Transgenic or gene editing: challenges for new varieties

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21st century Agriculture Challenges

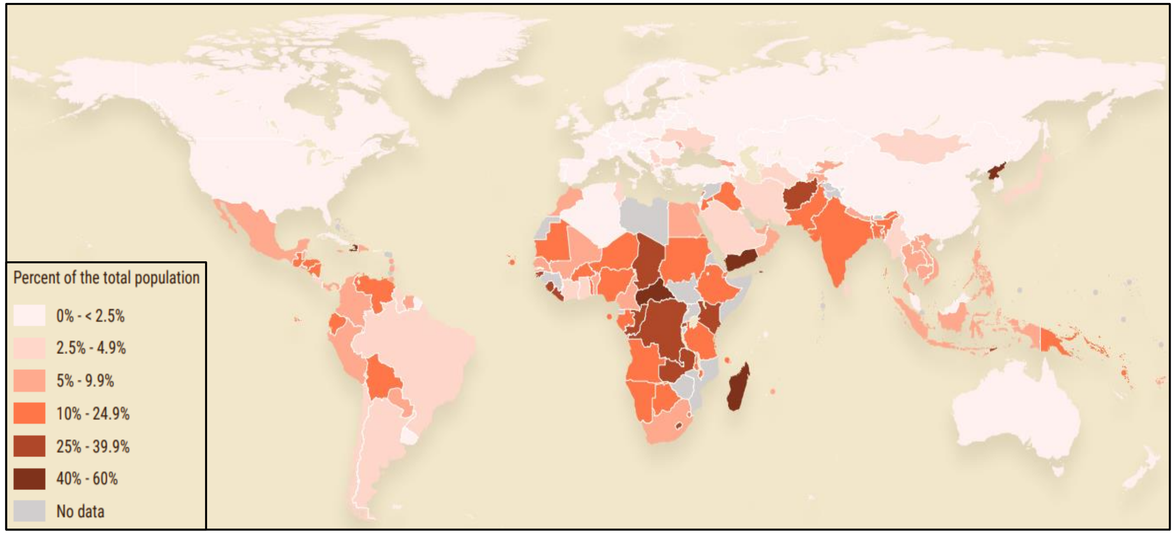
World population of 9.5 billion by 2050 (2/3 in Africa)

Will need 70% increase in food production

Agricultural land declining since 2001

7-12% GHG emission from crop production

World population increase



Yield predicted to decline by 2-6% per decade due to climate change

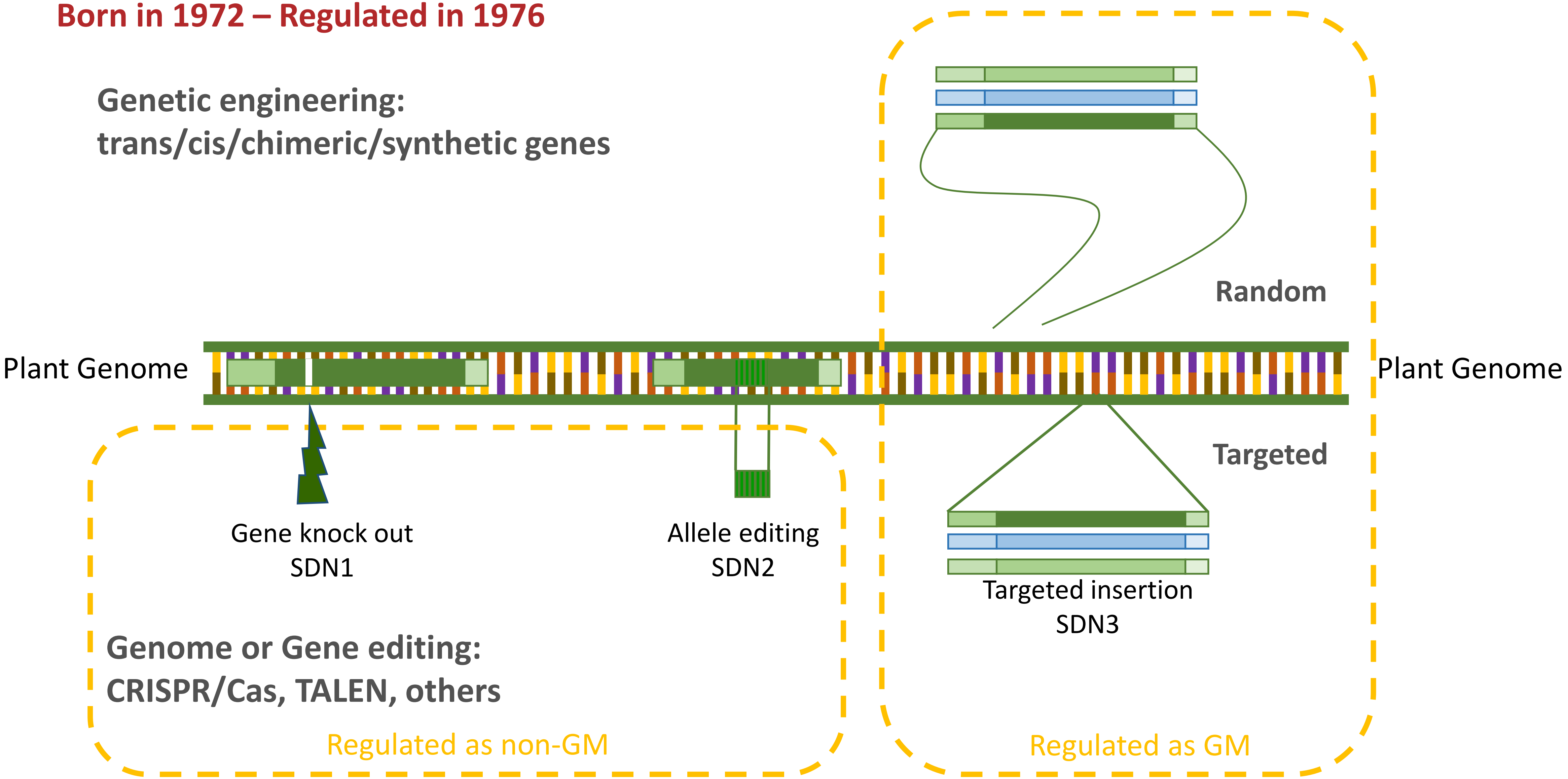
Around 20% of production is lost to pests and diseases and 22% of the production is lost after harvest

