

CG920 Genomics

Lesson 12

Practical Applications

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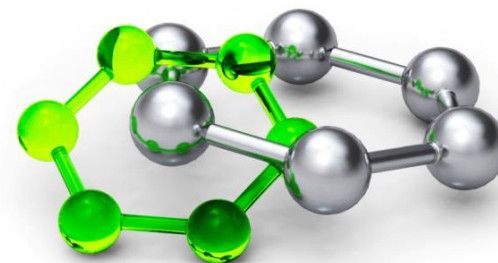
And

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M U N I
S C I



Literature

- Broughton, J.P., Deng, X., Yu, G., Fasching, C.L., Servellita, V., Singh, J., Miao, X., Streithorst, J.A., Granados, A., Sotomayor-Gonzalez, A., Zorn, K., Gopez, A., Hsu, E., Gu, W., Miller, S., Pan, C.Y., Guevara, H., Wadford, D.A., Chen, J.S., and Chiu, C.Y.** (2020). CRISPR-Cas12-based detection of SARS-CoV-2. *Nat Biotechnol* **38**, 870-874.
- Dietel, M., and Sers, C.** (2006). Personalized medicine and development of targeted therapies: The upcoming challenge for diagnostic molecular pathology. A review. *Virchows Arch* **448**, 744-755.
- Gaudelli, N.M., Komor, A.C., Rees, H.A., Packer, M.S., Badran, A.H., Bryson, D.I., and Liu, D.R.** (2017). Programmable base editing of A*T to G*C in genomic DNA without DNA cleavage. *Nature* **551**, 464-471.
- Goh, K.I., Cusick, M.E., Valle, D., Childs, B., Vidal, M., and Barabasi, A.L.** (2007). The human disease network. *Proc Natl Acad Sci U S A* **104**, 8685-8690.
- Chen, J.S., Ma, E., Harrington, L.B., Da Costa, M., Tian, X., Palefsky, J.M., and Doudna, J.A.** (2018). CRISPR-Cas12a target binding unleashes indiscriminate single-stranded DNase activity. *Science* **360**, 436-439.
- Koblan, L.W., Erdos, M.R., Wilson, C., Cabral, W.A., Levy, J.M., Xiong, Z.M., Tavares, U.L., Davison, L.M., Gete, Y.G., Mao, X., Newby, G.A., Doherty, S.P., Narisu, N., Sheng, Q., Krilow, C., Lin, C.Y., Gordon, L.B., Cao, K., Collins, F.S., Brown, J.D., and Liu, D.R.** (2021). In vivo base editing rescues Hutchinson-Gilford progeria syndrome in mice. *Nature*.
- Li, X., Qian, X., Wang, B., Xia, Y., Zheng, Y., Du, L., Xu, D., Xing, D., DePinho, R.A., and Lu, Z.** (2020). Programmable base editing of mutated TERT promoter inhibits brain tumour growth. *Nat Cell Biol* **22**, 282-288.

Outline

- **Medicine**
 - Molecular Diagnosis
 - Personalized Medicine
 - Gene Therapy
- **Biotechnology**
- **Genetically Modified Organisms**
 - Transgenesis
 - Genome Editing
- **Model Organisms**
- **Principles of PCR**

Outline

- Medicine
 - Molecular Diagnosis

Molecular Diagnosis

- around 10,000 disorders in humans resulting from a single mutation
 - cystic fibrosis
 - sickle cell disease
 - muscular dystrophy
 - beta thalassemia
 -
- Early molecular diagnosis
 - mutations or infections
 - PCR
 - DNA (chip) hybridization
 - Cas-based

Molecular Diagnosis

- Mammoth Biosciences
 - Co-founded by Jenifer Doudna

<https://youtu.be/IPe4IdgKGdQ>



Outline

- Medicine
 - Molecular Diagnosis
 - Personalized Medicine

Personalized Medicine

- uses knowledge of the genome for:
 - prediction of health risks
 - diagnosis
 - selection of the most appropriate type of treatment
 - minimizing the side effects of treatment
 - prevention

Personalized Medicine

What is Personalized Medicine?

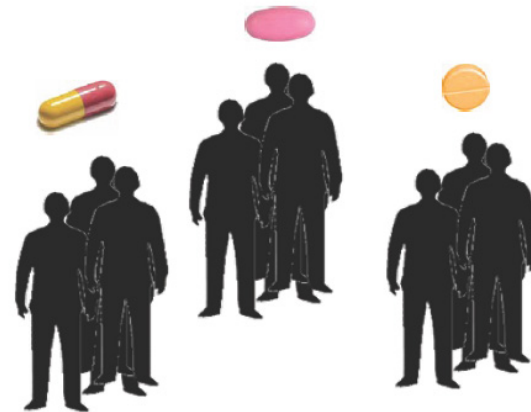
Current Practice



One size fits all

Trial and error

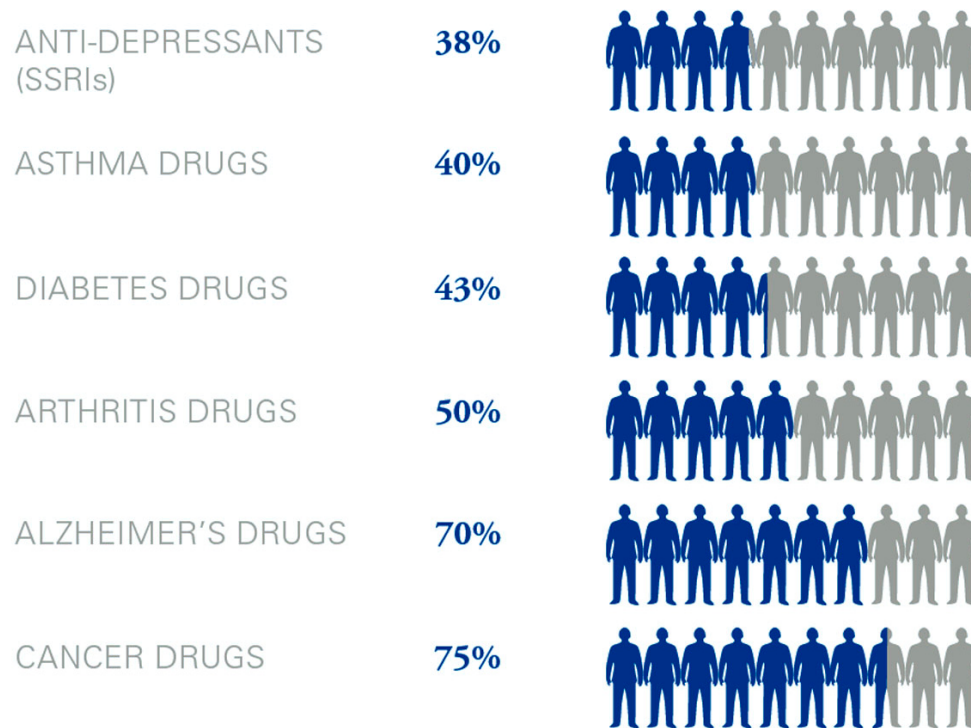
Personalized Medicine



The **right treatment** for
the **right person** at the
right time

Personalized Medicine

PERCENTAGE OF THE PATIENT POPULATION FOR WHICH A PARTICULAR DRUG IS INEFFECTIVE, ON AVERAGE



- Just in hospitals: about 6.7% of patients (2.2 million) experience serious adverse drug reactions



Serious adverse drug reactions in even smaller percentages of treated populations have led to the withdrawal of several drugs from the market

Zelnorm Vioxx Cylert

“Are good drugs going to the wrong people?”

