Mutation Breeding for Food Security

03 July 2017, Vietnam

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Joint FAO/IAEA Division

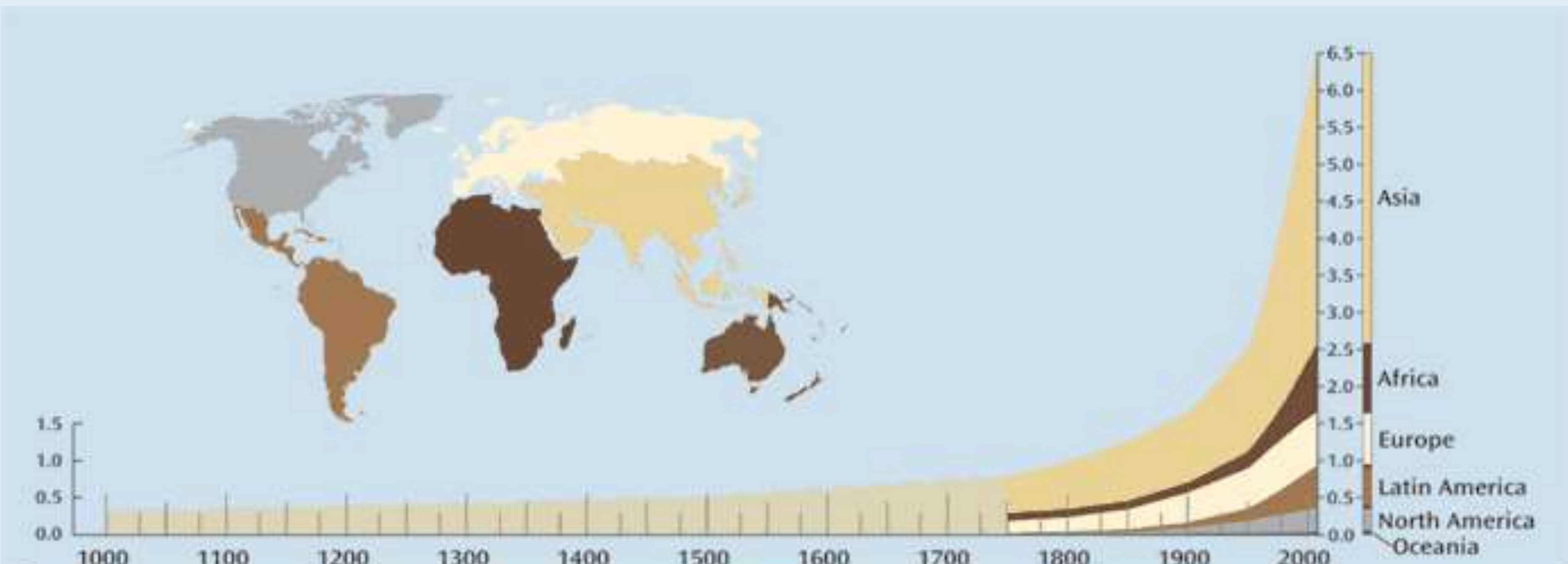
Nuclear Techniques in Food and Agriculture





Main challenge

The main challenge world agriculture will face in the coming decades is to produce 70% more food for an additional 2.3 billion people by 2050 while at the same time combating poverty and hunger, using scarce natural resources more efficiently and adapting to climate change.



Sources: 1 - The World at Six Billion; Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2004 Revision and World Urbanization Prospects: The 2003 Revision, <http://esa.un.org/unpp> 2 - United Nations, 1973. "The Determinants and Consequences of Population Trends, Vol.1" (United Nations, New York). United Nations, (forthcoming). "World Population Prospects: The 1998 Revision" (United Nations, New York). <http://www.geohive.com/global/>

FAO Global Goals:

- Eradication Hunger, food insecurity and malnutrition
- Elimination of poverty
- Sustainable Management and utilization of natural resources

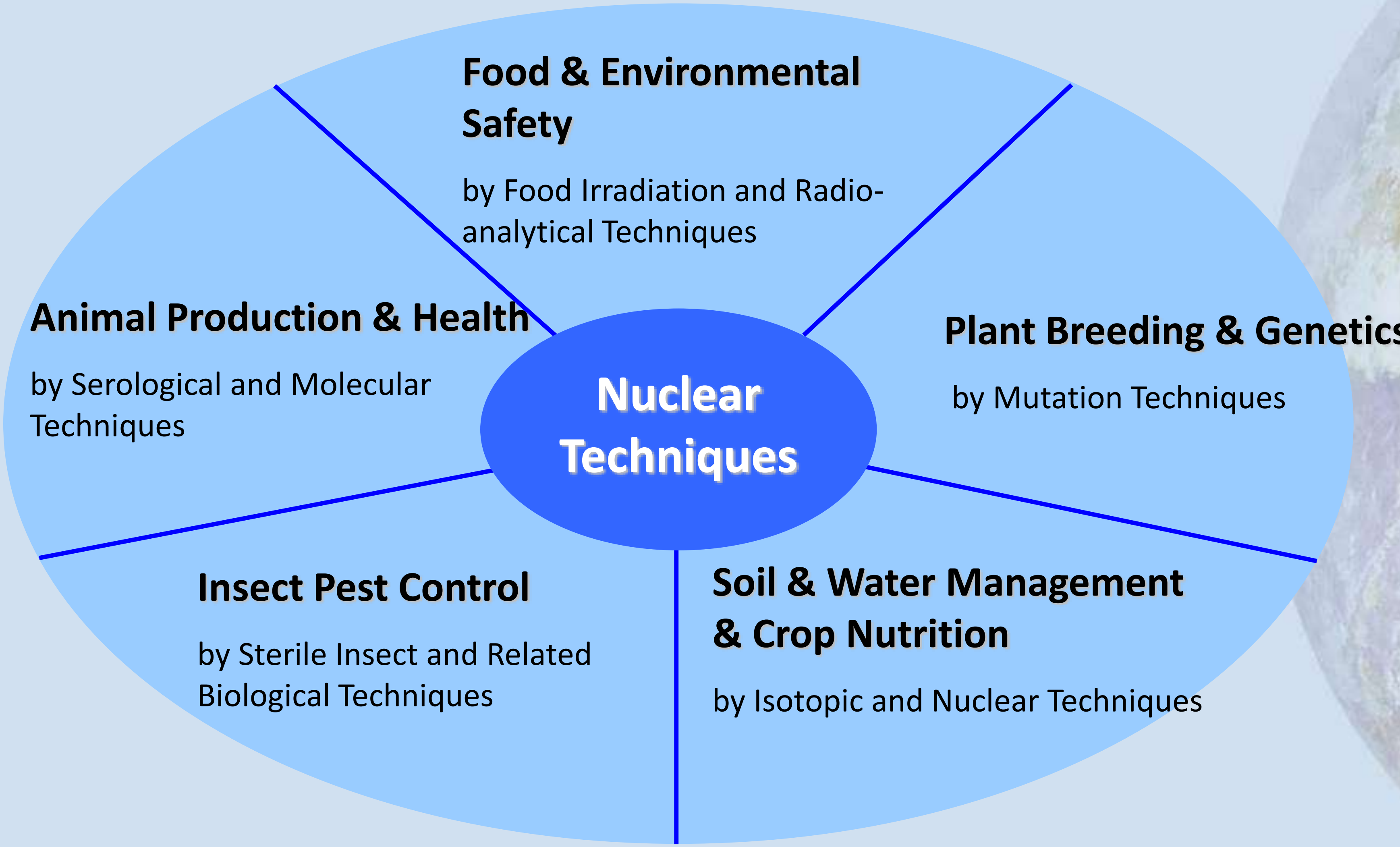
Joint FAO/IAEA Programme

The Programme serves as the global focal point for nuclear cooperation, mobilising peaceful applications of nuclear science and technology for critical needs in developing countries, including fighting hunger, disease, poverty and pollution of the environment and thereby contributing to the sustainable development goals of its Member States