Staple crops, in general, are poor in micronutrient content

Conventional breeding cannot alone deliver the needed nutritious and resilient varieties

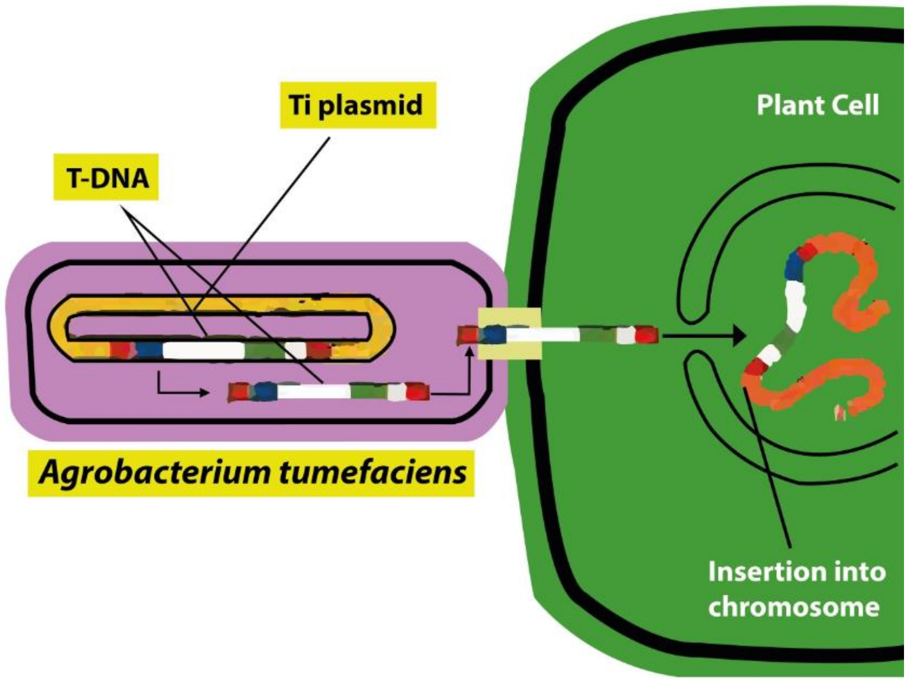
Recombinant DNA / Gene Technology

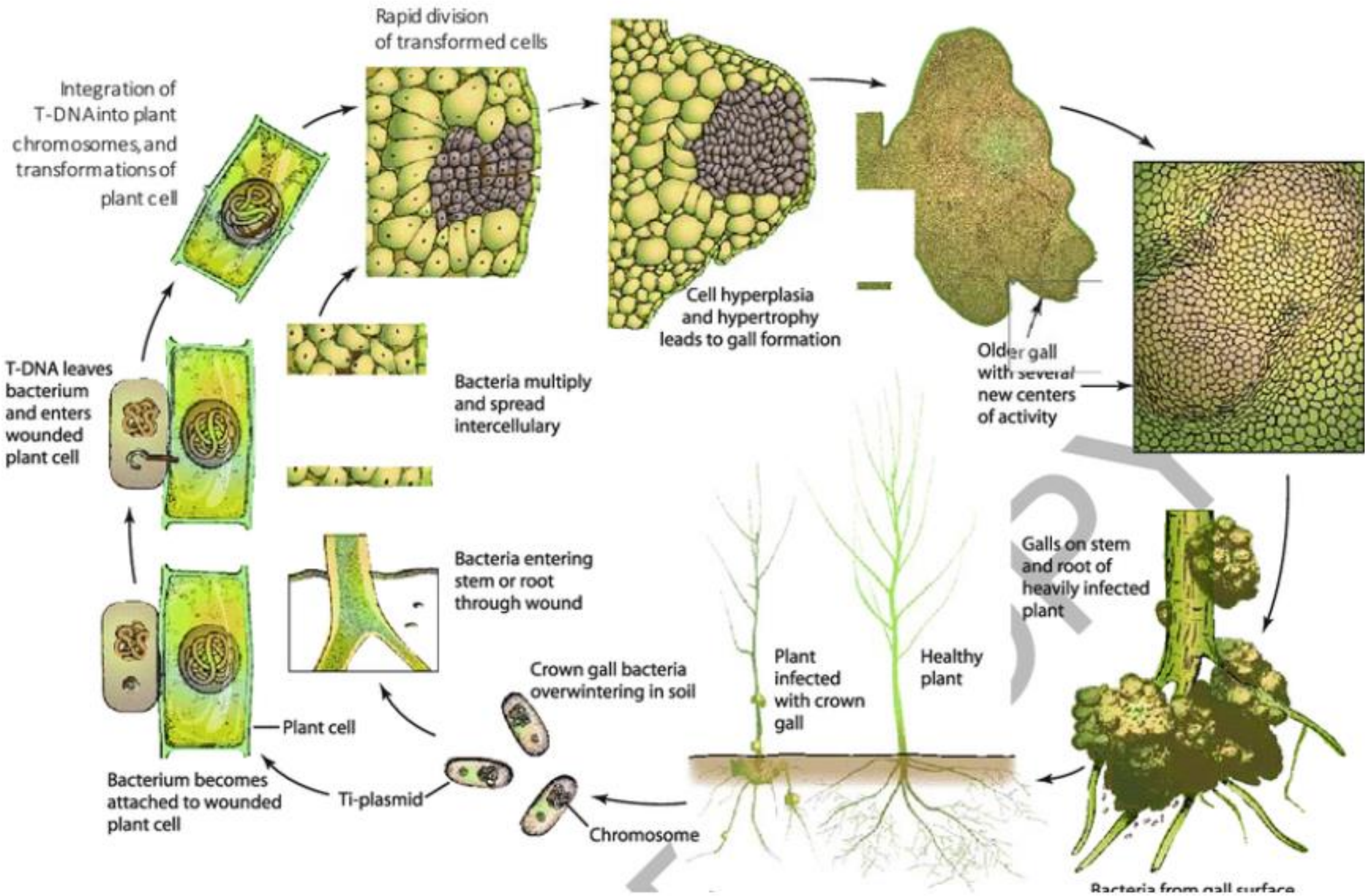
Born in 1972 – Regulated in 1976



Domestication of a natural gene transfer process

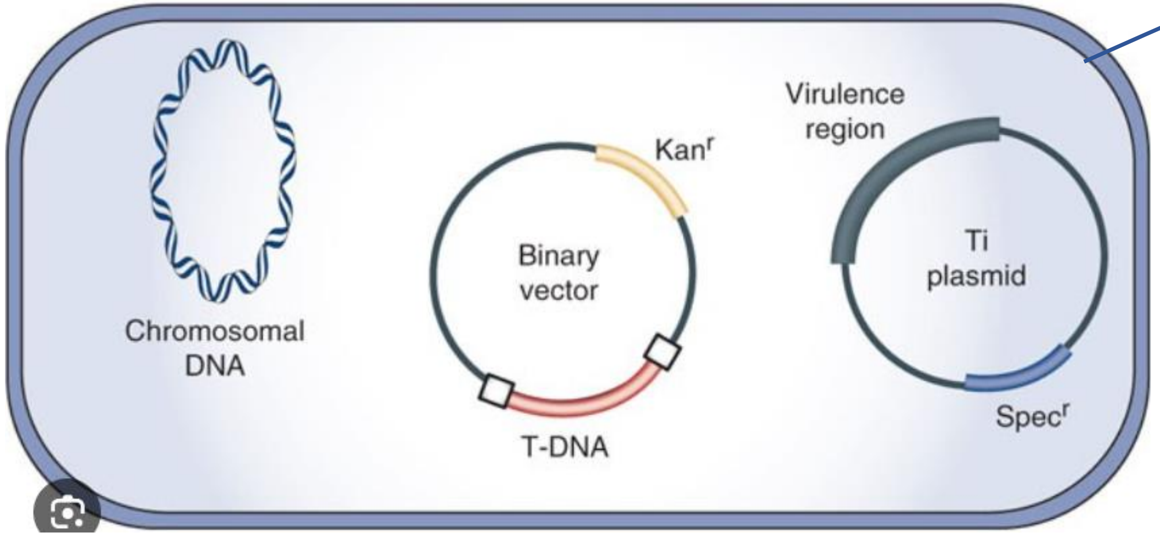
Discovery in 1977 of gene transfer from *Agrobacterium tumefaciens* caused the crown gall disease