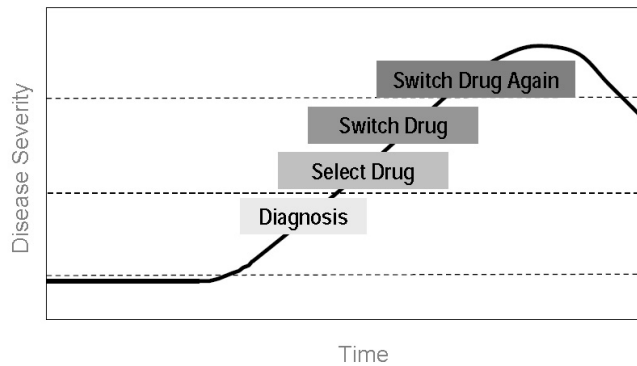
Rezulin Baycol Lotronex*

Source of data: Brian B. Spear, Margo Heath-Chiozzi, Jeffery Huff, “Clinical Trends in Molecular Medicine,” Volume 7, Issue 5, 1 May 2001, Pages 201-204.

Personalized Medicine

The Old Paradigm: Treatment of Disease

Reactive Medical Care

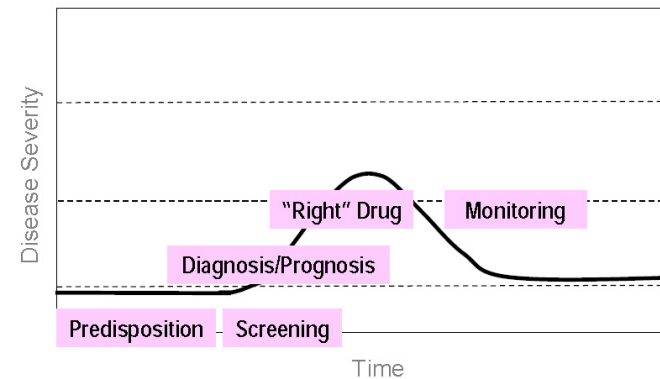


Diagnose Disease; Treat Symptoms; Costly, Trial and Error Treatment

PMC Personalized Medicine Coalition

Personalized Medicine Paradigm: Health Management

Efficient Medical Care



Health Management; Molecular Screening; Early Detection; Rapid Effective Treatment; Improved Quality of Care

PMC Personalized Medicine Coalition

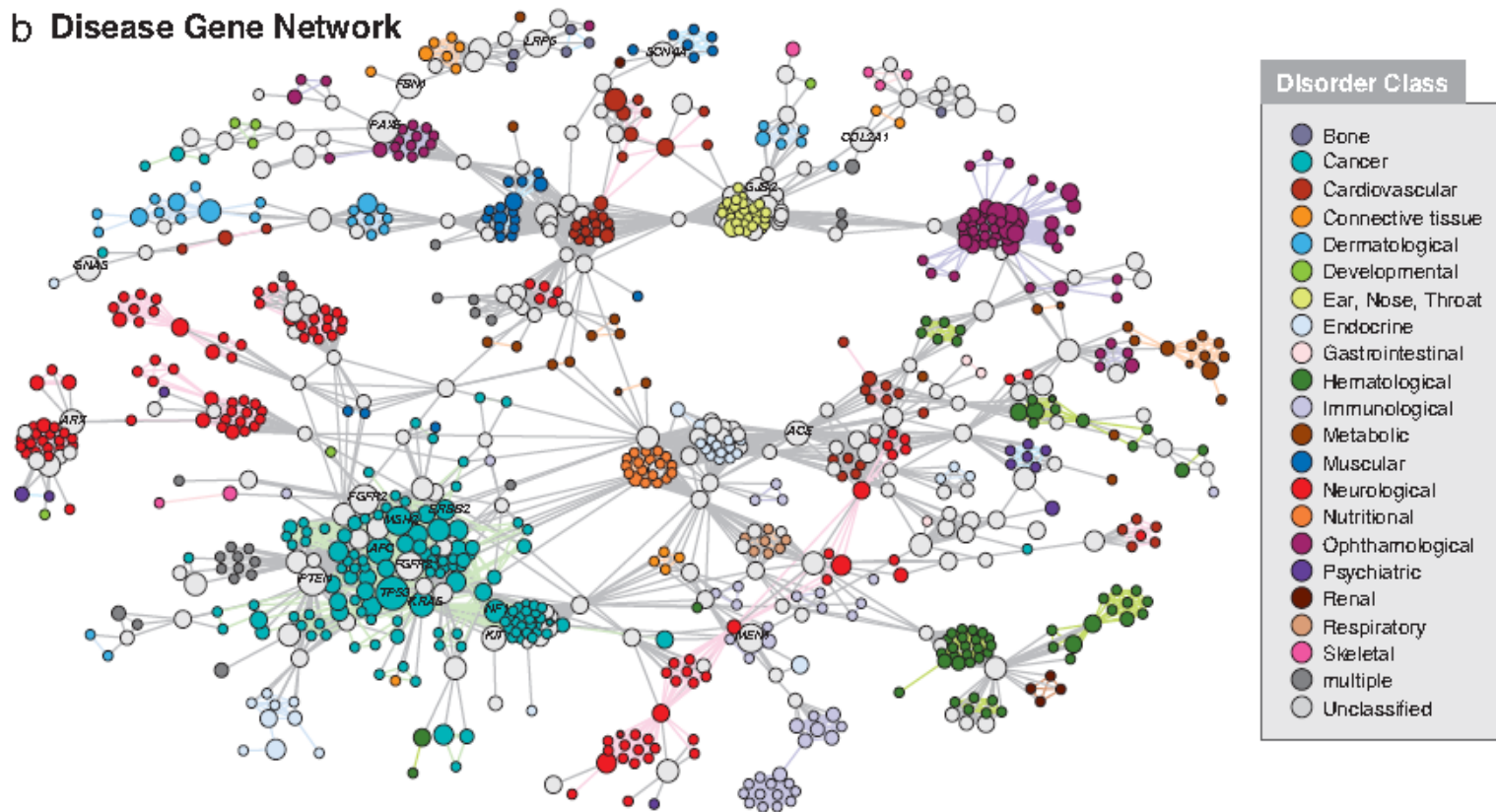
<http://www.personalizedmedicinecoalition.org/>

CETEC

Personalized Medicine

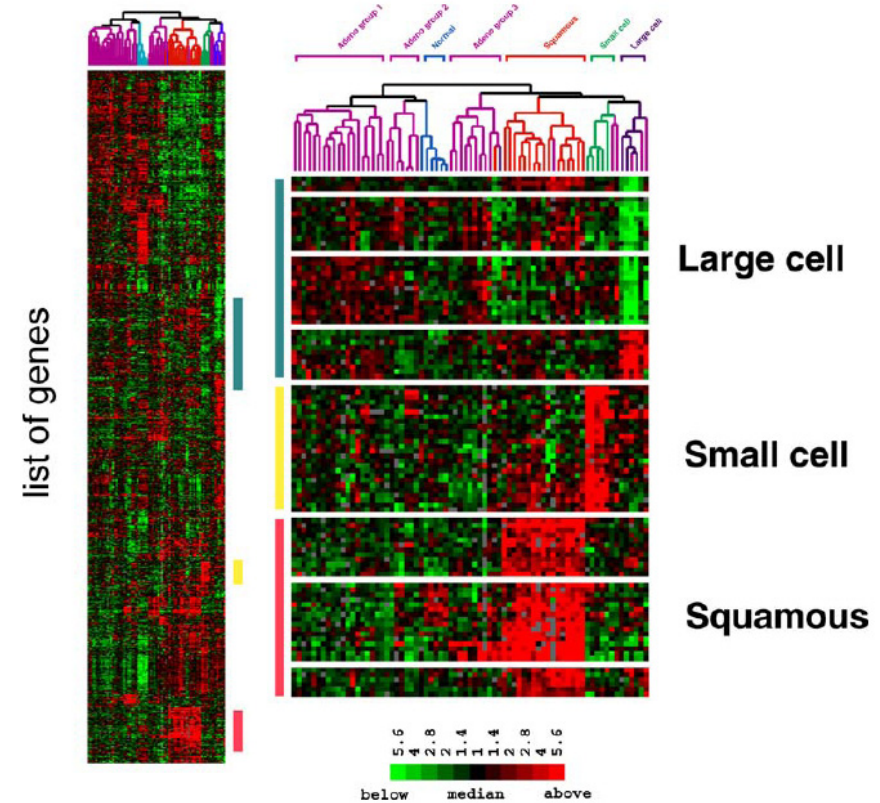
- Problem:
 - multigene conditionality of most human diseases

b Disease Gene Network



Personalized Medicine

- Problem solving
 - **systems biology** - uses e.g. gene clustering to identify genes involved in the observed phenomenon



Personalized Medicine

- Problem solving
 - biomarkers
 - tests

Table: Selected Personalized Medicine Drugs, Treatments and Diagnostics as of September 2011 *

Indications in quotes and otherwise unattributed, are cited from the therapeutic or diagnostic product label.