IAEA

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

NAFA and Sections



Plant Breeding and Genetics Subprogramme

Plant Breeding and Genetics Section (PBGS)

- Supporting and implementation of Technical Cooperation Projects (TCP)
- Implementation of Coordinated Research Projects (CRP)

Plant Breeding and Genetics Laboratory (PBGL)

- Research & Development
- Supporting and implementation of CRPs
- Capacity development in Member States through training
- Services for Member States




Core areas of work

- **Mutation induction**
  - ***Develop and improve the techniques for mutation induction***
  - ***Speed up mutant line development by using biotechnology***
  - ***Increase mutant germplasm for improving biodiversity***
- **Mutation detection**
  - ***Increase the efficiency of screening for desired traits***
  - ***Develop and improve selecting techniques for mutation breeding***
  - ***Explore molecular discovery of mutation by biotechnology***





Plant Breeding and Genetics Laboratory

Ms Lydia Horn (Namibia) *in the green house at Joint FAO/IAEA laboratories, during training in 2009*

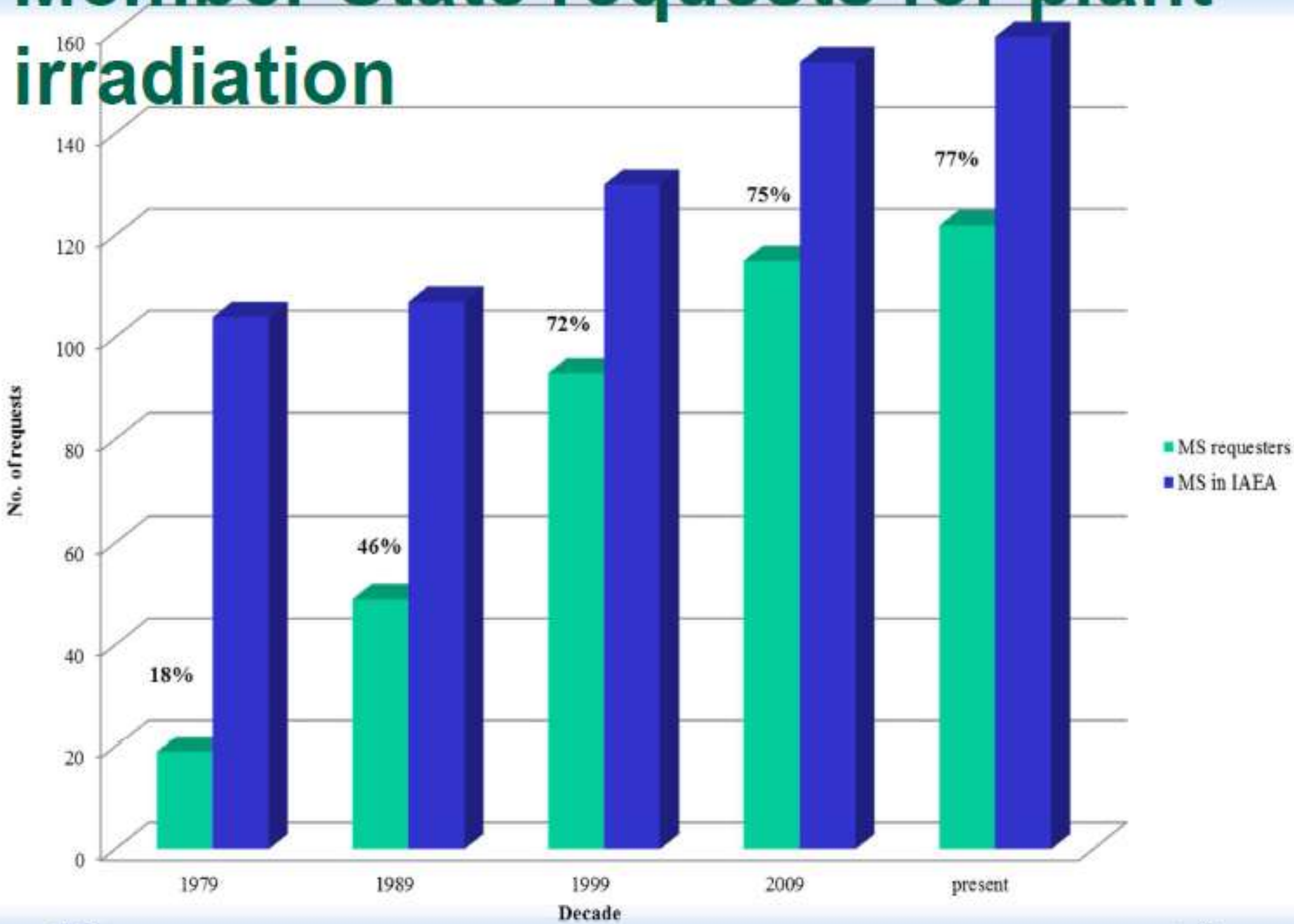
Training options offered by PBGL:

- Individual fellowship training
- Group fellowship training
- Individual internship training
- Regional and Inter-regional group training courses
- Workshops

On average, 30 people are trained per year in the following areas:

- Mutation induction and discovery
- *In vitro* tissue culture
- DNA markers

Member State requests for plant irradiation



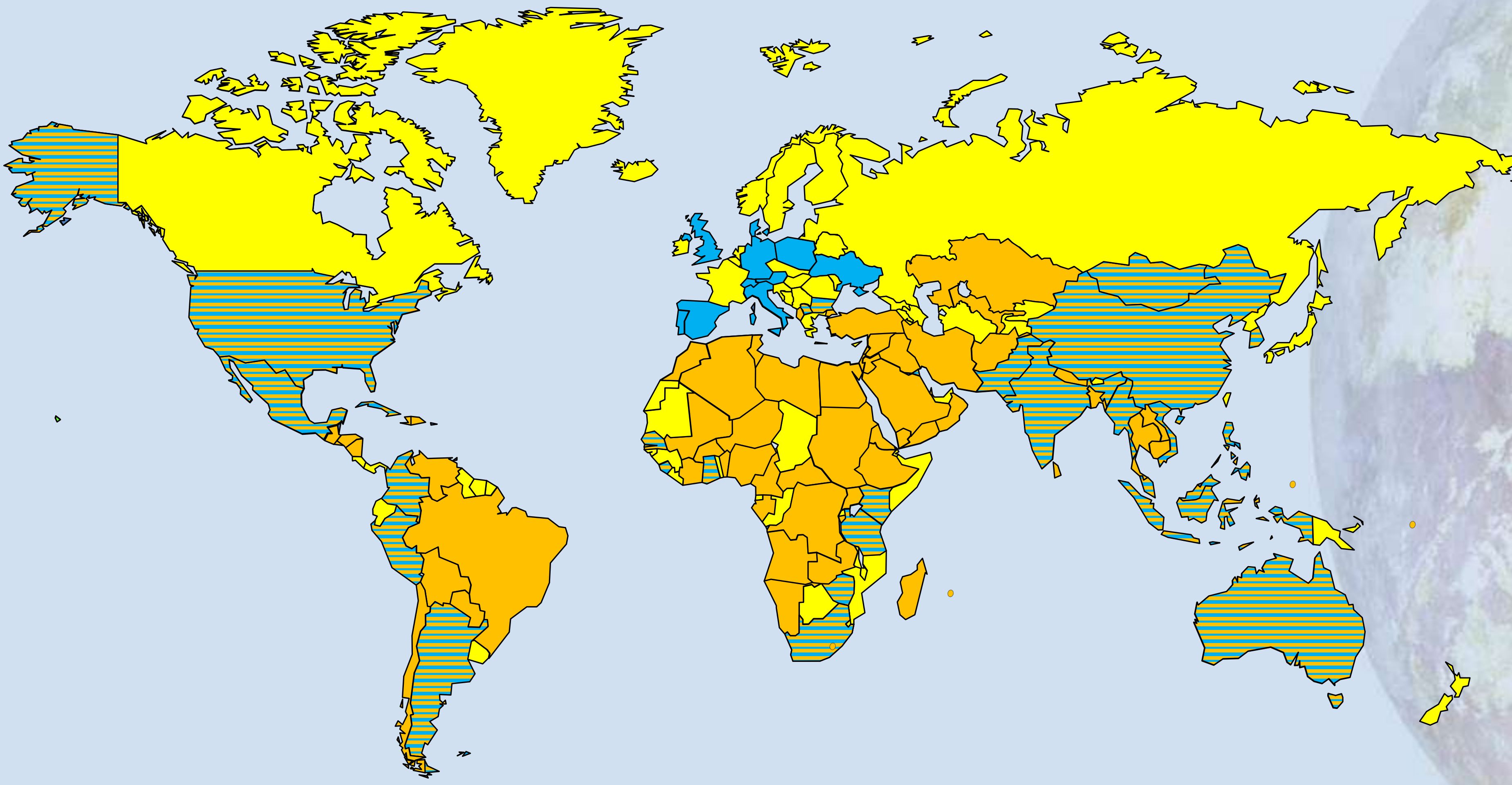
Technical Co-operation projects

- **National (2 years)**
  - capacity building (fellowships, scientific visits)
  - expertise in plant breeding
  - infrastructure building (equipment)
- **Regional & Interregional (4-5 years)**
  - capacity building

Coordinated Research Project - CRP

- R&D
- Development of technology packages, protocols, guidelines for MSs

3 CRP & 57 TCP



2015-2016

Plant Breeding Methods

- Modern plant breeding, based on the means of generating genetic variability, is classified into:
- Cross breeding: the key component is “cross” [between commercial varieties and/or landraces] and “selection”; the end products are recombinants of existing alleles. The potential is mostly explored by prospection (spontaneous mutations).
- Mutation Breeding: Generating new gene alleles not existing in the germplasm; or improving a few key traits in a otherwise excellent variety (induced mutations). No GMO, no intellectual property (IP) issues.
- Transgenic breeding: Adding foreign genes into a commercial variety. GMO, IP issues (monopoly of new varieties)

Physical mutagens

X and UV rays	Small suppressions
γ rays	Translocations, duplications, inversions, suppressions
Transposable Elements	Precise integration of nucleotides
Cosmic rays	Translocations, duplications, inversions, suppressions
Ion and Electron beam	Translocations, duplications, inversions, suppressions

Irradiator

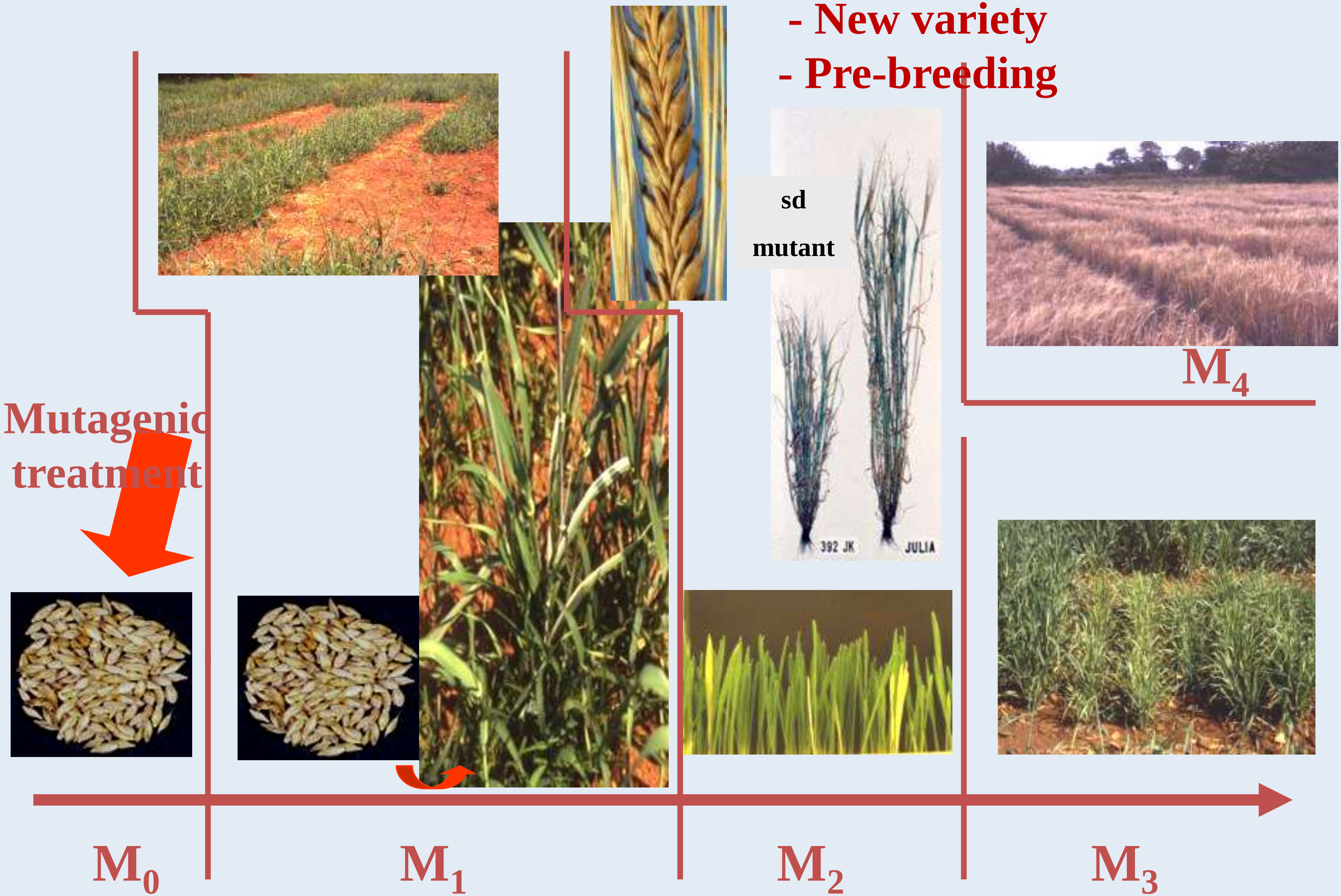
Chemical Mutagens

Types	Effects
EMS: Ethyl methane sulfonate	G/C-A/T transition
ENU: N-ethyl N-nitrosourea	alcalinisation agent AT to TA transversions AT to GC transitions
Formaldehyde	Small deletions

Crop improvement by mutation techniques

Technical basis;

