INTRODUCTION TO PLANT BREEDING
PLANT BREEDING

Developing new varieties through:

• creation of new genetic diversity
• reassembling existing diversity
• aid of special techniques & technologies
DOMESTICATION
DOMESTICATION

- Precursor to plan breeding - started 10k-18k years ago
- Plants: most impact morphology (seed size, plant architecture, dispersal mechanisms) & physiology (timing of germination or ripening)
DOMESTICATION FOLLOWED BY PLANT BREEDING
DOMESTICATION FOLLOWED BY PLANT BREEDING

ANCESTORS OF WHEAT (CA. 7-10 KERNELS)

MODERN DAY WHEAT (50 KERNELS)
DOMESTICATION FOLLOWED BY PLANT BREEDING

TEOSINTE: ANCESTOR OF MAIZE | 19 MM

MODERN DAY MAIZE | 19CM
DOMESTICATION FOLLOWED BY PLANT BREEDING

WATERMELON
3000 B.C.

WATERMELON
17TH CENTURY

WATERMELON
PRESENT DAY

INTRODUCTION TO PLANT BREEDING
DOMESTICATION FOLLOWED BY PLANT BREEDING

WILD BANANA

MODERN DAY BANANA
DOMESTICATION FOLLOWED BY PLANT BREEDING

WILD CARROT

MODERN DAY CARROT
DOMESTICATION FOLLOWED BY PLANT BREEDING

WILD EGGPLANT

MODERN DAY EGGPLANT

INTRODUCTION TO PLANT BREEDING
DOMESTICATION FOLLOWED BY PLANT BREEDING

TEOSINTE: ANCESTOR OF MAIZE

MODERN DAY WHITE MAIZE
MODERN DAY CORN

CORN 7000 BC

INTRODUCTION TO PLANT BREEDING
MODERN DAY WATERMELON

3000 BC WATERMELON

INTRODUCTION TO PLANT BREEDING
DOMESTICATION FOLLOWED BY PLANT BREEDING

PEACH 4000 BC

- 64% EDIBLE FLESH
- WAXY SKIN
- 35% STONE

MODERN DAY PEACH

- 90% EDIBLE FLESH
- 25 MM
- SOFT, EDIBLE SKIN
- 10% STONE

- TASTES ‘EARTHY’, ‘SWEET’, ‘SOUR’ AND SLIGHTLY ‘SALTY’
- 3x Reduction in Relative Stone size
- Sweet, refreshing and juicy
- 100 MM 64 Times Larger
DOMESTICATION FOLLOWED BY PLANT BREEDING

PEACH 4000 BC

MODERN DAY PEACH

INTRODUCTION TO PLANT BREEDING
EFFECT OF SELECTION
EFFECT OF SELECTION

INTRODUCTION TO PLANT BREEDING
MILESTONES IN PLANT BREEDING
MILESTONES IN PLANT BREEDING

INTRODUCTION TO PLANT BREEDING
SPECIES OF PLANTS AND ANIMALS WILL CHANGE OVER TIME.

The changes or mutations that help a species survive are the traits that are then more likely to be passed on to the next generation.
MAJOR BREAKTHROUGHS - HYBRIDS & HETEROSIS

CROSSING DIFFERENT PURE LINES =>
HYBRID PLANTS USUALLY MORE VIGOROUS THAN THEIR PARENTS.

DESCRIPTION OF HETEROSIS:
1876 - Darwin
1877 - Beal
1881 - E. Davenport
1906 - Nilsson-Ehle
1908 - Shull
1908 - East
1908 - C. Davenport
Discovery of the molecular structure of nucleic acids => Significance in information transfer in living material
MAJOR BREAKTHROUGHS - MENDELIAN INHERITANCE

Genetic basis for inherited traits & demonstration of control
MENDELIAN INHERITANCE
BREEDING METHODS
INTRODUCTION TO PLANT BREEDING
BREEDING METHODS – HYBRID BREEDING

INTRODUCTION TO PLANT BREEDING

INTRODUCTION TO PLANT BREEDING
BREEDING METHODS - HYBRID BREEDING

F1 HYBRID:
Uniform & hybrid vigor

F2:
Heterogeneous & no hybrid vigor
BREEDING METHODS - HYBRID BREEDING

BENEFITS:

- Homogeneity & predictability
- Higher performance
- F2 segregates
- Same maturity
BREEDING METHODS - HYBRID BREEDING

DRAWBACKS:

- Costly => higher seed price
- F2 segregates
- Same maturity
## DEVELOPMENT OF HYBRIDS

### INTRODUCTION TO PLANT BREEDING

<table>
<thead>
<tr>
<th>Period</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960s</td>
<td>Maize</td>
</tr>
<tr>
<td>1962</td>
<td>Sugar Beet</td>
</tr>
<tr>
<td>1970s</td>
<td>Vegetables</td>
</tr>
<tr>
<td>1970s</td>
<td>Cotton</td>
</tr>
<tr>
<td>1970s</td>
<td>Wheat</td>
</tr>
<tr>
<td>1972</td>
<td>Sunflower</td>
</tr>
<tr>
<td>1973</td>
<td>Rice</td>
</tr>
<tr>
<td>1984</td>
<td>Rye</td>
</tr>
<tr>
<td>1985</td>
<td>Oilseed Rape</td>
</tr>
<tr>
<td>1998</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>2000</td>
<td>Barley</td>
</tr>
</tbody>
</table>
GENETIC DIVERSITY
GENETIC DIVERSITY

INTRODUCTION TO PLANT BREEDING
PLANT BREEDING

REMOVE ANTHERS: EMASCULATION

PLACE ANther OF DESIRED MALE: POLLINATION

HULLING, FOLLOWED BY SEED HARVEST

INTRODUCTION TO PLANT BREEDING
INTRODUCTION TO PLANT BREEDING
EVOLUTION IN WHEAT

INTRODUCTION TO PLANT BREEDING
HISTORICAL & UK WHEAT YIELDS 500BCE – 2015CE
YIELD EVOLUTION IN CORN

[Graph showing yield evolution in corn over the years with different line types for open pollinated, double cross, single cross, and biotech gmo with respective growth rates.]
DNA BASED METHODS

INTRODUCTION TO PLANT BREEDING
HIGH THROUGHPUT AUTOMATION
ROBOTIZATION OF SELECTION PROCESS
PLANT BREEDERS TOOLBOX
PLANT BREEDING INNOVATION

- Reverse breeding
- Synthetic genomics
- Cisgenesis & intragenesis
- Grafting (on GM rootstock)
- RNA-dependent DNA methylation (RdDM)
- Oligonucleotide directed mutagenesis (ODM)
- Agro-infiltration (agro-infiltration “sensu-stricto”, agro-inoculation, floral dip)
- Gene or genome editing (incl. Zinc Finger nuclease (ZFN), Site Directed Nucleases (SDN), Meganucleases, TALEN’s & CRISPR)
PLANT BREEDING INNOVATION

- Several new techniques (20+yrs)
- Great potential, but efficiency to be improved
- Products similar/indistinguishable
- Legal certainty needed for industry
- Product that determines safety, not method
- Need for international alignment: similar approach per technique across jurisdictions leading to legal certainty => lowest chance of trade disruptions.
WHAT IS A PLANT VARIETY?

INTRODUCTION TO PLANT BREEDING
VARIETY ASSESSMENT

UPOV: INTERNATIONAL UNION FOR THE PROTECTION OF NEW VARIETIES OF PLANTS

INTRODUCTION TO PLANT BREEDING
VARIETY ASSESSMENT
VARIETY ASSESSMENT

NATIONAL / REGIONAL IMPLEMENTATION

CPVO VARIETY DESCRIPTION

1. Reference number of reporting authority : DEE 4016751
2. Reference number of requesting authority : 44/2007
3. Breeder’s reference / document denomination : Rg2406 / RG2406
4. Applicant (name and address) : RAPS Gbr Saatzucht Lundsgaard
   Lundsgaard Weg 1
   24976 GRUNDFHOF Allemagne
   : RAPS Gbr Saatzucht Lundsgaard
5. Breeder’s name :
6. Botanical name of taxon : Brassica napus L.
7. Common name of taxon : Swede rape
8. Variety denomination :
9. Variety type : Inbred line
10. Date and document number of CPVO Test guidelines : 25/03/2004, CPVO-TP/06/1
## Agricultural species - Varieties