Therapeutic product labels contain pharmacogenomic information as:

- Information only
- Recommended
- Required
- Unhighlighted products have no pharmacogenomic information, recommendations or requirements in the label.

THERAPY	BIOMARKER/TEST	INDICATION
Mivacron® (mivacurium)	Cholinesterase gene	Anesthesia adjunct: "Mivacron is metabolized by plasma cholinesterase and should be used with great caution, if at all, in patients known to be or suspected of being homozygous for the atypical plasma cholinesterase gene."
Ansaid® (flurbiprofen)	CYP2C9	Arthritis: " <i>In vitro</i> studies have demonstrated that cytochrome P450 2C9 plays an important role in the metabolism of flurbiprofen to its major metabolite, 4'-hydroxy-flurbiprofen."
Depakote® (divalproex)	UCD (NAGS; CPS; ASS; OTC; ASL; ARG)	Bipolar disorder: "Hyperammonemic encephalopathy, sometimes fatal, has been reported following initiation of valproate therapy in patients with urea cycle disorders [UCDs]...particularly ornithine transcarbamylase deficiency [OTC]."
Aromasin® (exemestane) Arimidex® (anastrozole) Nolvadex® (tamoxifen)	Estrogen Receptor (ER)	Breast cancer: Exemestane is indicated for adjuvant treatment of postmenopausal women with ER-positive early breast cancer. Anastrozole is for treatment of breast cancer after surgery and for metastases in postmenopausal women. Tamoxifen is the standard therapy for estrogen receptor-positive early breast cancer in premenopausal women.
Chemotherapy	Mammostrat®	Breast cancer: Prognostic immunohistochemistry (IHC) test used for postmenopausal, node negative, estrogen receptor expressing breast cancer patients who will receive hormonal therapy and are considering adjuvant chemotherapy.
Chemotherapy	MammaPrint®	Breast cancer: Assesses risk of distant metastasis in a 70-gene expression profile.
Chemotherapy	OncoType DX® 16-gene signature	Breast cancer: A 16-gene signature (plus five reference genes) indicates whether a patient has a low, intermediate, or high risk of having a tumor return within 10 years. Low-risk patients may be treated successfully with hormone therapy alone. High-risk patients may require more aggressive treatment with chemotherapy.
Chemotherapy	CompanDx® 31-gene signature	Breast cancer: The test predicts "time to event" for metastasis of breast cancer, following surgery or biopsy.
Faslodex® (fulvestrant)	Hormone Receptor (HR)	Breast cancer: Fulvestrant is indicated for the treatment of hormone receptor positive metastatic breast cancer in postmenopausal women with disease progression following anti-estrogen therapy.
Herceptin® (trastuzumab) Tykerb® (lapatinib)	HER-2/neu receptor	Breast cancer: "...for the treatment of patients with metastatic breast cancer whose tumors overexpress the HER-2 [Human Epidermal growth factor Receptor 2] protein and who have received one or more chemotherapy regimens for their metastatic disease." High levels of HER-2 expression have been associated with increased disease recurrence in breast cancer, but show a better response to trastuzumab.
Pharmaceutical and surgical prevention options and surveillance	BRCA 1/2	Breast cancer: Guides surveillance and preventive treatment based on susceptibility risk for breast and ovarian cancer.
Nolvadex® (tamoxifen)	Breast Cancer Index™ (HOXB13, IL17BR)	Breast cancer: Calculates a combined risk analysis for recurrence after tamoxifen treatment for ER-positive, node-negative breast cancer.



Personalized Medicine

- Other problems
 - Ethical Issues
 - the condition is genetic testing or knowledge of the genome - easily abused
 - risk: insufficient data security
 - in some countries, employers or insurance companies do not have access to such data
 - High Costs
 - medicine could be divided into first-class and low-class services
 - globalization gap could grow even larger - poor countries would not be able to afford this
 - Privacy
 - crucial and complex issue
 - what information about oneself can/should be considered private?

Outline

- Medicine
 - Molecular Diagnosis
 - Personalized Medicine
 - Gene Therapy

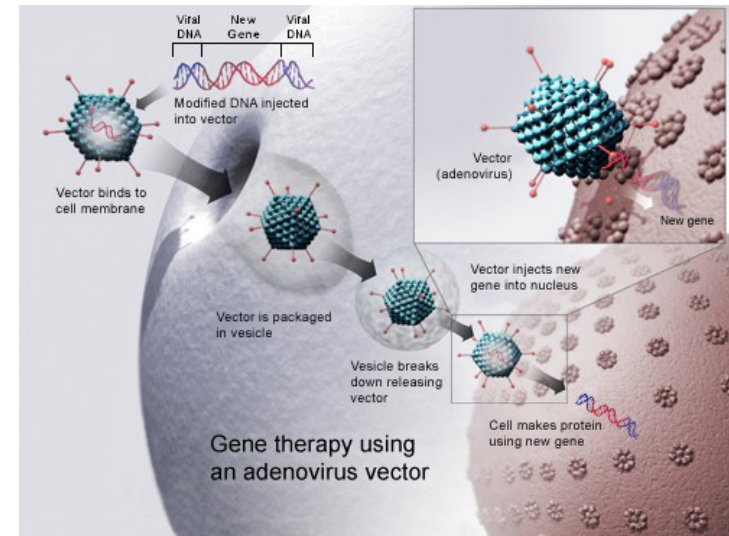
Gene Therapy

Procedure in which the DNA sequence is inserted into the patient genome to replace or supplement the original gene

- Options:
 - replace the mutated gene
 - repair the mutation
 - deliver DNA encoding a therapeutic protein
 - antisense therapy
- In the future useful for treating e.g. hereditary diseases
- Types:
 - somatic gene therapy
 - gene therapy of germ cells

Gene Therapy

- Methods
 - viral vectors
 - retroviruses
 - adenoviruses
 - herpes simplex virus
 - non-viral methods
 - injection of plasmid DNA into muscle
 - increased efficiency of DNA delivery
 - electroporation
 - sonoporation
 - „gene gun“ (biolistic)
 - magnetofection
 - genome editing