- Variation is the source of evolution
- Spontaneous mutation rate is $1\times10^{-8} \sim 1\times10^{-5}$
- Radiation can cause genetic changes in living organisms and increase mutation rate up to $1\times10^{-5} \sim 1\times10^{-2}$
- Mutagen application accelerates the process
- Mutation induction create a variant that is different from the parent
- Induced mutants are not GMOs, as there is no introduction of foreign hereditary material into



Mutated generations

Plant Biotechnologies

In vitro Culture:

- ✓ Micropropagation,
- ✓ Somatic embryogenesis,
- ✓ Doubled Haploids techniques,
- ✓ Protoplast and cell cultures,
- ✓ Embryos rescue,
- ✓ Cryopreservation…

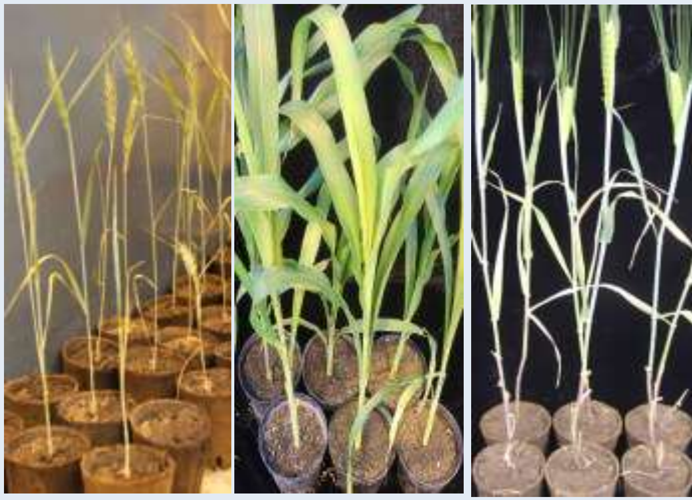
Molecular Techniques:

- ✓ DNA, Protein Fingerprinting,
- ✓ QTL Characterization,
- ✓ Gene identification and expression studies,
- ✓ Sequencing

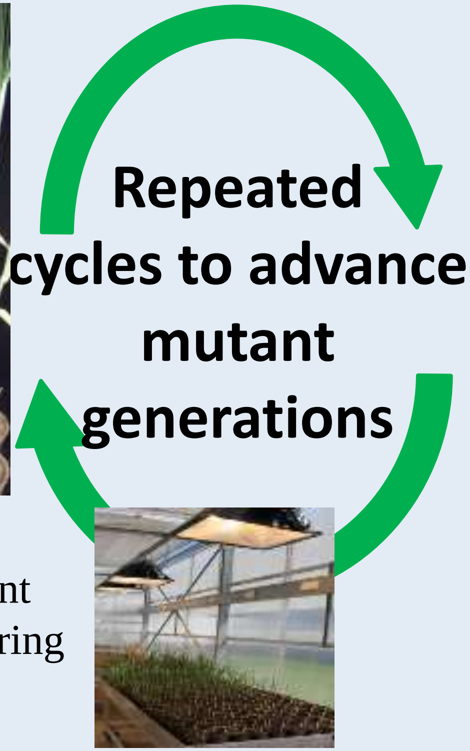
Mutagenesis

- ✓ Spontaneous mutations
- ✓ Induced Mutations

6-7 cycles per year



Wheat Sorghum Barley



Shortening the crop cycle by management techniques such as small pots, light watering and continuous light

Rescue of immature embryos to gain time

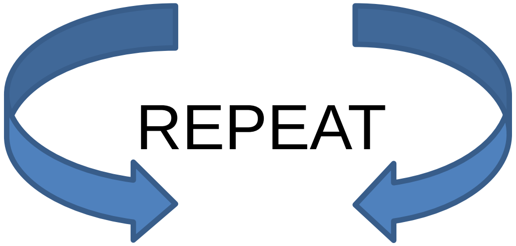
Rapid cycling techniques to accelerate mutants development

Rapid generation cycling







Three to four generations per year

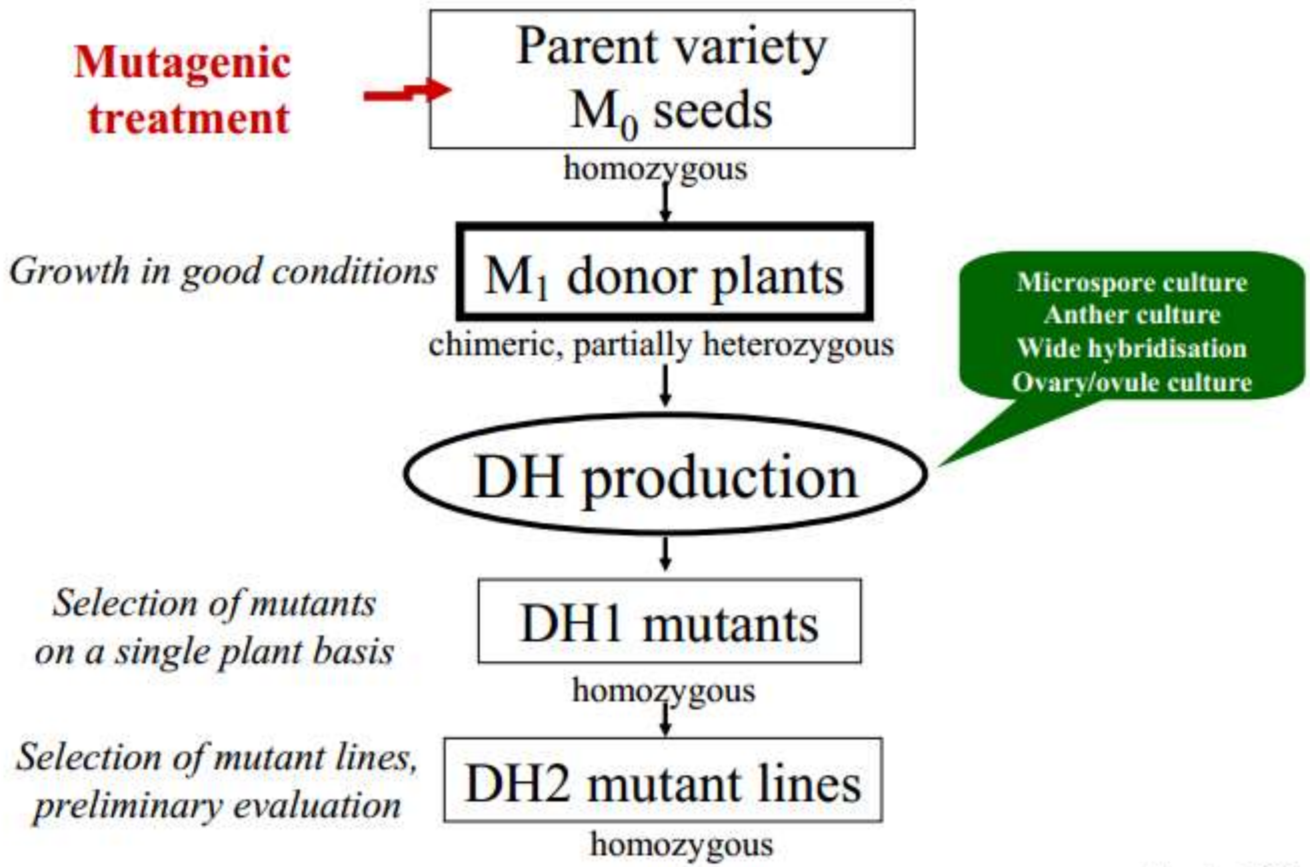
- Small pots (3 spikes)
- Continuous lighting
- Embryo culture

Doubled Haploid: Practical Issues

Widely used methods:

- Anther Culture
- Microspore culture
- Ovule culture
- Irradiated pollen
- Wide hybridization (cereals)

Development of mutant lines using seed mutagenesis and DH systems



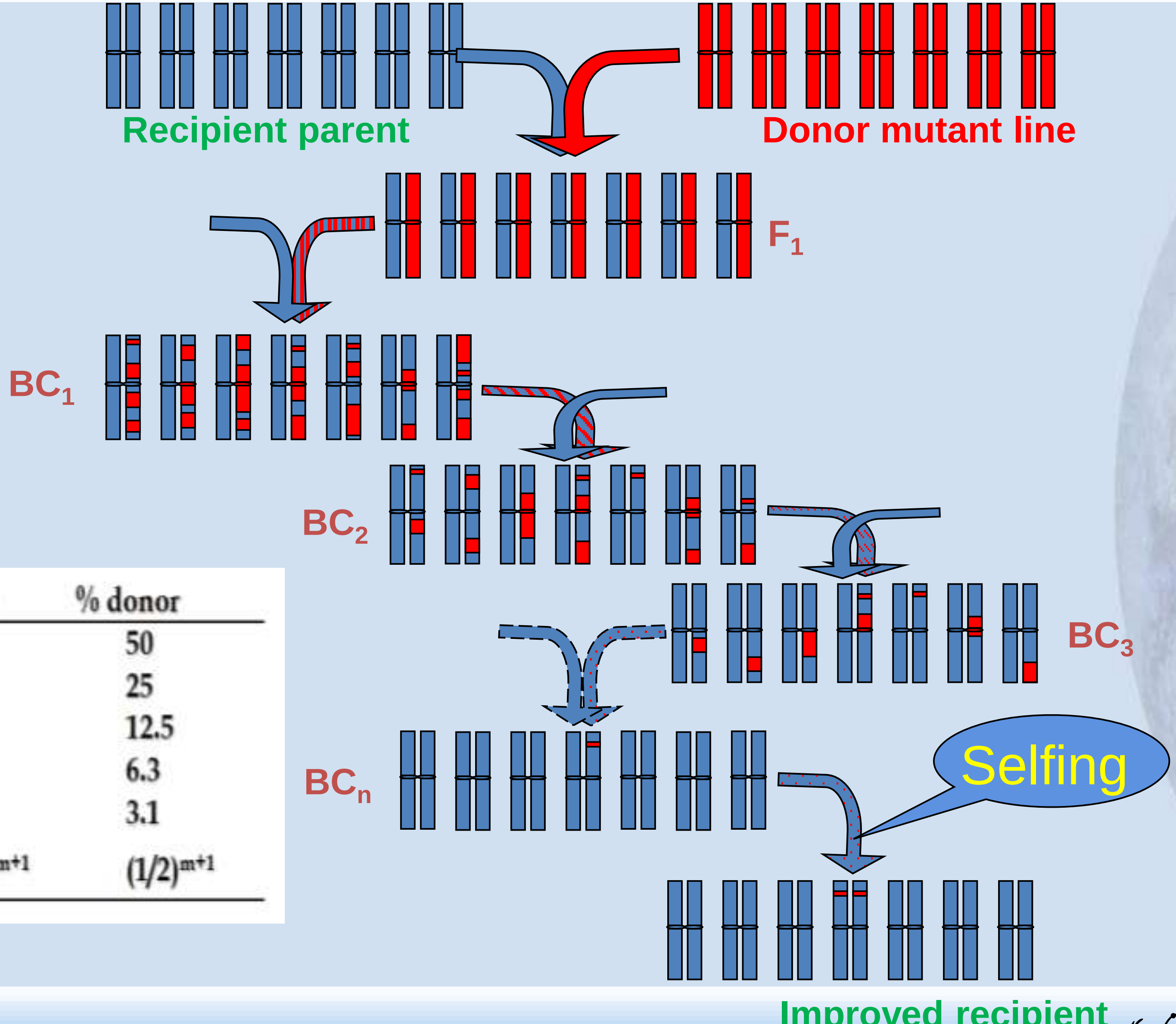
Szarejko, 2003

The advantages of DH system in mutation techniques

- Shortening the production of pure mutant/ recombinant lines
- Increased selection efficiency of desired mutants
- Rapid fixing of mutated genotypes
- Avoiding chimerism
- Screening for recessive mutants in the first generation after mutagenic treatment