<table>
<thead>
<tr>
<th>#</th>
<th>Variety name</th>
<th>Common catalogue status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13996</td>
<td>Registered</td>
</tr>
<tr>
<td>2</td>
<td>355</td>
<td>Registered</td>
</tr>
<tr>
<td>3</td>
<td>102</td>
<td>Registered</td>
</tr>
<tr>
<td>4</td>
<td>23377</td>
<td>Registered</td>
</tr>
<tr>
<td>5</td>
<td>23789</td>
<td>Registered</td>
</tr>
<tr>
<td>6</td>
<td>23780L6</td>
<td>Registered</td>
</tr>
<tr>
<td>7</td>
<td>23780A05</td>
<td>Registered</td>
</tr>
<tr>
<td>8</td>
<td>23781M-2357M</td>
<td>Registered</td>
</tr>
<tr>
<td>9</td>
<td>23M</td>
<td>Registered</td>
</tr>
<tr>
<td>10</td>
<td>24570</td>
<td>Registered</td>
</tr>
<tr>
<td>11</td>
<td>20A</td>
<td>Registered</td>
</tr>
<tr>
<td>12</td>
<td>20T</td>
<td>Registered</td>
</tr>
<tr>
<td>13</td>
<td>2LUN</td>
<td>Registered</td>
</tr>
<tr>
<td>14</td>
<td>10M</td>
<td>Registered</td>
</tr>
<tr>
<td>15</td>
<td>3101985</td>
<td>Registered</td>
</tr>
<tr>
<td>16</td>
<td>715</td>
<td>Registered</td>
</tr>
</tbody>
</table>

### # Varieties
- **Maize:** 5316
- **Wheat:** 2448
- **Potato:** 1664
- **Sugar Beet:** 1693
- **Sunflower:** 1543
- **Soybean:** 487
- **Rice:** 386
- **Cotton:** 200
- **Tomato:** 4050
- **Lettuce:** 2282
- **Fr. Bean:** 1263
- **Melon:** 996
CONTRIBUTIONS OF PLANT BREEDING

- Yield
- Resistance to biotic stress
- Tolerance to abiotic stress
- Earliness
- Taste
- Size
- Quality
- Firmness
- Shelf-Life
- Plant type
- Labor cost
- Harvestability
- Harvestability
- Dwarfness
CONTRIBUTIONS OF PLANT BREEDING

• Food security & hunger alleviation
• Increase employment & income
• Increase nutritional values
• Reduction of pesticides / fossil fuels
• Reduction GHG emissions
CONTRIBUTIONS OF PLANT BREEDING 2

• Land saving/decrease deforestation
• Conserve biodiversity
• Increase carbon sequestration
• Improved economic functioning
• Enhanced social stability
CONTRIBUTIONS OF PLANT BREEDING

- YIELD
  - Resistance to biotic stress
  - Tolerance to abiotic stress

- Earliness
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- Plant type
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INTRODUCTION TO PLANT BREEDING
Winter wheat yields: trebled over the past 60 years
  • 2.5 tonnes/ha (mid-1940s) to 8 tonnes/ha today.
NIAB study 2008: wheat, barley, oats
  • 300 varieties (>3 yrs), 3600 trials, 53,000 data points
1947-1986: 50% of increase in yield attributed to plant breeding.
  • Rest to fertilizers, crop protection products, crop husbandry and machinery (Silvey, 1986)
Since 1982: 90% of all yield increase due to introduction of new varieties (yield: 5t/ha => 8t/ha)
CONTRIBUTIONS OF PLANT BREEDING - YIELD

Wheat yields in selected countries, 1950-2004

Source: FAO
CONTRIBUTIONS OF PLANT BREEDING - YIELD

Wheat yields in developing countries, 1950-2004

Source: FAO
CONTRIBUTIONS OF PLANT BREEDING - YIELD

World Grain Production 1961-2012

Source: FAO
LAND SPARED IN INDIA THROUGH INCREASING WHEAT YIELD
### Major Famines

