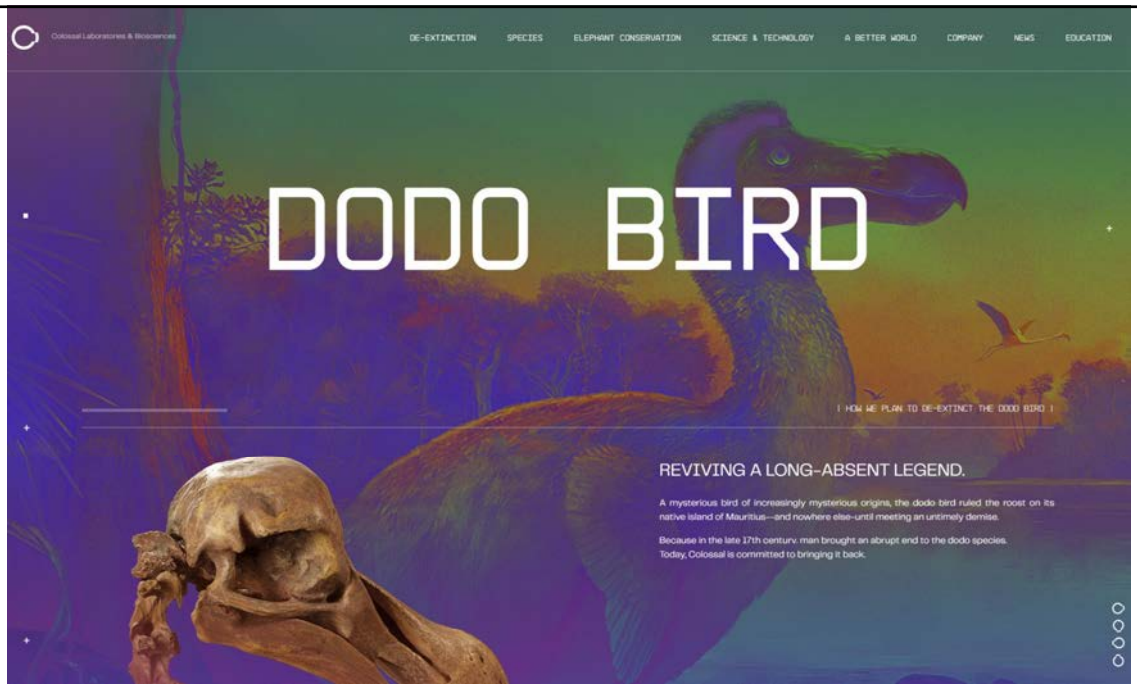

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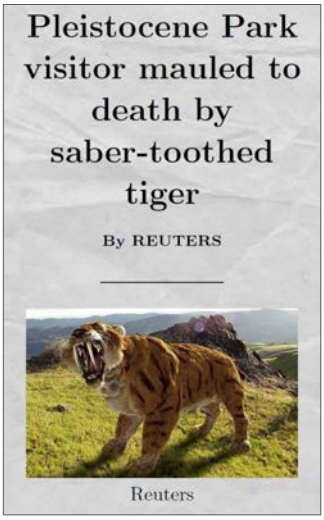

Pleistocene Park visitor mauled to death by saber-toothed tiger

By REUTERS

Reuters

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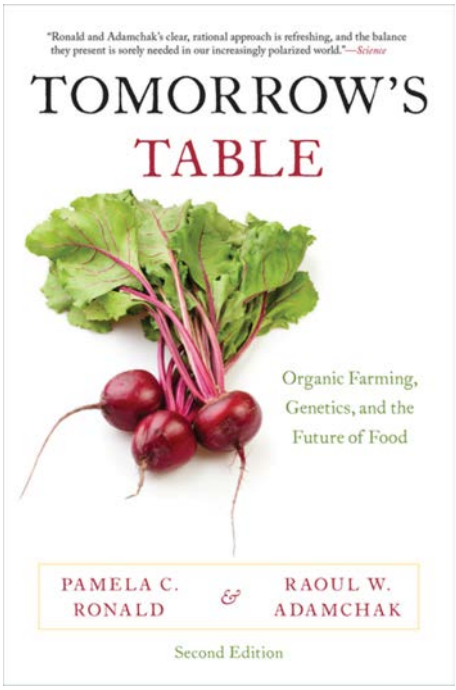