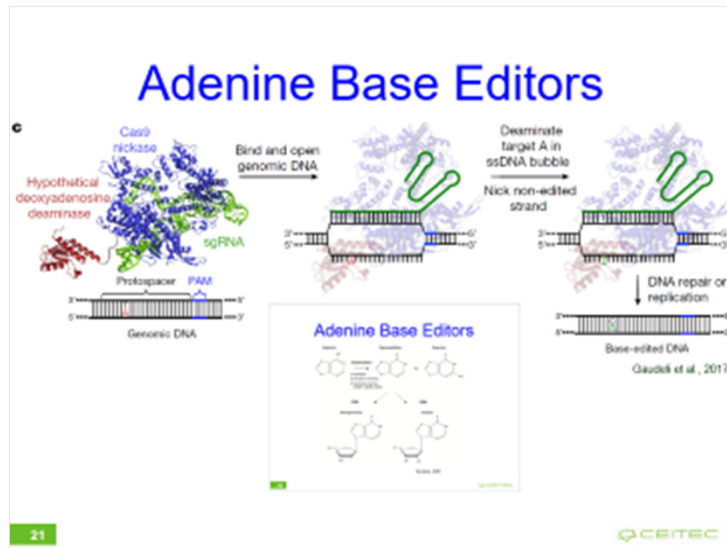


Gene Therapy

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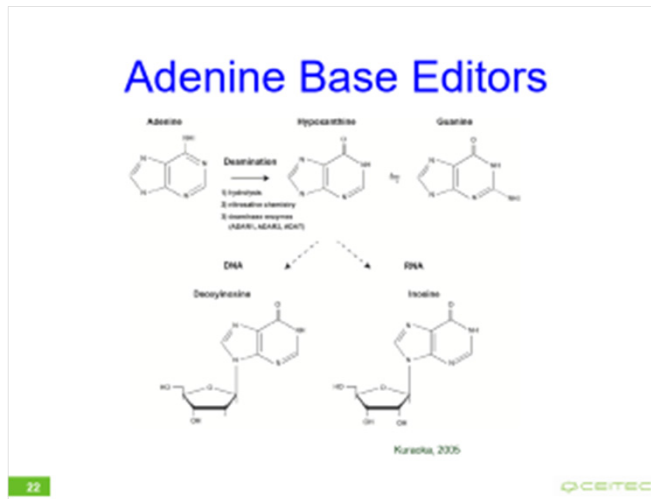
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Gene Therapy



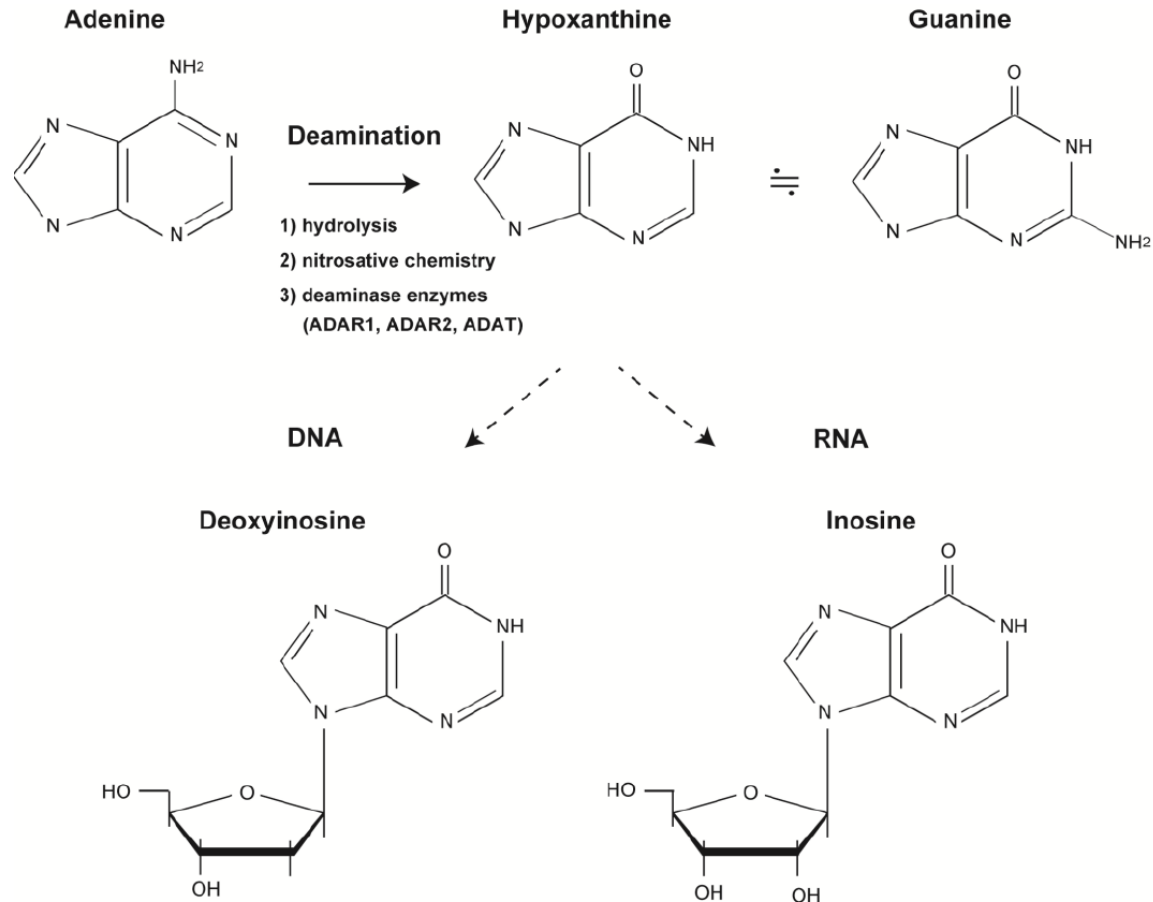
- Hutchinson–Gilford progeria syndrome
 - C•G-to-T•A mutace (c.1824 C>T; p.G608G) v genu pro laminin (*LMNA*)
 - Defekt v sestřihu RNA vede k tvorbě toxického proteoinu **progerinu**
 - Věk dožití cca 14 let
 - **In vivo oprava** pomocí ABEs potvrzena u myši a **lidských fibroblastů** (Koblan et al., 2021)

Adenine Base Editors



Gaudeli et al., 2017

Adenine Base Editors



Kuraoka, 2005

Ethical Issues

- International Commission on the Clinical Use of Human Germline Genome Editing
 - convened by the U.S. National Academy of Medicine (NAM), the U.S. National Academy of Sciences (NAS), and the Royal Society of the U.K. ...
 - ...to identify a number of scientific, medical, and ethical requirements that should be considered, and could inform the development of a potential pathway from research to clinical use — if society concludes that heritable human genome editing applications are acceptable
 - more details at <https://nationalacademies.org/gene-editing/international-commission/index.htm>

Ethical Issues

- Alliance for Regenerative Medicine
 - international group representing the cell and gene therapy sector
 - put out a “statement of principles” on genome editing endorsed by 13 of the most active companies in this field
 - changing heritable DNA in sperm, eggs or a new embryo — came true in November 2018 when He Jiankui, a Chinese biophysicist, said that his lab had edited two baby girls to make them resistant to HIV infection. This mutation will be inherited by their descendants.
 - 31 clinical trials for gene edited therapies are in progress around the world, 20 of which are in oncology. None is yet close to commercialisation. The US has the largest number of trials (19) followed by China (10) and the UK (6)

FT, Clive Cookson, Science Editor August 27 2019



Ethical Issues

- Genome editing as a **bioweapon**?
 - ongoing research program funded by the U.S. Defense Advanced Research Projects Agency (DARPA)
 - aims to disperse **infectious genetically modified viruses** that have been **engineered to edit crop chromosomes** directly in fields
 - the means of **delivery** of these **viral horizontal environmental genetic alteration agents (HEGAAs)** into the environment should be **insect-based dispersion**
 - Part of **scientific community** does not find the program useful for the U.S. **agriculture**, but points to its **possible misuse**



Editing as a bioweapon?

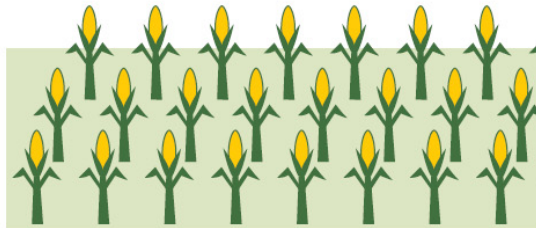
Insects infected with genetically modified virus are released into the environment.



Species include leafhoppers, whiteflies, and aphids.