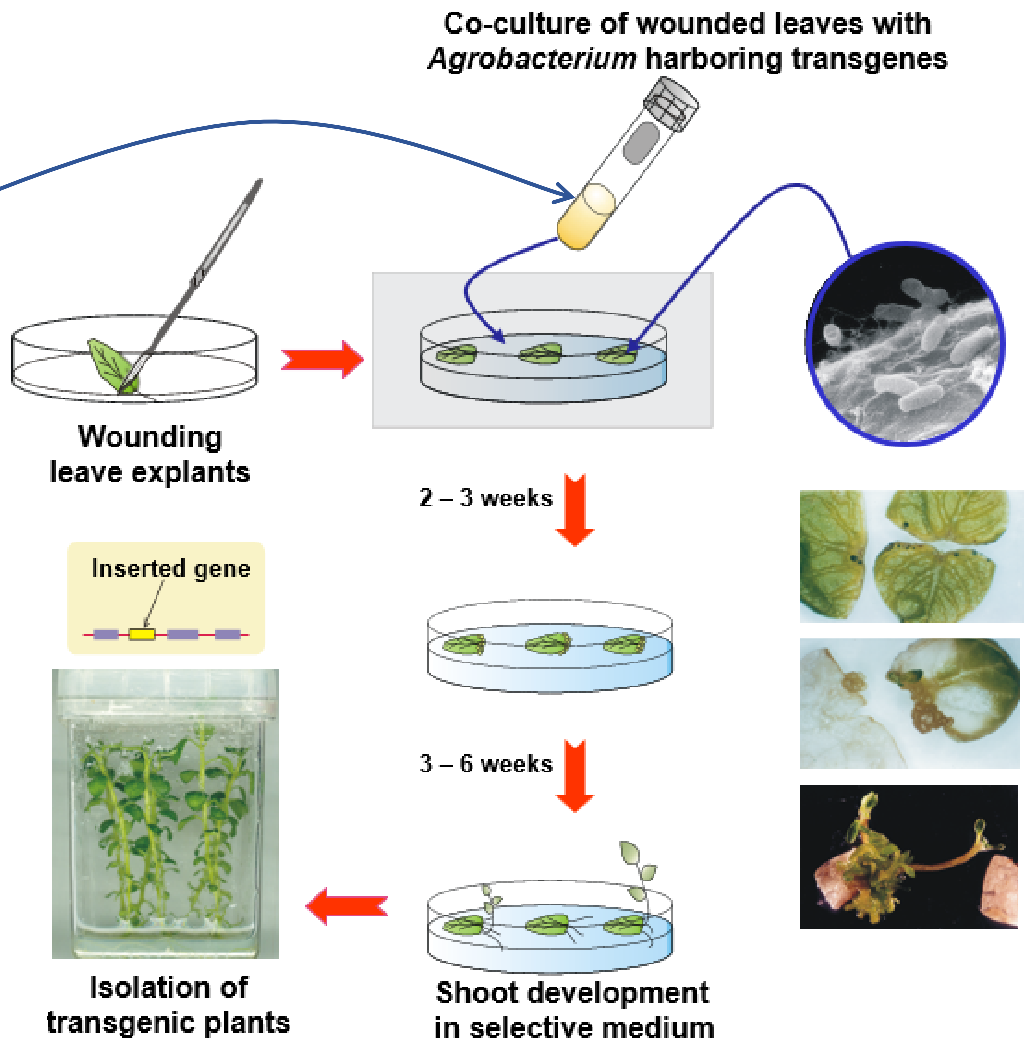




Agrobacterium-mediated transformation of potato

Agrobacterium strain harboring the gene(s) of interest



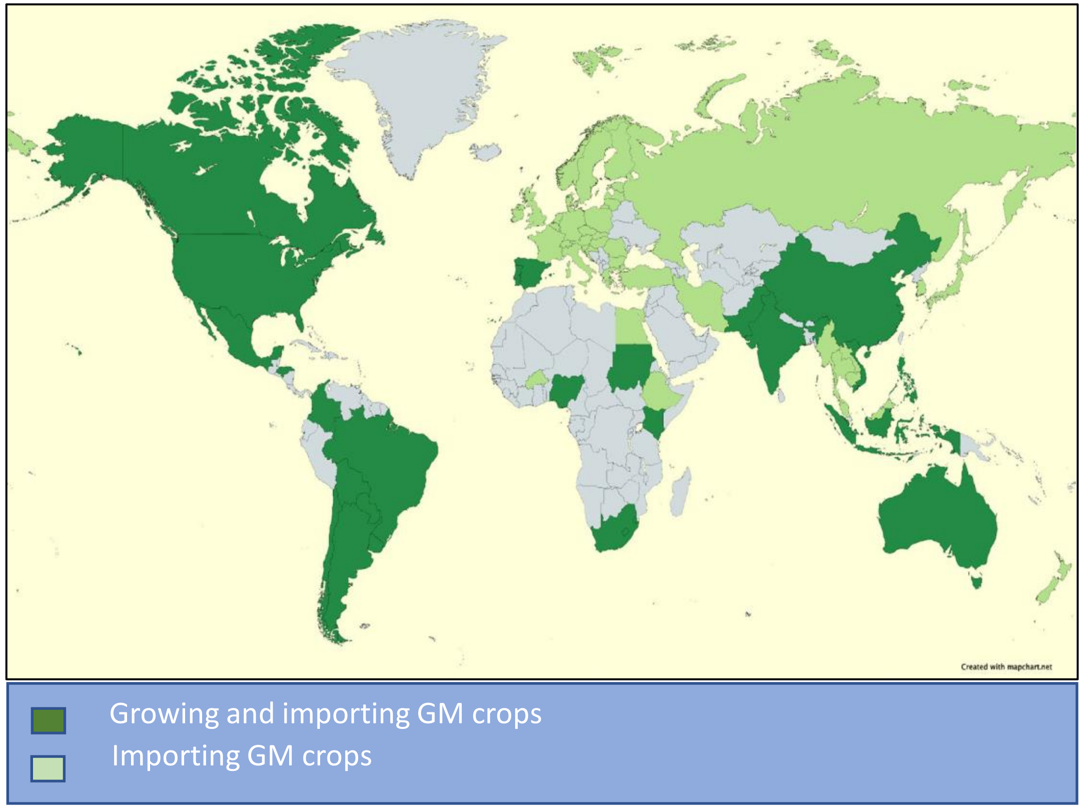


Regulatory landscape of genetically engineered crops

29 countries planted GM crops on 190.4 million Ha (13.6% of world arable land)

Difficult public acceptance fuelled by rejection from civil society organizations opposed to:

- Industrialization of agriculture
- Technology development
- Intellectual property on seeds
- Globalization of seed trade



GM crops in 2018

Phytophthora infestans : the plant destroyer

- **Extremely efficient pathogen**: airborne - 5 days life cycle - Xrate 100,000 - travels over 30 km => whole fields can be destroyed within just a few days

