Improving the Bean Value Chain via Breeding at the NDSU Dry Bean Program

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Dry Bean Breeder/Geneticist

Department of Plant Sciences
North Dakota State University
Fargo - ND

NDSU North Dakota State University, Fargo, ND
ND Agricultural Experiment Station

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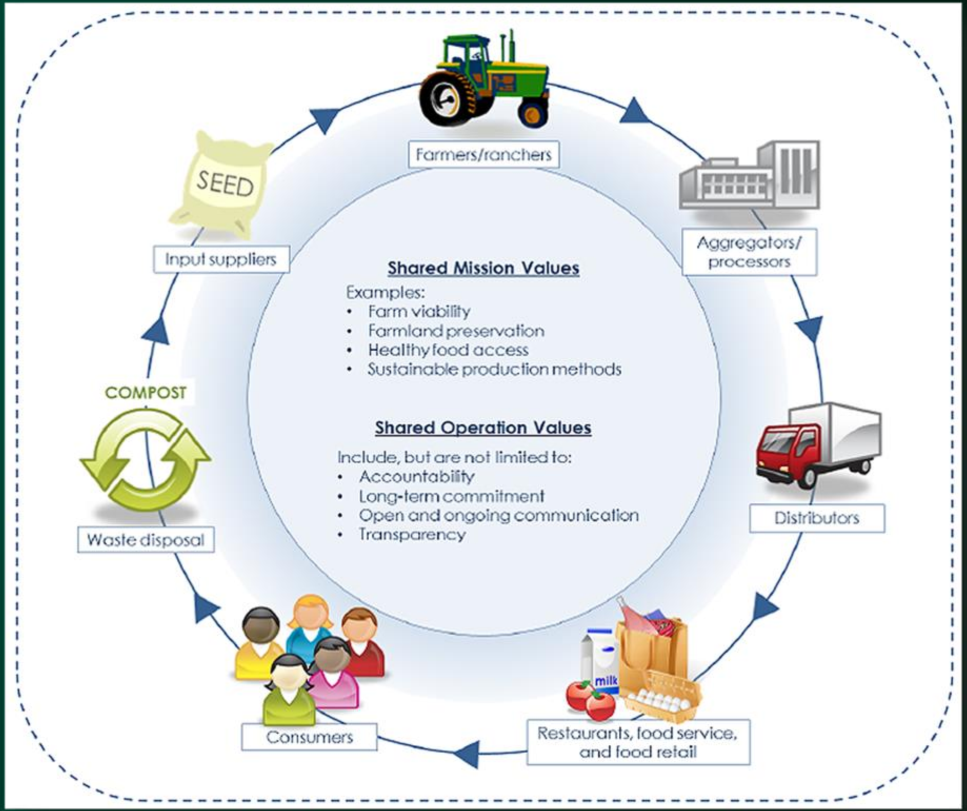
The Value of Interactions: GART Station, July 2022, Zambia

Customer-Based Research?

- Applied context within the food value chain (but still backed up by basic science)
- Attempts to solve specific/practical problems
- Affects all/most actors within the value chain
- Economic, social and/or environmental benefit



https://www.ams.usda.gov/sites/default/files/media/Food%20Value%20Chains%20-%20Synopsis.pdf

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Breeding = Impact

"The breeder is at the very beginning of the food value chain, so you start here if you want to make impact"

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NDSU: North Dakota State University
~12k students (medium size)
Among top 100 Research-1 (R1) institutions in the US
(Carnegie Classification of Institutions of Higher Education)

North Dakota is Number One

Rank	Crop	Percent of US total
1st	Spring wheat	50
1st	Durum wheat	56
1st	Sunflowers	43
1st	Barley	35
1st	All dry edible beans	34
1st	Navy beans	38
1st	Pinto beans	56
1st	Canola	90
1st	Flaxseed	95
1st	Dry edible peas	67
1st	Lentils	44
1st	Honey	24

Source: National Agricultural Statistics Service - 2009

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NDSU Jack Dalrympe Greenhouse complex

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Crop Breeding Programs
ND Ag. Experiment Station