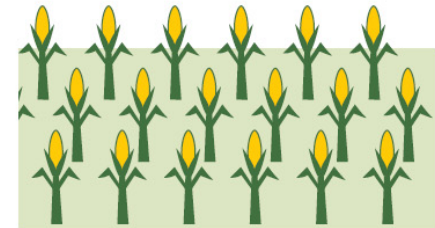
Field 1

Growing maize variety 1 **without** CRISPR target



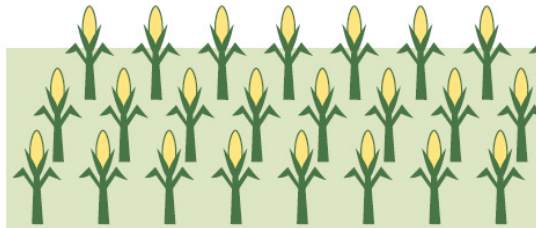
Next season's crops are completely unaffected.

Crop yields for next season are **unaffected**.



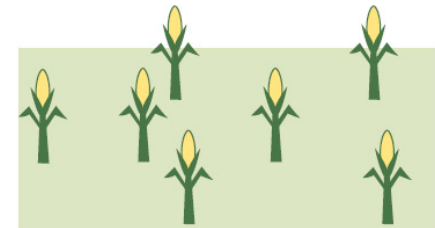
Field 2

Growing maize variety 2 **with** CRISPR target



Many seeds saved from the previous season fail to grow, owing to chromosomal editing.

Fields experience a food and seed **shortage**.



Reeves et al., 2018

Outline

- Medicine
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 - Gene Therapy
- Biotechnology

BIOTECHNOLOGY

- It uses living organisms, cells or parts of cells (enzymes) for research, leading to new products and applications in medicine, agriculture, food, environmental protection
- Also used in developing better/sustainable production methods for the chemical industry and other industrial processes
- An **interdisciplinary approach** requiring knowledge of chemistry, biology, physics, material sciences, engineering and informatics
- The origin of biotechnology can be traced 4,000 years back, when the Sumerians (although not knowingly) used microbes for the production of alcoholic beverages.

BIOTECHNOLOGY

- Examples
 - effective utilization of **plant biomass** for **fuel production**
 - acquisition of starting material (**monomers**) for the **production of polymers** from living organisms instead of from fossil sources
 - **phytopharmaceuticals** – using plants in new vaccination methods such as expression of **antibodies** or **antigens** suitable for **immunization**
- **European Federation of Biotechnology**

EFB EUROPEAN FEDERATION OF BIOTECHNOLOGY

EFB MEMBERS WHY JOIN? CONTACT LOGIN

European Federation of Biotechnology (EFB) is Europe's non-profit federation of National Biotechnology Associations, Learned Societies, Universities, Scientific Institutes, Biotech Companies and individual biotechnologists

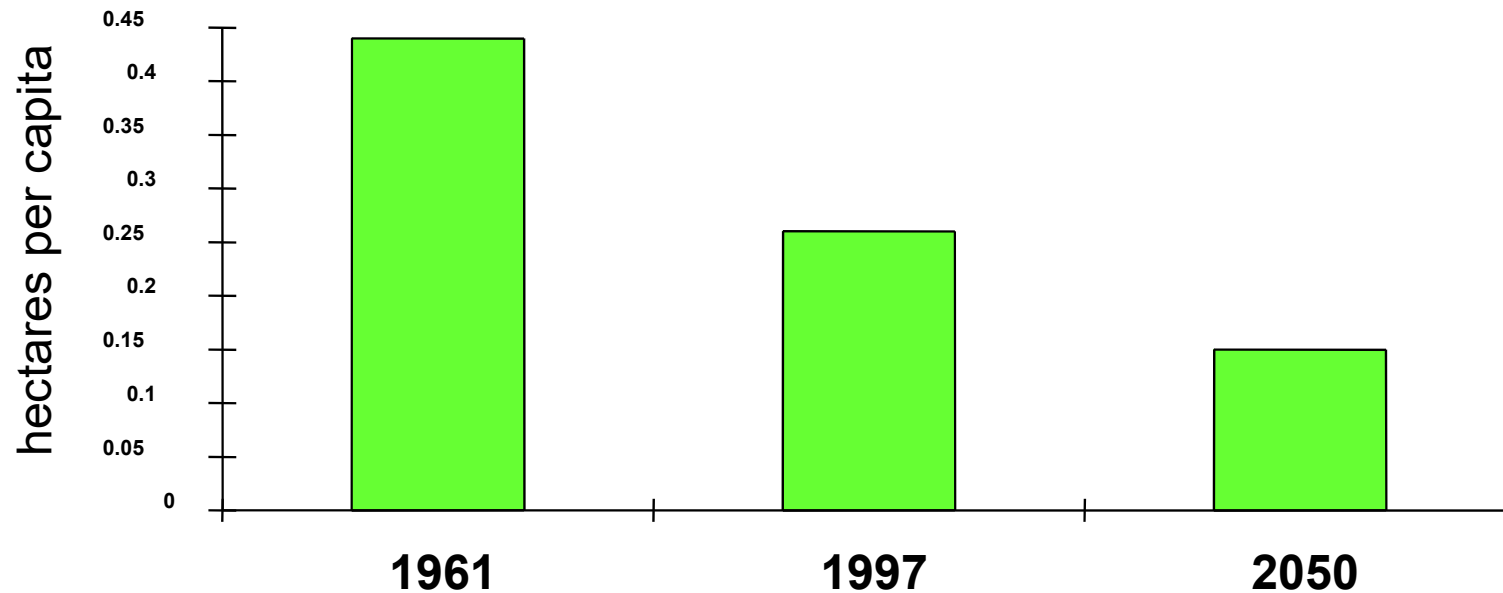
CEITEC

<http://www.efb-central.org>

Outline

- Medicine
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- Biotechnology
- **Genetically Modified Organisms**
 - Transgenesis

Human Population vs Arable Land Availability




Source: UN Millennium Ecosystem Assessment

Nutrition Deficiency

The world-total deficiency in food production of ...

214 trillion additional calories is equal to:



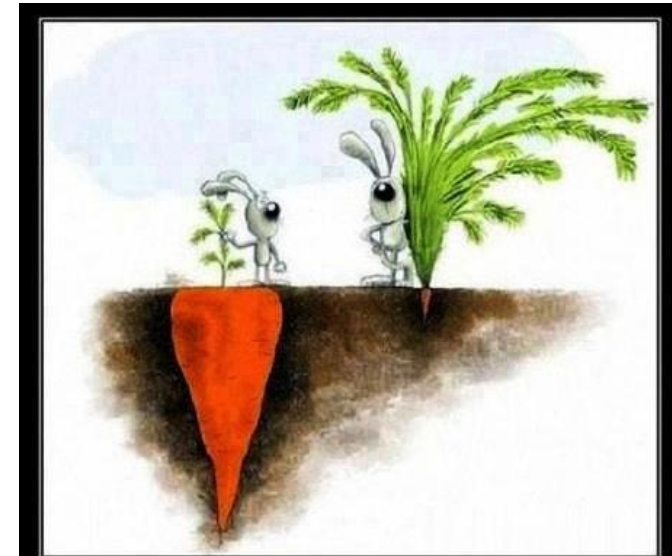
...as soon as in 2027?

The image shows a woman in a blue patterned dress standing on a stage, presenting to an audience. The background features a large screen displaying the text and graphics described above.