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
<th>Location</th>
<th>Estimated Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972–73</td>
<td>Famine in Ethiopia caused by drought and poor governance; failure of the government to handle the crisis led to the fall of Haile Selassie and to Derg rule</td>
<td>Ethiopia</td>
<td>62,000&lt;sup&gt;[111]&lt;/sup&gt;</td>
</tr>
<tr>
<td>1974</td>
<td>Bangladesh famine of 1974</td>
<td>Bangladesh</td>
<td>27,000–1.5 million&lt;sup&gt;[citation needed]&lt;/sup&gt;</td>
</tr>
<tr>
<td>1975–76</td>
<td>Khmer Rouge. An estimated 2 million Cambodians lost their lives to murder, forced labor and famine</td>
<td>Cambodia</td>
<td>2 million&lt;sup&gt;[citation needed]&lt;/sup&gt;</td>
</tr>
<tr>
<td>1980–81</td>
<td>Caused by drought and conflict&lt;sup&gt;111&lt;/sup&gt;</td>
<td>Uganda</td>
<td>30,000&lt;sup&gt;[111]&lt;/sup&gt;</td>
</tr>
<tr>
<td>1984–85</td>
<td>1983–1985 Famine in Ethiopia</td>
<td>Ethiopia</td>
<td>400,000&lt;sup&gt;[112]&lt;/sup&gt;</td>
</tr>
<tr>
<td>1985–86</td>
<td>Famine in Somalia caused by drought and civil war&lt;sup&gt;111&lt;/sup&gt;</td>
<td>Somalia</td>
<td>300,000&lt;sup&gt;[111]&lt;/sup&gt;</td>
</tr>
<tr>
<td>1996</td>
<td>North Korean famine&lt;sup&gt;113&lt;/sup&gt;&lt;sup&gt;114&lt;/sup&gt; Scholars estimate 600,000 died of starvation (other estimates range from 200,000 to 3.5 million)&lt;sup&gt;113&lt;/sup&gt;</td>
<td>North Korea</td>
<td>200,000 to 3.5 million</td>
</tr>
<tr>
<td>1988</td>
<td>1998 Sudan famine caused by war and drought</td>
<td>Sudan</td>
<td>70,000&lt;sup&gt;[111]&lt;/sup&gt;</td>
</tr>
<tr>
<td>1988–2000</td>
<td>Famine in Ethiopia. The situation worsened by Eritrean–Ethiopian War</td>
<td>Ethiopia</td>
<td>3.8 million&lt;sup&gt;[citation needed]&lt;/sup&gt;</td>
</tr>
<tr>
<td>2005–06</td>
<td>Second Congo War. 3.8 million people died, mostly from starvation and disease</td>
<td>Democratic Republic of the Congo</td>
<td>3.8 million&lt;sup&gt;[citation needed]&lt;/sup&gt;</td>
</tr>
<tr>
<td>2005–06</td>
<td>2005–06 Niger food crisis: At least three million were affected in Niger and 10 million throughout West Africa&lt;sup&gt;[citation needed]&lt;/sup&gt;</td>
<td>Niger and West Africa</td>
<td>3.8 million&lt;sup&gt;[citation needed]&lt;/sup&gt;</td>
</tr>
<tr>
<td>2011–12</td>
<td>Famine in Somalia, brought on by the 2011 East Africa drought&lt;sup&gt;115&lt;/sup&gt;</td>
<td>Somalia</td>
<td>295,000</td>
</tr>
<tr>
<td>2012</td>
<td>Famine in West Africa, brought on by the 2012 Sahel drought&lt;sup&gt;117&lt;/sup&gt;</td>
<td>Senegal, Gambia, Niger, Mauritania, Mali, Burkina Faso</td>
<td>295,000</td>
</tr>
<tr>
<td>2016–present</td>
<td>Famine in Yemen, arising from the blockade of Yemen by Saudi Arabia</td>
<td>Yemen</td>
<td>At least 85,000 children&lt;sup&gt;118&lt;/sup&gt; Unknown number of adults.</td>
</tr>
<tr>
<td>2017–present</td>
<td>Famine in South Sudan&lt;sup&gt;119&lt;/sup&gt;, Famine in Somalia, due to 2017 Somali drought. Famine in Nigeria</td>
<td>South Sudan, Unity State, Somalia, and Nigeria</td>
<td>At least 85,000 children&lt;sup&gt;118&lt;/sup&gt; Unknown number of adults.</td>
</tr>
</tbody>
</table>
CONTRIBUTIONS OF PLANT BREEDING

- Yield
- **RESISTANCE TO BIOTIC STRESS**
- Tolerance to abiotic stress

- Earliness
- Taste
- Size
- Quality
- Firmness
- Shelf-Life
- Plant type
- Labor cost
- Harvestability
- Harvestability
- Dwarfness

INTRODUCTION TO PLANT BREEDING
CROPS UNDER ATTACK:

- 30,000 species of Weeds
- 10,000 species of Insects
- 3,000 species of Nematodes
- Bacteria, Water Molds, Fungi, Viruses
Plant Breeding has provided
=> 10,000s of resistant varieties
Resistance breeding
=> major breeding goal
RESISTANCE TO PHYTOPHTHORA BLIGHT IN PEPPERS

Above: resistant variety; below: susceptible variety
Tomato Yellow Leaf Curl Virus

1990s: Destroyed 95% of tomato harvest in Dom. Rep.