- Cause loses of up to **10 billion US$/year*** in the developing world

- 100 million US$/year in Uganda alone

*Haverkort et al., 2009 Potato Research (2009) 52:249–264 using 2017 production data

Economic impact of late blight disease

- Irish potato famine in 1845-49 when 1.5 million people died and a million more emigrated: 8.4 million in 1844 had fallen to 6.6 million by 1851, and still is (2016).

- Cause loses of up to 2.75 billion US$/year in the developing world and 15 billion USD/year worldwide

Control of Late Blight

Fungicide sprays*

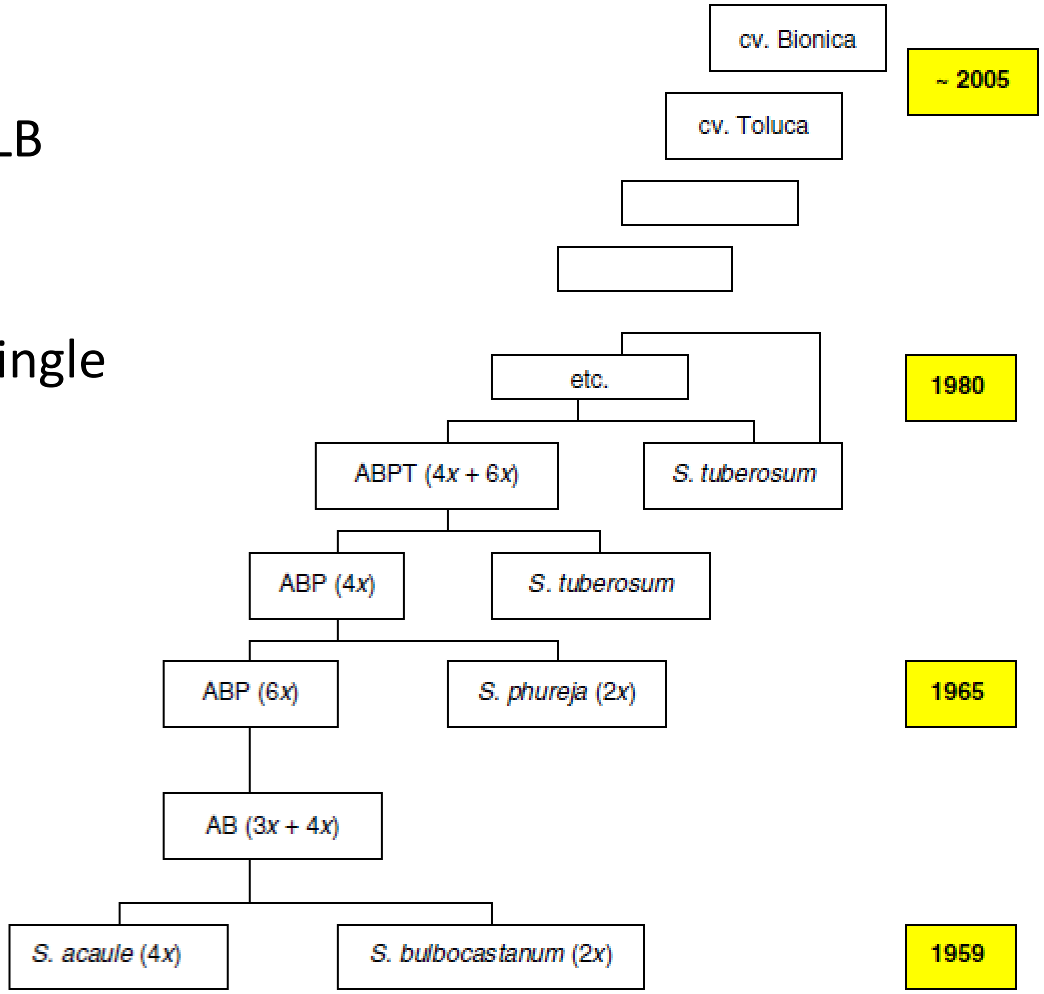
Resistant varieties

Field sanitary measures

* The European Food Safety Authority (EFSA) has released fresh data which re-confirms the toxicity of copper compounds, pesticides that are used in organic farming (2018).