<https://qz.com/africa/1064653/the-world-could-run-out-of-food-two-decades-earlier-than-thought/>

Breeding

- organisms naturally vary due to mutations
- before the era of genetic engineering - question of chance
- breeding tools
 - selection and crossing
- modern breeder learned to change hereditary information – increase the mutants allele frequency
 - chemicals, radiation ...
- results are incidental/non-targeted

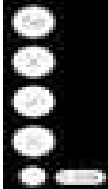
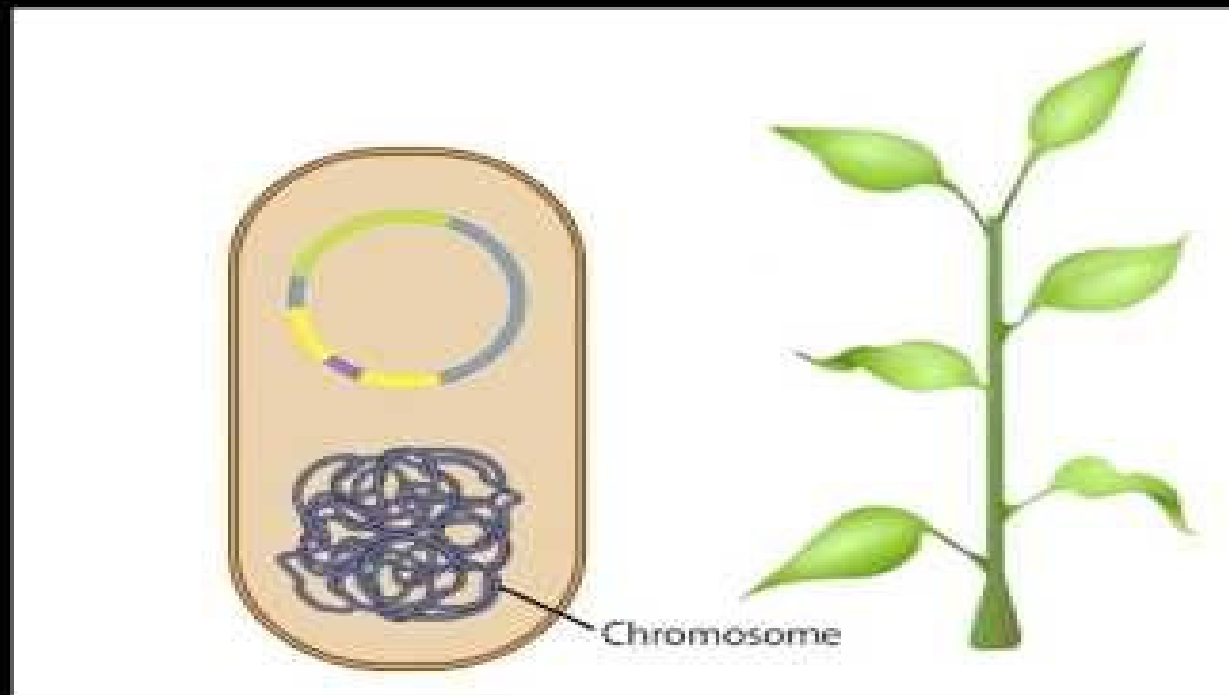


Success
is not always visible at a glance

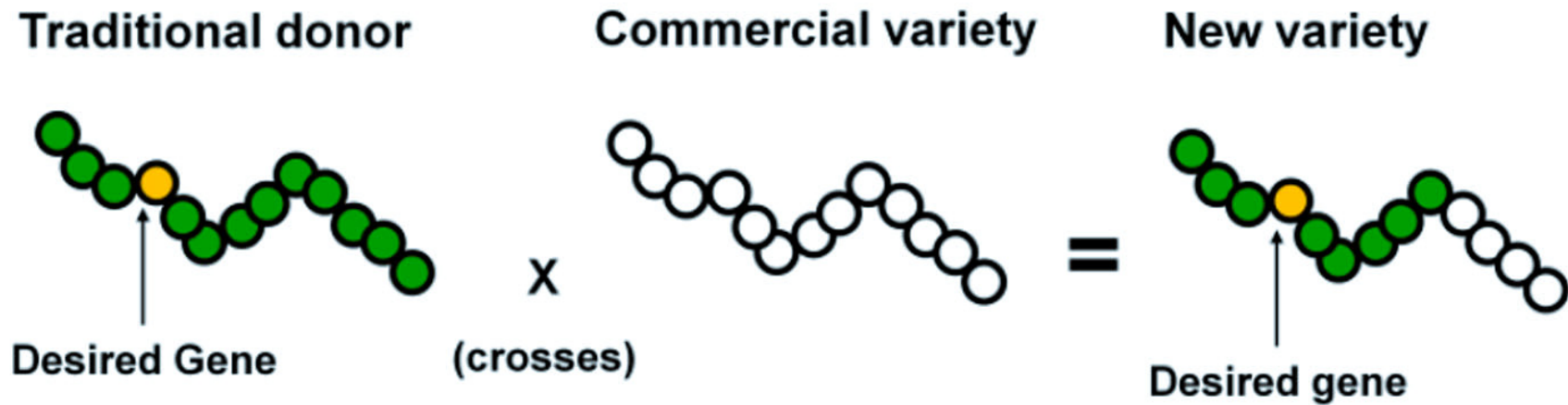
Genetic Engineering

- Targeted modification ("targeted breeding")
 - ability to transfer genes = transgenesis
- the first practical application: production of human insulin in bacteria - 1978

Plant Transgenesis



Breeding Vs. Genetic Engineering



Genetically Modified Organisms (GMOs)

- Organisms carrying modified genetic information – either own or foreign (from another organism), enabling targeted changes in the organism and its use for specific purposes
- GMOs
 - plants
 - bacteria
 - animals

<http://www.gmo-compass.org/>

Genetically Modified Plants

- resistance to **pests**
- **herbicide** resistance
- resistance to **drought**
- resistance to **cold**
- resistance to **salinity**
- more efficient **nitrogen utilization**
- increasing **nutritional quality**



<http://ipbo.vib-ugent.be/>

Bt Plants

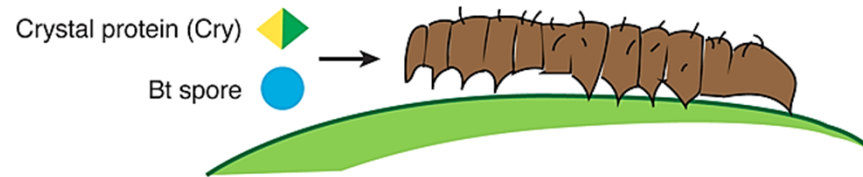
- resistance to **insect pests**
- corn, cotton, rice
- genes from *Bacillus thuringiensis* (**Bt**)
- Expression of crystalline delta-endotoxins - **Crystal (Cry)** proteins
- increasing **yields**, **reducing** the amount of **chemical sprays**



European corn borer damage and fungal infection in non-Bt (left) and Bt hybrids (right)

Bt Plants

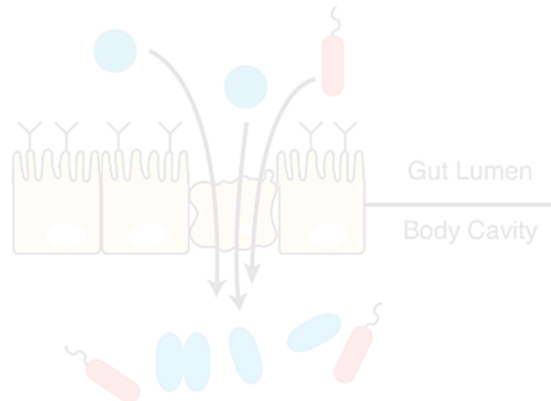
(A) Larvae ingest Bt spores and Cry proteins



(B) In larval midgut, proteolytic digestion of proteins release Cry toxins, which bind to epithelial receptors



(C) Toxin binding causes cell lysis destroying barrier to body cavity



Ht Plants

- resistance to systemic herbicides
- glyphosate
 - interferes with the synthesis of aromatic amino acids; animals without the appropriate enzymatic apparatus = harmless
 - blocks the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) in chloroplasts – affects green plants
 - ineffective for bacterial EPSPS - evolutionarily divergent
 - soya, maize, sugar beet, canola, cotton, alfalfa - added enzyme for tolerance
 - company Bayer (Monsanto), trade name Roundup

Ht Plants

- resistance to systemic herbicides
- glufosinate (phosphinothricin)
 - prevents processing of ammonium - toxic
 - *Streptomyces hygroscopicus* synthesizes and transforms it: acetylation by the enzyme phosphinothricin acetyltransferase – coding gene isolated in 1987 - named *bar*
 - trade names: **Basta**, Liberty, Finale, Radical ...