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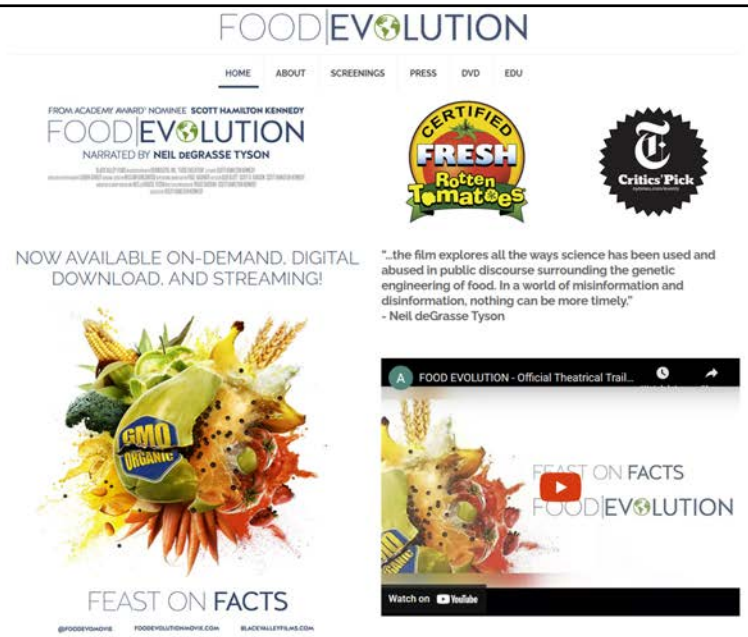

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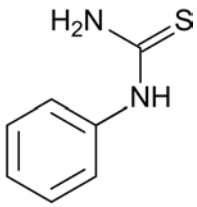
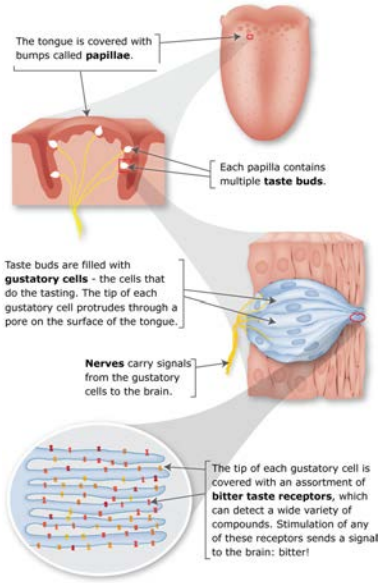
The phenylthiocarbamide (PTC) taste test
Tasting/non-tasting is due to a SNP in the *TAS2R38* gene



C/C	C/G	G/G
Can taste PTC ~25% of Europeans	Can taste PTC ~50% of Europeans	Cannot taste PTC ~25% of Europeans



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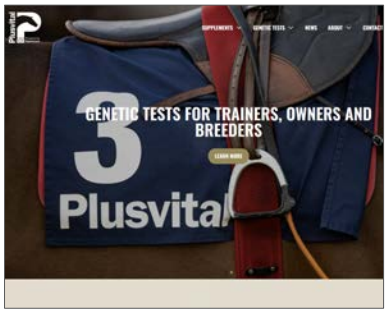
Declaration of agricultural genomics/biotechnology commercial interests



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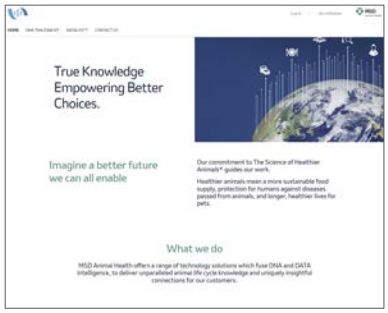

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