Genetic improvement of potato varieties

- Crossing and selection using wild species bearing LB resistance genes took **46 years*** to introgress one single *R* gene.
- About **50 potato varieties**** were found to bear single or multiple *R* genes.
- Long development timeline and durability not guaranteed



*Haverkort, A. J., Struik, P. C., Visser, R. G. F., & Jacobsen, E. J. P. R. (2009). Applied biotechnology to combat late blight in potato caused by Phytophthora infestans. Potato research, 52, 249-264.

**Paluchowska, P., Śliwka, J., & Yin, Z. (2022). Late blight resistance genes in potato breeding. *Planta*, *255*(6), 127.

3 R-gene LBR biotech potato

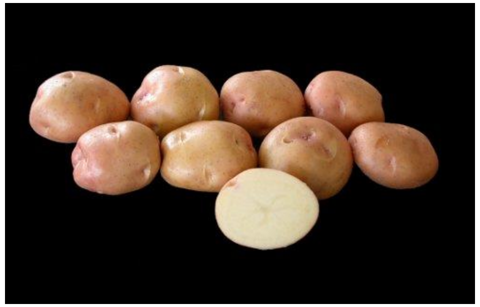
Stack of 3 *R* genes from wild relatives

2-4 years

Farmer-preferred varieties:

- Victoria/Asante, Shangi, Tigoni, Desiree, Jalene, and Diamant

Countries: Uganda, Kenya, Nigeria, Rwanda, and Ethiopia

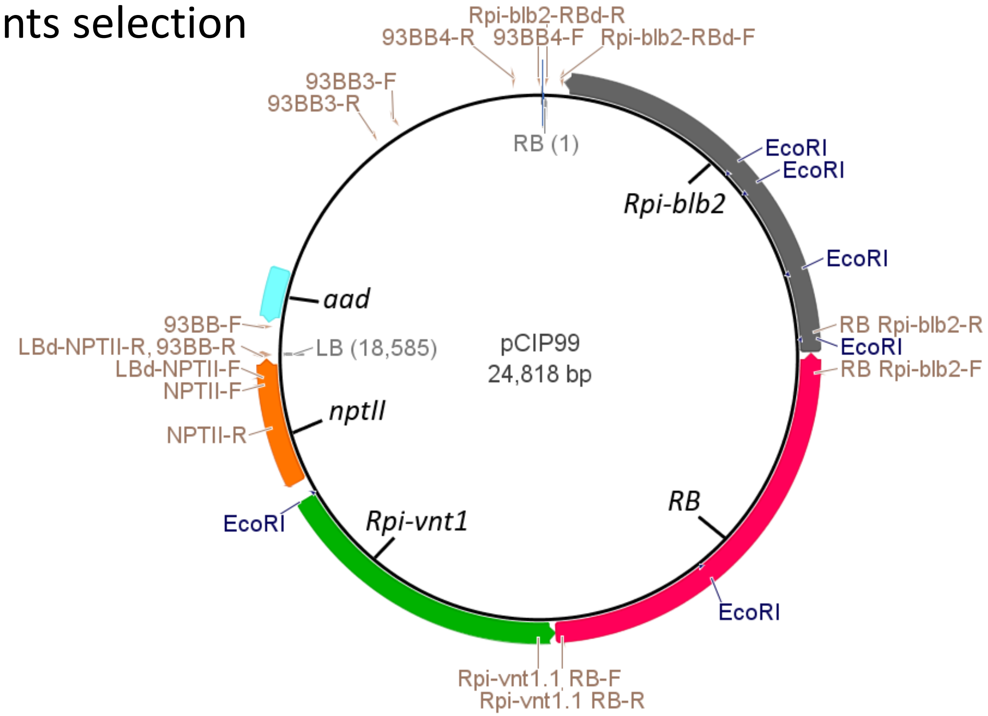


3 *R* genes from wild relatives of the potato

Stack of 3 *R* genes from wild relatives:

- ***RB*** (*Rpi-blb1*) and ***Rpi-blb2*** from *Solanum bulbocastanum*
- ***Rpi-vnt1.1*** from *Solanum venturii*
- *nptII* gene for transgenic plants selection

pCIP99 (24,819 bp) /
T-DNA (18,585 bp)



Transformation and bioassays of transgenic potatoes

- Farmer-preferred varieties (Uganda, Kenya, Rwanda, Burundi, DR Congo (Kivu), Tanzania, Ethiopia): Victoria/Asante, Shangi, Tigoni, Desiree, and Jalene
- Production of ± 100 transgenic events per variety
- Whole-plant assays and detached-leaf assays using aggressive strains in biosafety greenhouses in PE and KE
- Selection of the transgenic events completely resistant to LB disease

Multilocation trials in Uganda (17)

CFT-2 at KaZARDI – NARO Uganda: natural infestation, no fungicide sprays

CFT-4 at KaZARDI – NARO Uganda: Vic.1 yield estimated to 40 t/ha

Desiree and Victoria varieties died (empty plots)
Transgenic plants were all healthy (green plots)
No obvious agronomic / phenotypic changes

Ghislain et al., 2019. Plant Biotechnology J, 17:1119–1129

Multilocation trials in Kenya (9)

Asante (Victoria), Shangi, Tigoni varieties were greatly affected by LB disease.

Transgenic plants were unaffected by LB disease and showed good agronomic performances.

One of them from the most popular variety Shangi, was selected for commercial release.