Multiresistant Plants

- Bt resistance + herbicide
- multiresistant corn - the majority of total production in the USA
- example of multiresistant corn:
 - three Bt genes for resistance to air pests
 - three Bt genes for resistance against soil pests
 - two genes for herbicide resistance

Disease-Tolerant Plants

- **viruses** - no chemical agents available
- gene encoding **non-infectious viral envelope** protein - increases resistance to viral infection
 - **banana; papaya** - Hawaii, Southeast Asia
 - **cassava** - a basic food ingredient for more than **500 million people** + animal feed



Left: Papaya with Papaya ringspot disease
Right: Biotech Papaya resistant

Disease- and Stress-Tolerant Plants

Drought in Ethiopia



- **Chickpeas** - more resistant to drought, but toxic
 - **GMOs with inactivated toxin**
- **Corn** resistant to drought

4 New drought-tolerant maize (right) needs less water.

Nitrogen Use Efficiency

- use of nitrogen from fertilizers
 - rice with gene from barley - 3x higher nitrogen utilization under oxygen deficiency

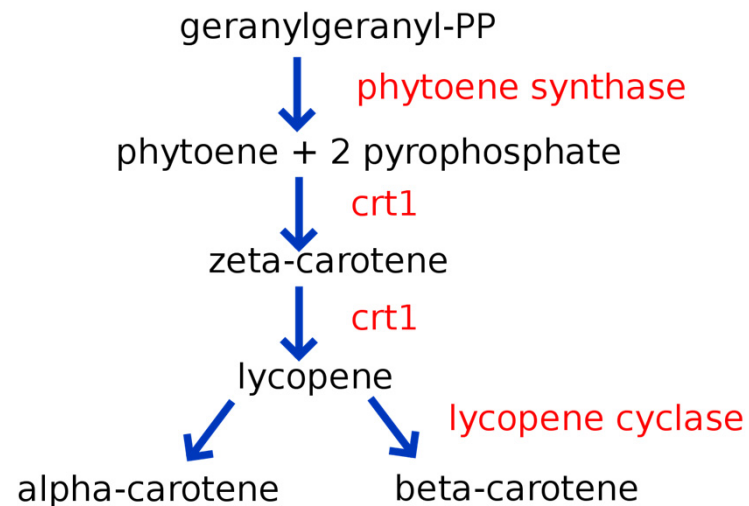


The effect of Nitrogen Use Efficiency (NUE) in rice growth with reduced N applications. Left: rice engineered

Improved Nutrition Value

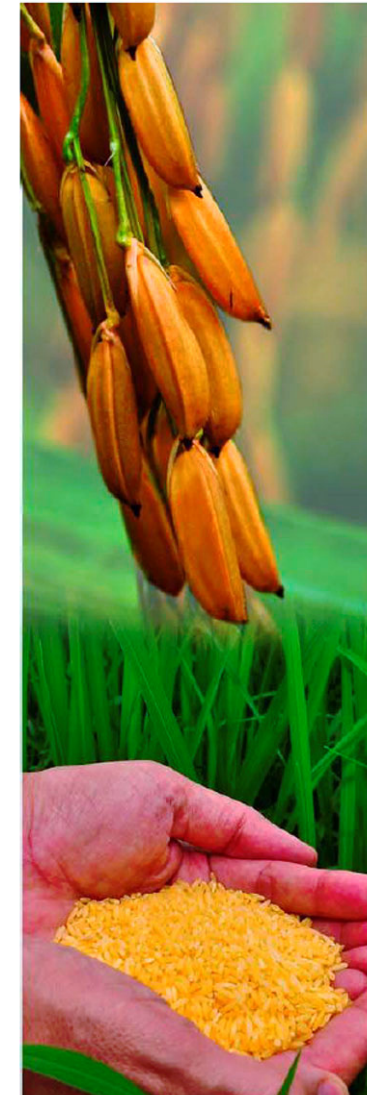
- Golden rice

- several genes from maize encoding enzymes for the biosynthesis of β -carotene (precursor of vitamin A)



- Canola and Soybean

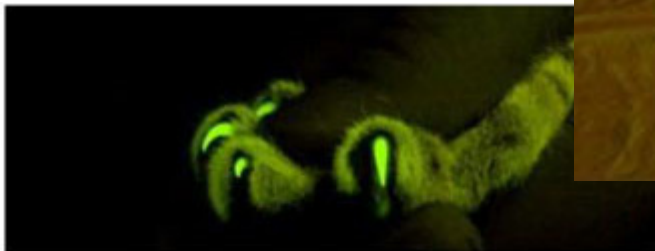
- improved oil properties: stable, resistant to high temperatures, long storage



Golden Rice
LEI TEL

GMO Animals

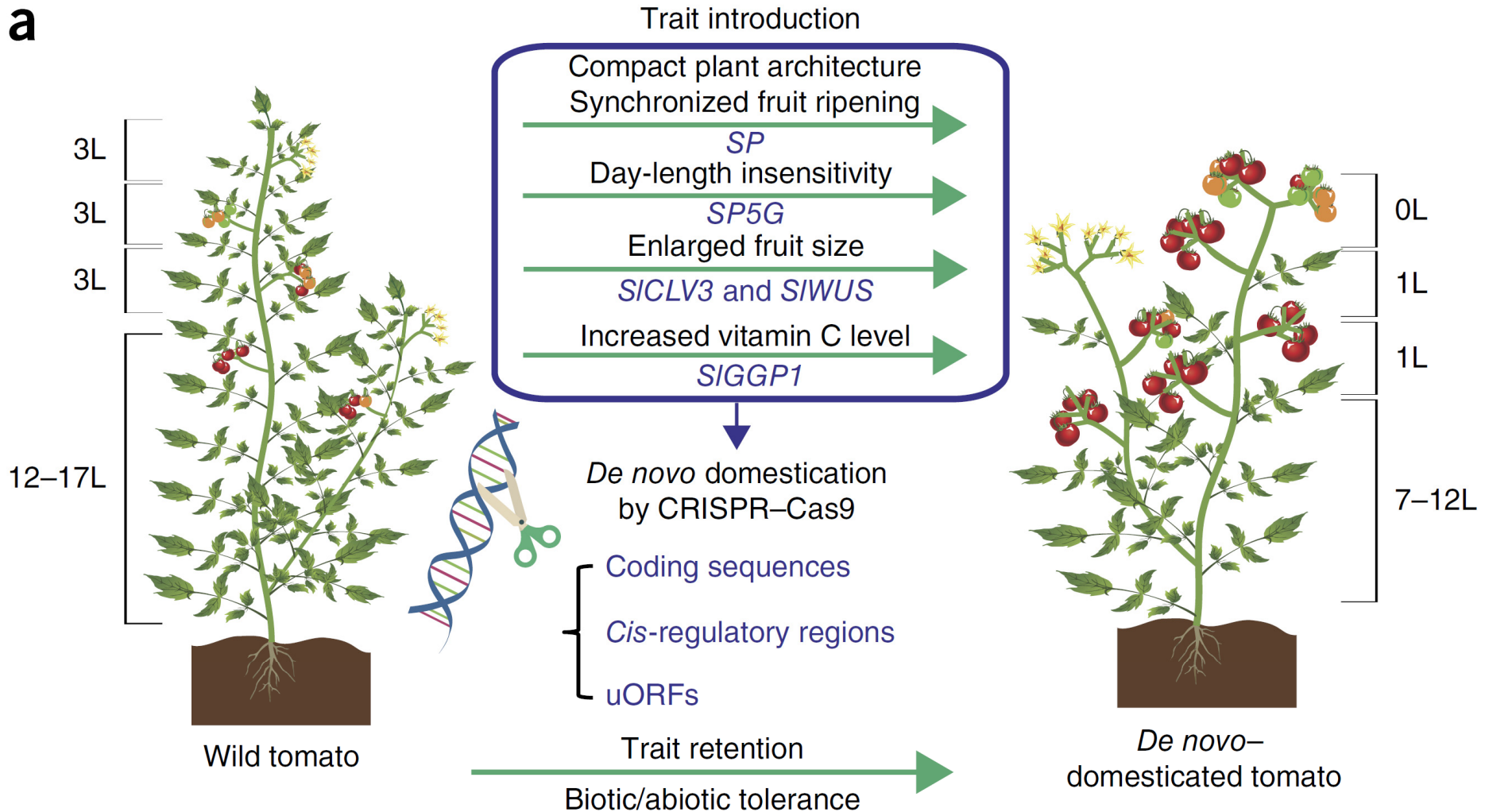
- Transgenic cats
 - **lentiviruses** are **sensitive** to **restriction factors**
 - specific **restriction factor**: rhesus macaque **TRIMCyp** + **eGFP**
 - uniform expression, no mosaicism and no silencing in F1 generation
 - **lymphocytes** of transgenic animals **resistant** to replication of **FIV**