- Oilseeds (canola, flax, crambe)
- Wheat (durum, spring, winter, etc.)
- Potato
- Pulses (dry pea, chickpea, lentil)
- Dry bean (pinto, navy, black, kidney, etc.)
- Barley (6-row & 2-row)
- Soybean
- Oat
- Trees
- Rye, Titricale, Safflower
- Vegetables

Dry Bean Breeding & Genetics

- ND is the largest producer of dry beans in the U.S. (~40%)
- MN: 2nd or 3rd largest (~15%)
- ~8 field testing locations across ND+MN
- ~30 Has of trials
- Additional variety trials at NDSU Stations

Crop Breeding Using Modern Tools to Improve Selection Efficiency

- Crop performance (field+quality)
  - High Throughput Phenotyping (HTP)
    - UAVs, robocars, sensors
  - DNA technology
    - Genome sequencing, genomics, DNA markers
    - NDSU: lead institution for 1st bean reference genome sequence (2014)
  - Bioinformatics
    - Big data analysis
    - Modeling and predictions

Bean genomics work in close collaboration with Phil McClean

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Main Market Classes in USA

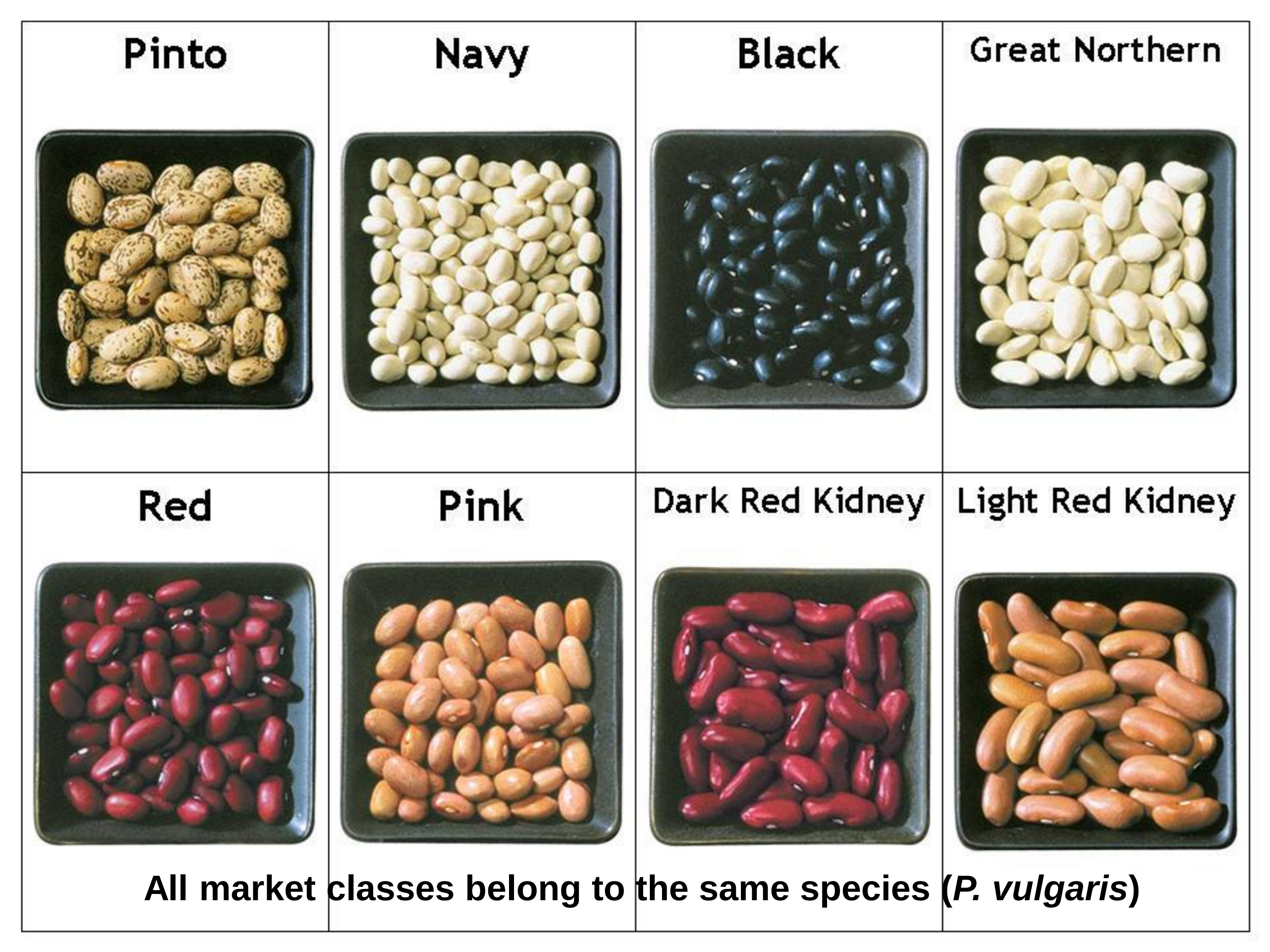

Photo:

Dr. J.R. Gelin

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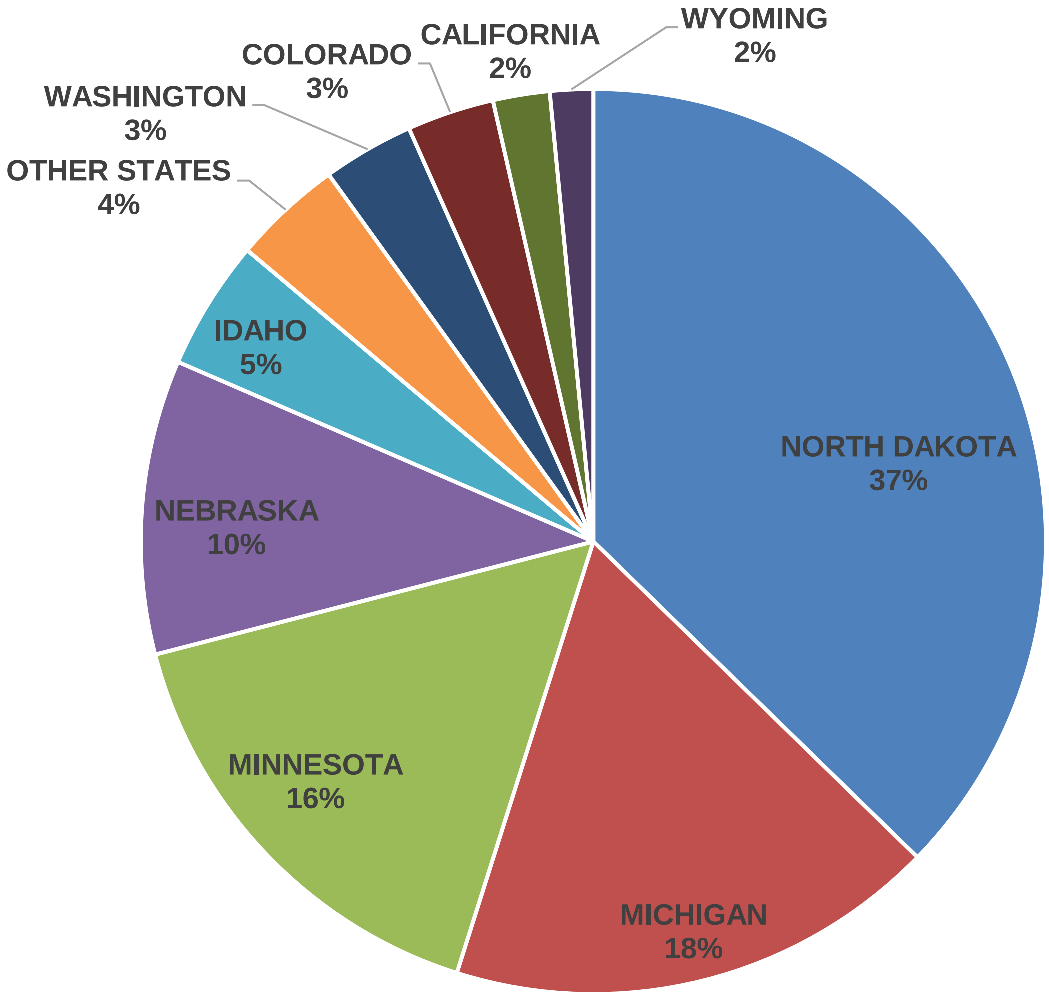