Confined field trial in Njabini, Kenya, 2023

Multilocation trials in Nigeria (4)

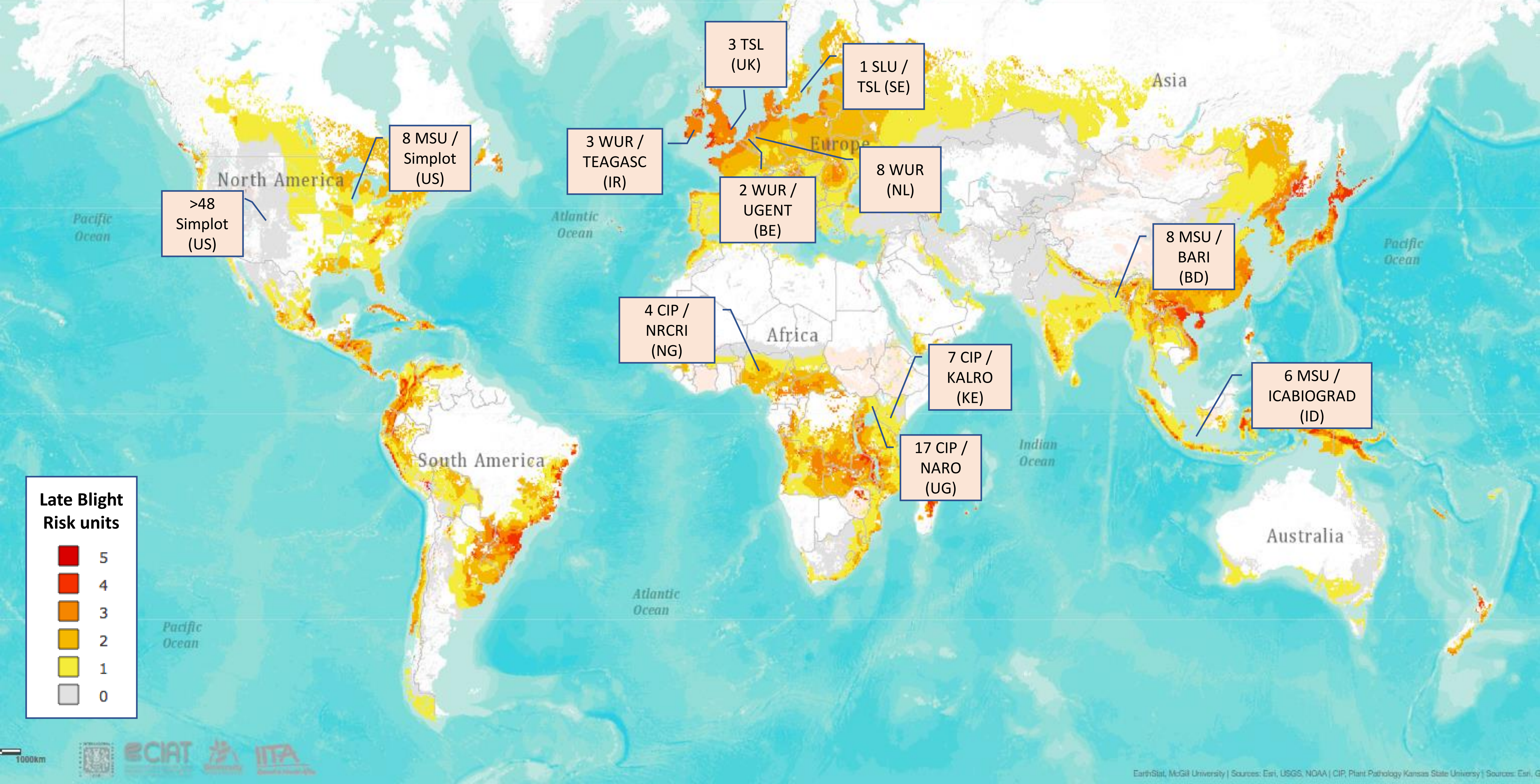
Asante (Victoria), Desiree, Diamant, Shangi, Tigoni varieties were greatly affected by LB disease.

Transgenic plants were unaffected by LB disease and showed good agronomic performances.

Multilocation trials on-going.

Confined field trial in Kuru, Nigeria, 2022

3*R*-gene LBR potato confined field trials (2011 – 2024)



An international team with long-term commitment from sponsors

Researchers since 2008:

- Andrade J., Gamboa S., Kreuze J., Lindqvist-Kreuze H., Rivera C. @ ABL-CIP, **Peru**
- Abuor A., Ghislain M., Irukani Q., Kaleku J., Kihiu E., Magembe E., Makoko I., Mogere D., Moyo M., Muruo R., Mwangi M., Njoroge A., Odingo J., Parker M., Webi E. @ BecA-CIP, **Kenya**
- Mbiyu M., Nyongesa M., Evans, Taracha C. @ KALRO, **Kenya**
- Amadi CH., Shuaibu K. @NRCRI, **Nigeria**
- Baguma, G., Barekye, A., Byarugaba A., Kiggundu A., @ NARO, **Uganda**
- Hui L., Suping Z.@ TSU, **USA**
- Douches D., Zarka K. @ MSU, **USA**

Sponsors since 2008:

USAID FROM THE AMERICAN PEOPLE

2BLADES FOUNDATION

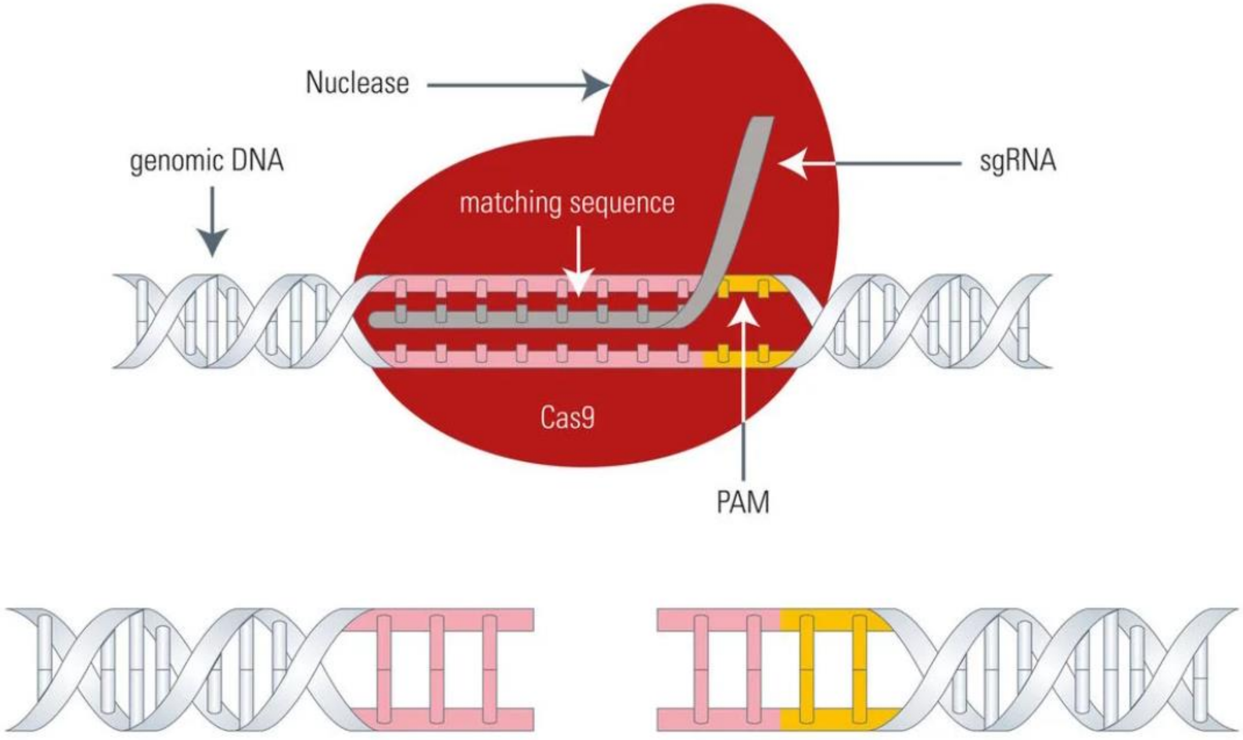
USDA

CGIAR Research Program on Roots, Tubers and Bananas

Domestication of a natural genome editing process

Discovery in 2012 of a bacterial antiviral defense system based on Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) allows to:

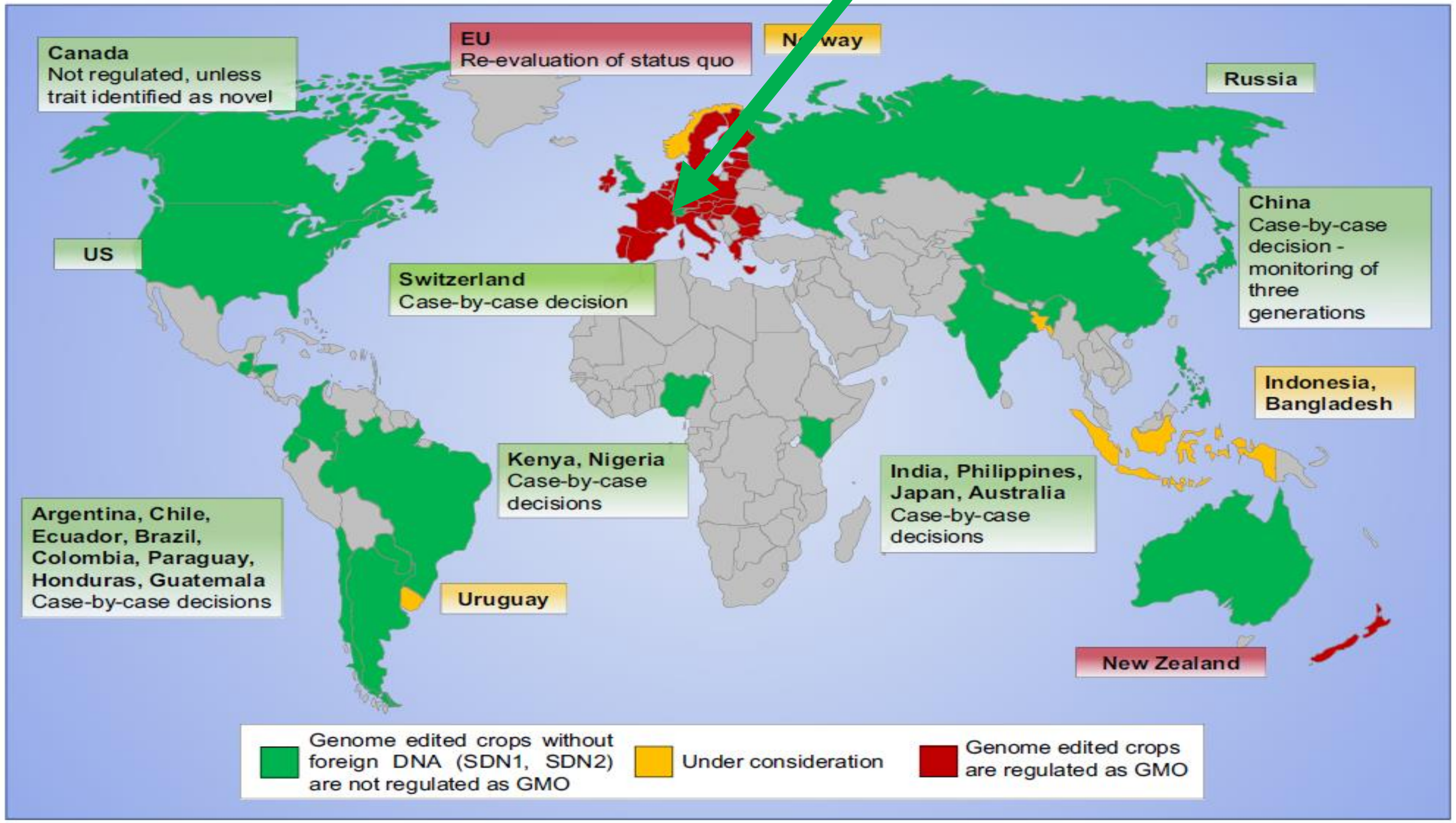
- Introduce mutations by non-homology end joining
- Insert short DNA templates by homologous recombination repair
- Base editing (convert A-T base pairs to G-C base pairs)
- Prime editing (copies RNA sequences)



Regulatory landscape of gene edited crops

2023-4: New EU regulation aligning to the rest of the world – under voting

6 genome-edited crop traits (soybean, canola, rice, maize, mushroom and camelina) approved for commercialization in 2022.