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- Medicine
 - Molecular Diagnosis
 - Personalized Medicine
 - Gene Therapy
- Biotechnology
- Genetically Modified Organisms
 - Transgenosis
 - **Genome Editing**

Gene Editing in Plant Domestication



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 - Genome Editing
- **Model Organisms**

Mus musculus

house mouse

- Low requirements for area
- Relatively large number of offspring (3-14, 6-8 on average)
- Genome size is close to the size of human genome (about 3000 Mbp), the number of genes as well (about 24K)
- 20 chromosomes (19+1)
- Suitable for a wide range of physiological experiments (anatomical and physiological similarity to human)
- Possibility to obtain (quite easily) KO mutants and transgenic lines



Mus musculus

house mouse

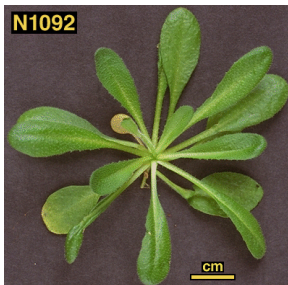
- Genome known since 2002
(<http://www.ncbi.nlm.nih.gov/projects/genome/assembly/grc/mouse/>)

The screenshot shows the 'Mouse Genome Overview' page from the Genome Reference Consortium. The page features a navigation bar with links like 'GRC Home', 'Data', 'Help', 'Report an Issue', 'Contact Us', 'Credits', and 'Curators Only'. Below the navigation, there are sub-links for 'Mouse Overview', 'Mouse Issues under Review', 'Mouse Assembly Data', and 'Report a problem'. The main content area is titled 'Mouse Genome Overview' and includes an ideogram of the mouse genome with chromosomes 1-19, X, and Y. Red triangles indicate regions with alternate loci, and orange triangles indicate regions with fix patches. A text box explains the GRC's goal to provide the best reference assembly by generating multiple representations for complex regions. It also provides links for 'Getting Data', including GRCm38.p1 (latest minor release), GRCm38 (latest major release), and alignments of MGSCv37 to GRCm38. A prominent orange box states: 'Next assembly update: The next assembly update (patch release 2) will be a minor update (only patches) and will happen in March 2013.' On the right side, there is a 'GRC Blog' section with recent posts and a 'Recently Resolved Mouse Issues' section listing specific problems like MG-4136 and MG-4212. At the bottom, there are tabs for 'GRCm38.p1', 'GRCm38', and 'MGSCv37', and a 'References' section with links to whole genome papers.

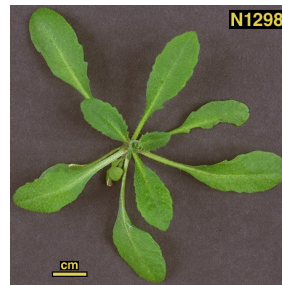
Arabidopsis thaliana

mouse-ear cress

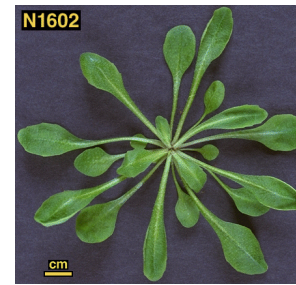
- Low requirements for cultivation area
- High number of seeds (20.000 per plant and more)
- Small and compact genome, (125 MBp, about 25.000 genes, average size 3 kb)
- 5 chromosomes
- Suitable for wide range of physiological experiments
- High natural variability (approximately 750 ecotypes (Nottingham Arabidopsis Seed Stock Centre))



Columbia 0

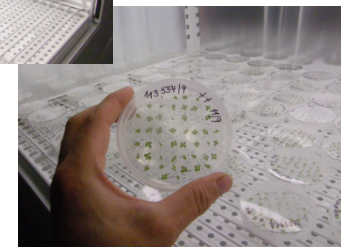


Landsberg 0



Wassilewskija 0

<http://seeds.nottingham.ac.uk/>



Arabidopsis thaliana

mouse-ear cress

- Genome known since 2000 (<http://www.arabidopsis.org/>)

The screenshot shows the TAIR website homepage. The browser window title is "TAIR - Home Page" and the address bar shows "www.arabidopsis.org". The page has a navigation menu with links for Home, Help, Contact, About Us, and Login/Register. Below the menu is a search bar and a navigation bar with links for Search, Browse, Tools, Portals, Download, Submit, News, and ABRC Stocks.

The main content area is titled "The Arabidopsis Information Resource" and contains the following text:

The Arabidopsis Information Resource (TAIR) maintains a database of genetic and molecular biology data for the model higher plant *Arabidopsis thaliana*. Data available from TAIR includes the complete genome sequence along with gene structure, gene product information, metabolism, gene expression, DNA and seed stocks, genome maps, genetic and physical markers, publications, and information about the Arabidopsis research community. Gene product function data is updated every two weeks from the latest published research literature and community data submissions. Gene structures are updated 1-2 times per year using computational and manual methods as well as community submissions of new and updated genes. TAIR also provides extensive linkouts from our data pages to other Arabidopsis resources.

The Arabidopsis Biological Resource Center at The Ohio State University collects, reproduces, preserves and distributes seed and DNA resources of *Arabidopsis thaliana* and related species. Stock information and ordering for the ABRC are fully integrated into TAIR.

TAIR is located at the Carnegie Institution for Science Department of Plant Biology and funded by the National Science Foundation with additional support from TAIR sponsors.

Updates on TAIR funding are available [here](#).

The banner at the bottom of the main content area reads:

Click here to try our new online submission form and submit the molecular function (e.g. *protein kinase*), biological process (e.g. *seed development*), localization (e.g. *plasma membrane*) or interacting partner of your favorite gene

The right sidebar contains several news items:

- Breaking News**
 - Subscribe to news feed
 - Follow our Twitter feed
 - Join our Facebook group
- New Set of Confirmed T-DNA Lines Available**
[November 28, 2012]
The fourth one-allele set of confirmed T-DNA lines representing 3,263 new loci is now available for ordering as **CS27944**.
- New from ABRC Education and Outreach!**
[October 31, 2012]
ABRC is pleased to announce a re-designed Education and Outreach website at <http://abrcoutreach.osu.edu>. The website allows quick and easy **donation of education modules**, direct ordering and **online evaluation of education kits**.
- 2012 MASC Report Now Available**
[July 11, 2012]
Please check out the **latest report** from the Multinational Arabidopsis Steering Committee.
- New Protein Chip and Cell Cultures at ABRC**
[May 9, 2012]
A new protein chip (**AtProteinChip 2**) developed by **M. Snyder and S.P. Dinesh-Kumar**, is now available. Cell

Outline

- **Medicine**
 - Molecular Diagnosis
 - Personalized Medicine
 - Gene Therapy
- **Biotechnology**
- **Genetically Modified Organisms**
 - Transgenesis
 - Genome Editing
- **Model Organisms**
- **Principles of PCR**



Polymerase Chain Reaction

Discussion