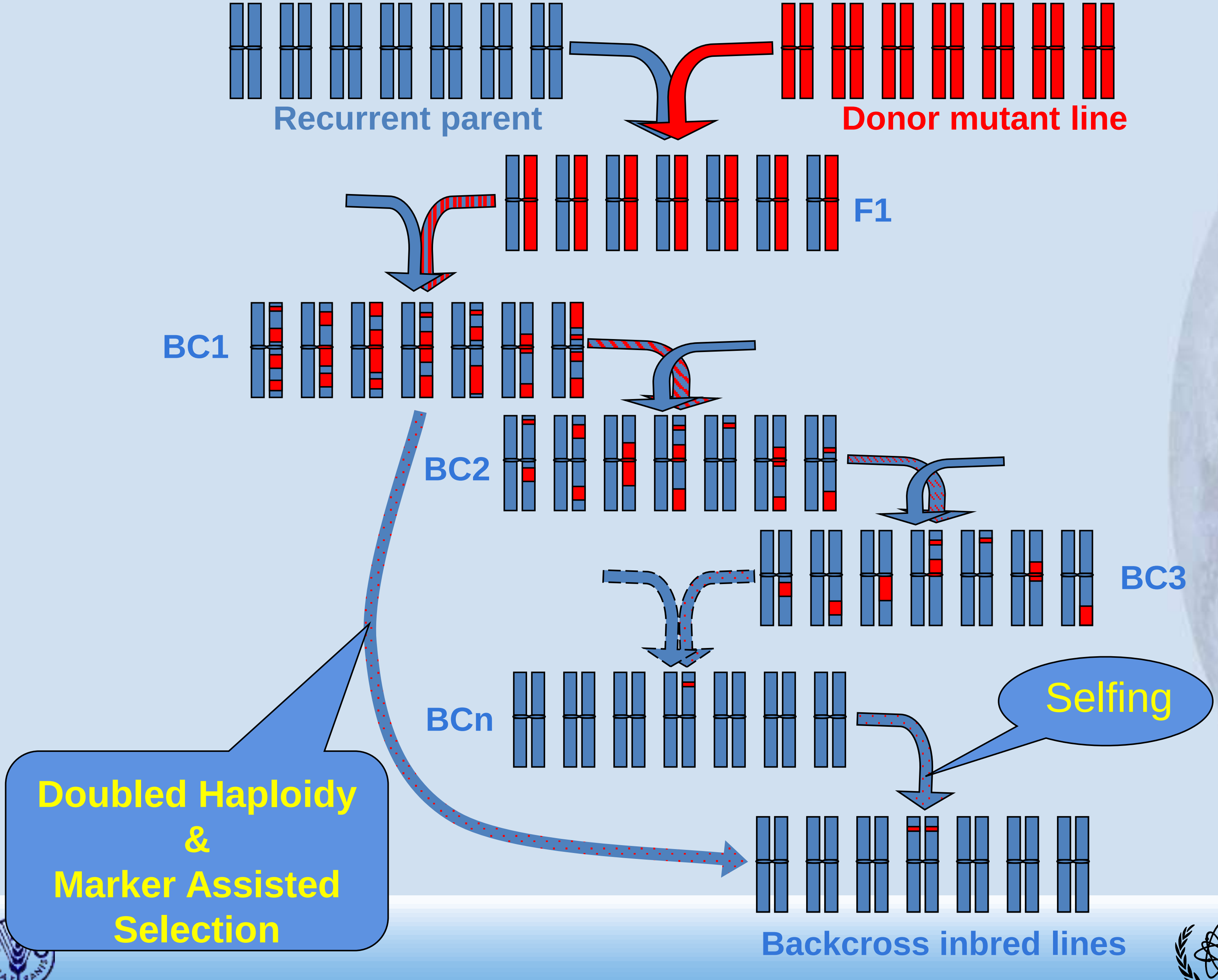
Doubled haploidy to save time

Scheme for backcross introgression

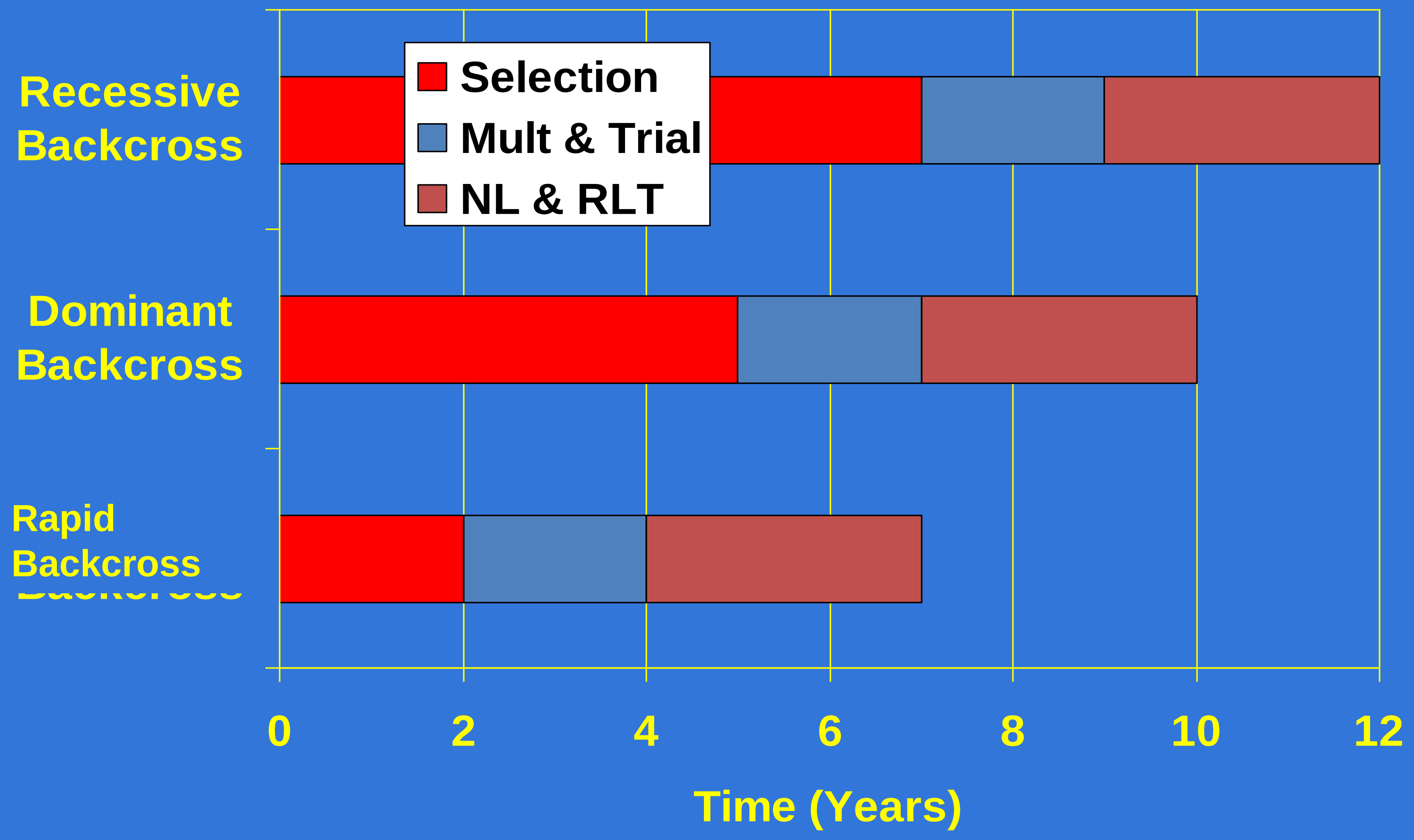


	% recurrent	% donor
F_1	50	50
BC_1	75	25
BC_2	87.5	12.5
BC_3	93.7	6.3
BC_4	96.9	3.1
BC_m	$1-(1/2)^{m+1}$	$(1/2)^{m+1}$