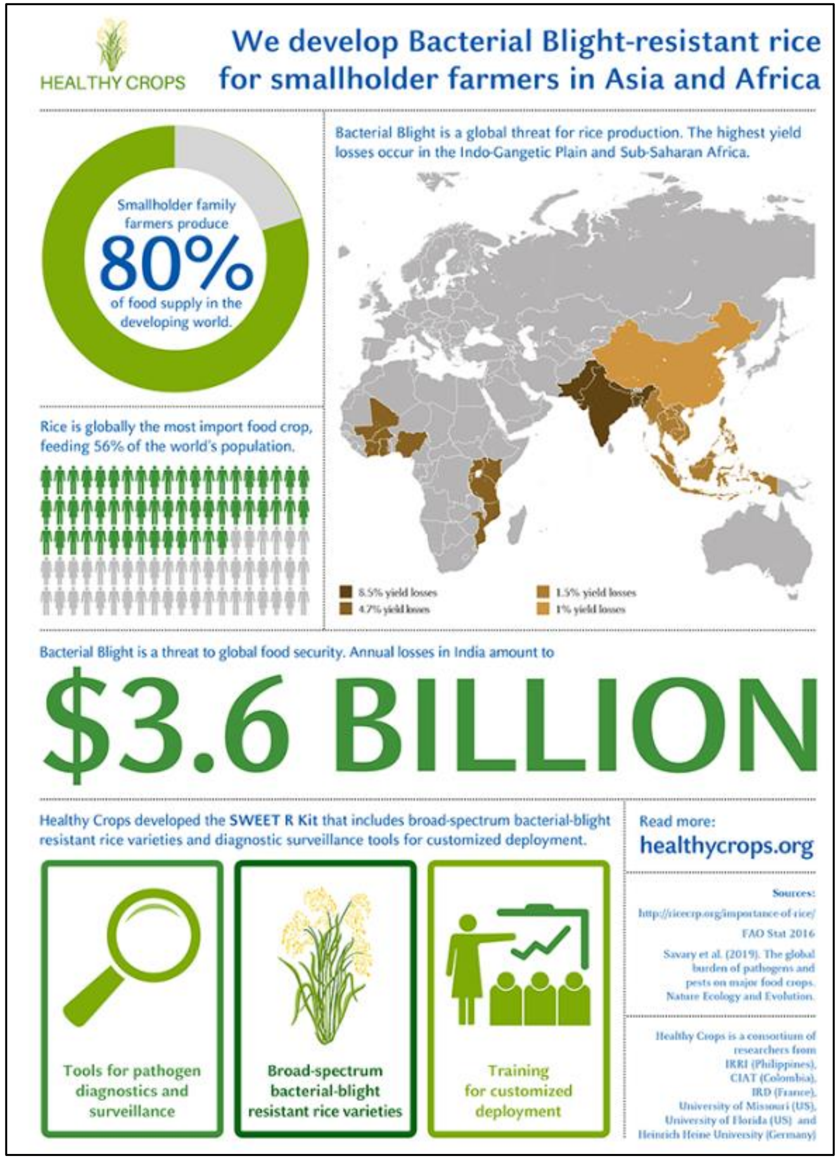
Buchholzer, M.; Frommer, W. B. 2022

Bacterial blight disease of rice

Bacteria of the family Xanthomonas oryzae pathovar oryzae (Xoo) can cause up to 70% rice crop loss.

Rice seeds are treated with authorized antibiotics with copper oxychloride or copper sulfate.

Infection with Xoo results in a strong infection of the rice plants with bacterial leaf blight.



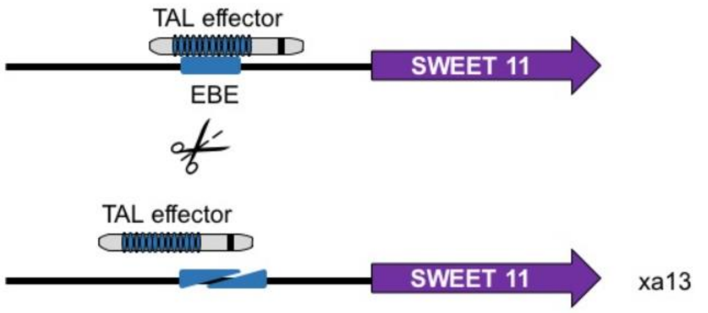
www.healthycrops.org

Developing bacterial blight resistant rice varieties

Xoo bacterium instructs rice genes to secrete sugar which is consumed by the bacterium.

By altering the effector binding element (EBE) of several SWEET genes and Introgressing them into rice BB resistant lines were developed.

These are considered as non-GMO and can be used in conventional breeding programs.



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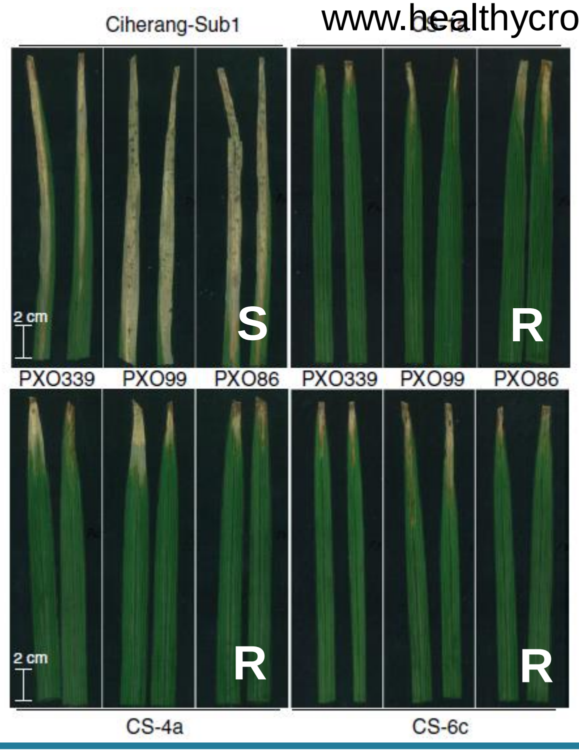

Oliva et al., 2019

Final key messages

- Transgenic and gene edited organisms exist in nature
- Transgenic crops can be costly (2-100M$) and lengthy to commercialise (5-20Y)
- Transgenic crops have a history of safe use for human health and the environment (30Y)
- Transgenic crops have delivered huge impact on farmers income, pesticide reduction, and environment protection
- Gene edited crops are inexpensive and easy to commercialise but limited to the crop’s primary gene pool
- Transgenic and gene editing are complementary technologies of modern biotechnology