Now resistant varieties
STILL WORK TO DO; EG CEREALS & GRASSES

Fusarium Head Blight, Ergot or Stem rust

- All Fungi, potentially fatal
- FHB: Yearly 1 billion losses in wheat yield and grain quality
- Ergot: In North Dakota, as much as 10% loss has been reported in wheat, while losses of 5% are common in rye.
- Ug 99: up to 100% crop loss reported
- Aim: Resistant varieties
ANNUAL GLOBAL LEVEL OF LOST FOOD PRODUCTION

$85 billion caused by pathogens

$46 billion caused by insects

UK: disease resistance alone saves 100 million GBP/yr in crop protection products
CONTRIBUTIONS OF PLANT BREEDING

- Yield
- Resistance to biotic stress
- TOLERANCE TO ABIOTIC STRESS
  - Earliness
  - Taste
  - Size
  - Quality
  - Firmness
  - Shelf-Life
  - Plant type
  - Labor cost
  - Harvestability
  - Dwarfness
CONTRIBUTIONS OF PLANT BREEDING: ABIOTIC STRESS TOLERANCE

Plant Breeders focus on tolerance for:

- Herbicides ($95 billion USD / yr lost on weeds = 380 million tonnes of wheat)
- Drought (90 million people affected / yr)
- Flood (106 million people affected / yr)
- Salt (900 million ha affected)
- Better nutrient uptake
CONTRIBUTIONS OF PLANT BREEDING

- Yield
- Resistance to biotic stress
- Tolerance to abiotic stress

- Earliness
- Taste
- Size

**QUALITY**
- Firmness
- Shelf-Life
- Plant type
- Labor cost
- Harvestability
- Dwarfness

INTRODUCTION TO PLANT BREEDING
CONTRIBUTIONS OF PLANT BREEDING: NATIONAL QUALITY

- WHO: 250 million preschool children affected by Vit. A deficiency
- Rice: staple crop, half of mankind
- Rice varieties with higher levels of carotenoids => ‘Golden rice’
- 2-3 million preventable child deaths
## CONTRIBUTIONS OF PLANT BREEDING

<table>
<thead>
<tr>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
</tr>
<tr>
<td>Resistance to biotic stress</td>
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<tr>
<td>Tolerance to abiotic stress</td>
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<td>Harvestability</td>
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<tr>
<td>Harvestability</td>
</tr>
<tr>
<td>Dwarfness</td>
</tr>
</tbody>
</table>
CONTRIBUTIONS OF PLANT BREEDING

- Machine harvestable Brussels sprouts or broccoli
- **Sugar beet**: Sugar production/ha doubled in 50 years
  - Monogerm varieties: fully mechanized cultivation
- Malting quality in **barley** improved
  - 1950: 2000 ltr/tonne => Now 8000 ltr/tonne
- Taste in many vegetables greatly improved
- Broccoli with higher levels of cancer fighting glucosinolate
CONTRIBUTIONS OF PLANT BREEDING

- Needs Investments:
  - High
  - Upfront
  - Longterm

- Needs Return on Investment
Innovation requires substantial, long-term & high-risk investments
IP ensures acceptable Return On research Investment (ROI)
Prerequisite to encourage further research efforts

“Motor for further innovation”
Essential to meet the challenges mankind has to face
ROI = small portion of total benefits
BENEFITS OF PLANT BREEDING

• Society (mainly farmers) reap 75% of total benefits

• Farmers get a $6 benefit for each $1 spent on private sector research (Lence S, Hayes D & Goggi S. 2009. Returns from Private Sector Seed Research. Study by Iowa State University. http://www.beyondtheseseed.org/commitment.asp)

• £1 invested in plant breeding => £40 in added value across the wider economy (takes into account higher yields & input savings at farm level as well as export earnings & enhanced processing efficiency within food & drink manufacturing sector) (DTZ, 2010. Economic Impact of Plant Breeding in the UK, Final Report, Commissioned by the British Society of Plant Breeders, July 2010, 19 pages.)
VALUE OF PLANT BREEDING

- EU arable farming since 2000
- In ag sector alone: Genetic crop improvements generated an additional social welfare gain of 9 billion € & added > 14 billion € to EU GDP
- Secure employment & increase of income
- 7000 € (30% of annual income of EU arable farmer) induced by plant breeding
- 70,000 jobs created in arable sector
Thank you for your time, and we hope you enjoyed this presentation. If you have any questions, or would like to share feedback, please contact us at: seedworldpro@issuesink.com