Short cut *via* doubled haploidy



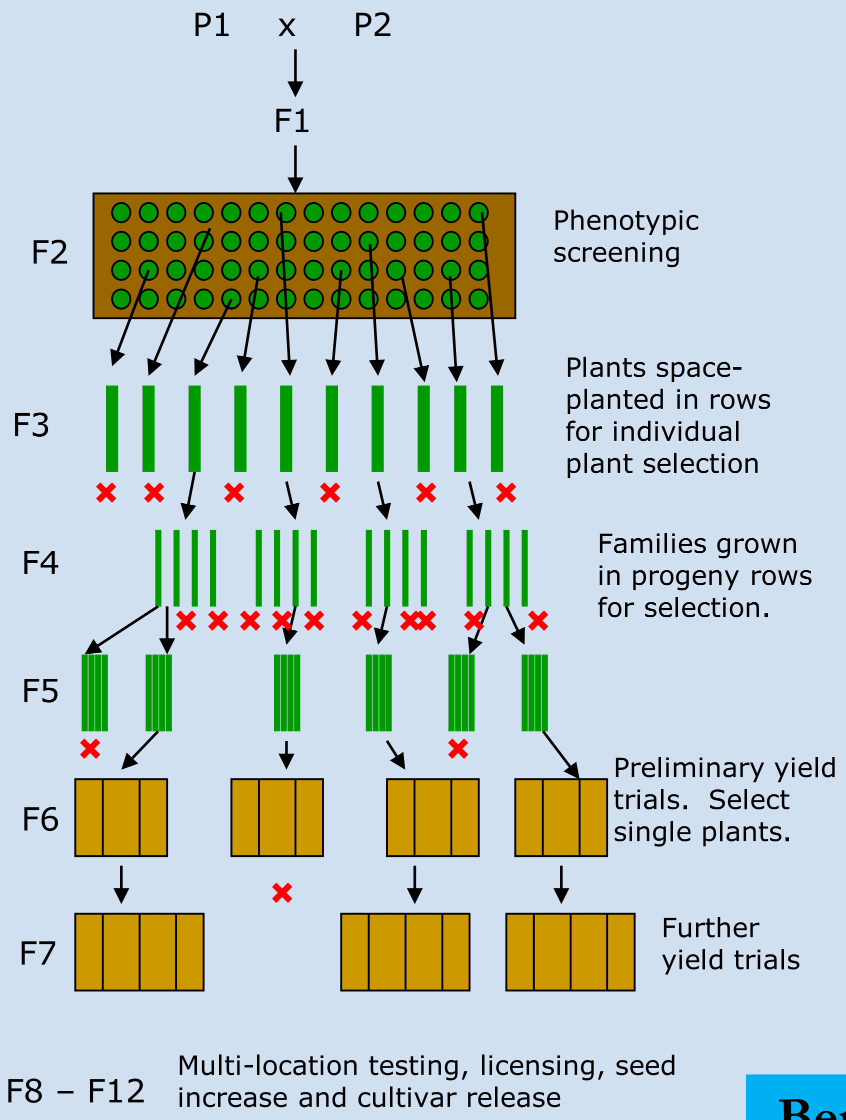
Time savings



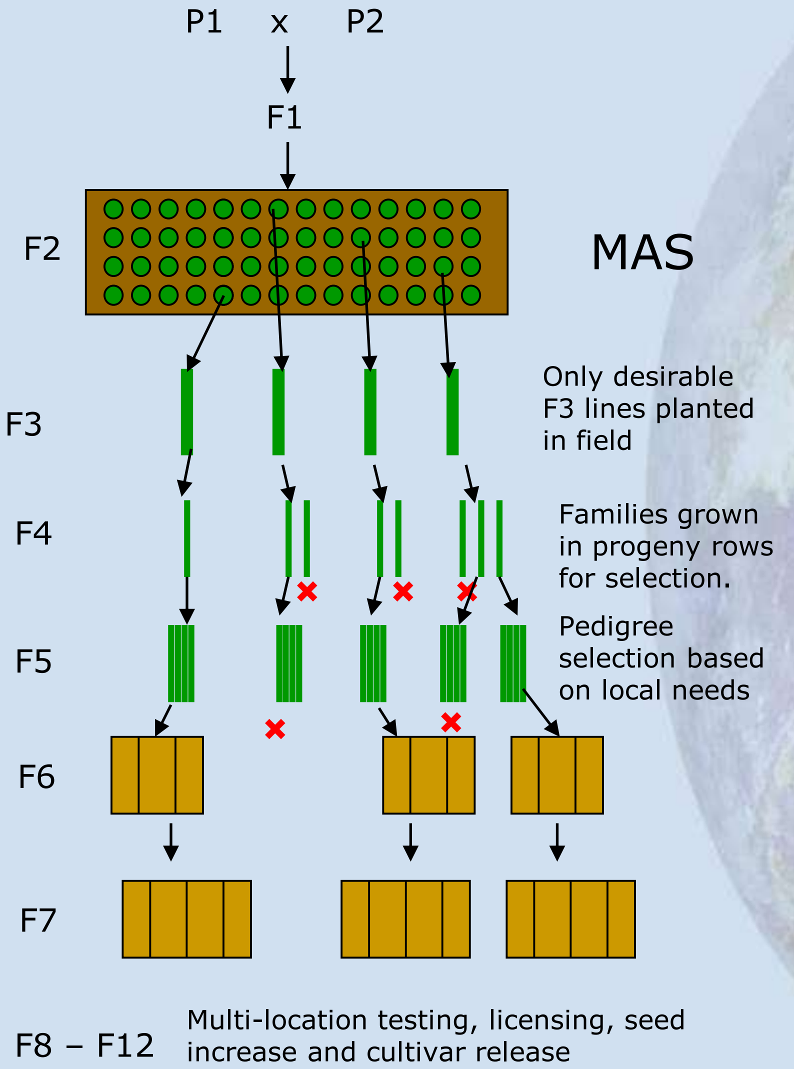
Molecular Markers in Crop Breeding

- Assessment of genetic variability and characterization of germplasm
- Identification and fingerprinting of genotypes
- Estimation of genetic distances between population, inbreeds and breeding materials
- Detection of monogenic and quantitative trait loci (QTL)
- Marker-assisted selection
- Identification of sequences of useful candidate genes

PEDIGREE METHOD



MARKER-ASSISTED SELECTION (MAS)



Benefits: breeding program can be efficiently scaled down to focus on fewer lines

Overview of ‘marker geno[illegible]g’

(1) LEAF TISSUE SAMPLING

(2) DNA EXTRACTION

(3) PCR

(4) GEL ELECTROPHORESIS

(5) MARKER ANALYSIS

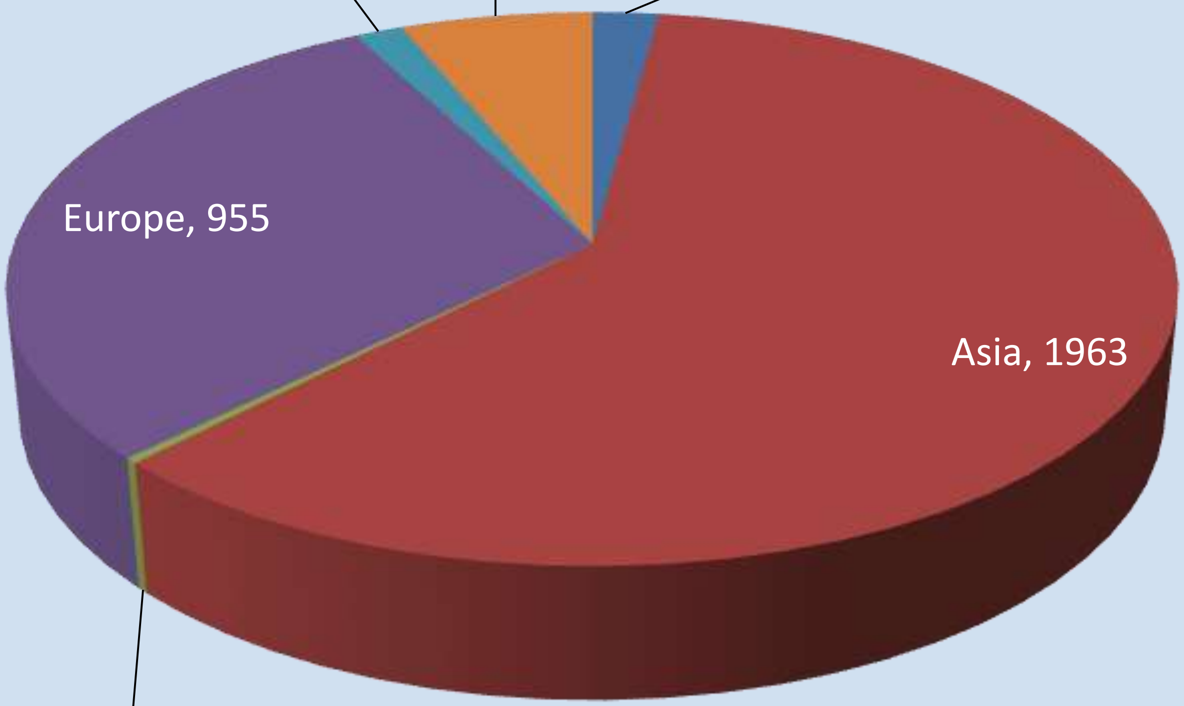
Advantages of MAS

- Simpler method compared to phenotypic screening
  - Especially for traits with laborious screening
  - May save time and resources
- Selection at seedling stage
  - Important for traits such as grain quality
  - Can select before transplanting
- Increased reliability
  - No environmental effects
  - Can discriminate between homozygotes and heterozygotes and select single plants

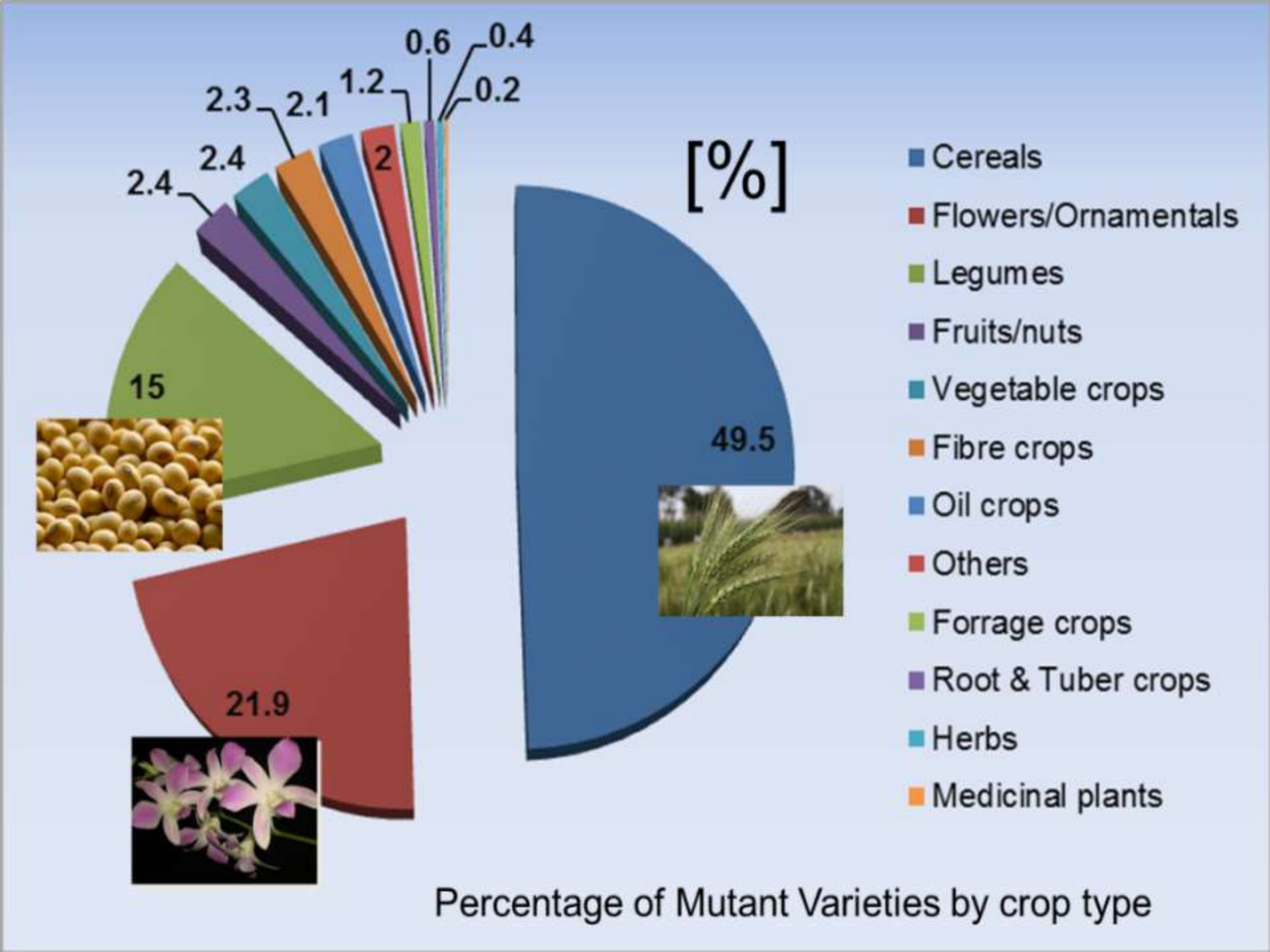
Major Achievements

Mutant Varieties Released

Total: 3246 varieties in 220 plant species



Mutant Variety Database: http://mvd.iaea.org


0.6
0.4
1.2
0.2
2.3
2.1
2
2.4
2.4
[%]
15
49.5
21.9
Cereals
Flowers/Ornamentals
Legumes
Fruits/nuts
Vegetable crops
Fibre crops
Oil crops
Others
Forrage crops
Root & Tuber crops
Herbs
Medicinal plants
Percentage of Mutant Varieties by crop type

High quality mutant rice varieties widely grown in Viet Nam

National Prize of Science and Technology of Viet Nam 2005

Mutant rice variety VND95-20 with ***high quality and tolerance to salinity*** became the key rice variety for export in 2005 (28% of the one million ha export rice area in the Mekong Delta).

Icon for success in Mutation Breeding
50 mutant varieties
8 new high quality rice mutant varieties

Mutant rice variety VND99-3, registered as a national variety with quality for export, is of short duration (100 days), meaning three rice harvests per year in the Mekong Delta.

TC project VIE/5/014

Hardy crops in harsh environments in Peru

Amaranth

"Centenario" mutant variety

- Released in 2006, cultivated on 470 000 ha, 3000 m above sea level and yielding 5,000 kg/ha
- High quality and cultivated under Good Agricultural Practices
- Certified as an organic variety
- Export increased from 20 MT to 200 MT in seven years

Barley

Mutant varieties

- Nine new improved mutant varieties cover 90% of the cropping area
- "Una La Molina 95" and "Centenario II" are popular mutant varieties
- Cultivated in the altiplano: 3,000-5,000 m above sea level
- Impressive yields of 6-8 tons/ha, compared to 4 tons /ha of

BATAN

Mutation breeding for multi-purpose sorghum in Indonesia

Sorghum mutation breeding for

- Tolerance to adverse conditions (drought, acid soils)
- Increased yield
- Grain quality for food, feed and fuel

Positive impact on food security in Indonesia: promotion of food diversification and sustainable agricultural development.

Improved snack foods: Sorghum chips with high protein and calcium

Transforming the crop production landscape in Bangladesh: A high yielding, early maturing rice mutant variety beats the Monga food insecurity problem

The Daily Star

1. Combating the seasonal food shortage
2. Creating job opportunities for farm workers during the off-season (monga)
3. Farmers can now produce another crop of potato after harvesting mutant rice varieties such as BINA Dhan-7 and 8
4. The rice straw can be sold at a good price as feed is also in short supply in October
5. BINA Dhan-9 is a salt tolerant mutant rice variety that can be grown in 2.8 million ha of saline coastal areas.
6. In addition, drought stress, which happens from time to time in November, is avoided

Juicy tomatoes from dry Cuban soil

Mutant selected under low water input condition (Mali, Carucha, Maybel y Domi)

Breeding Programme for Drought Tolerance in Tomato

Improved traits

- high number of fruits per plant
- high yielding under low water input
- improved fruit quality
- tolerance to drought

These mutant varieties are adopted by the farmers because they provide an increased income and greater flexibility in crop selection in several areas of Cuba which rely on low water and low fertilizer input agriculture.

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Cowpea, Bambaranut and Groundnut from Zimbabwe

- ✓ The crops: ***Cowpea, Bambaranuts and Groundnuts*** are important for food and nutritional security inline in Zimbabwe
- ✓ Advanced cowpea mutant lines with increased seed size (%7) and grain yields,
- ✓ Farmers field day in next week and release in September 2017,
- ✓ 14 DT cowpea mutant lines identified in pipeline (M5)
- ✓ ***Bambaranuts and Groundnuts continue…***

Cowpea, Sorghum and Millet from Namibia

- ✓ Cowpea, sorghum and millet are major staple food crops
- ✓ One of the driest countries of Sub-Saharan Africa (semi-arid and arid climatic condition regions), the project focused on drought
- ✓ 3 mutant varieties in cowpea, sorghum and millet with higher yield (10-20% than local varieties) and better drought tolerance - expected to be released in 2017
- ✓ Farmers field day to present new mutant lines to farmers will be in April 2017

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50 years, 1964–2014

Thank you