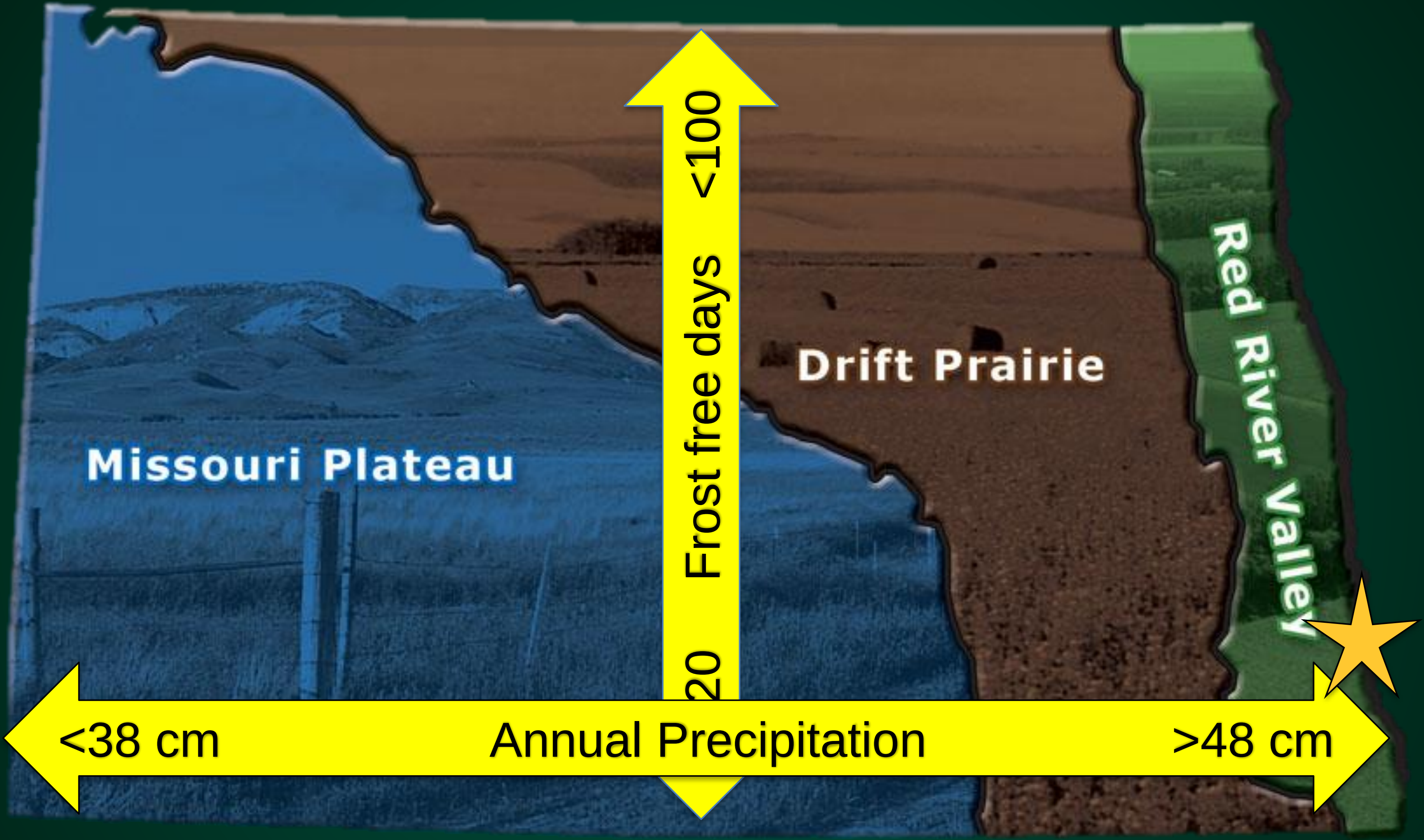
2020 U.S. Production
1.74 million MT - ~$1 billion USD



2022: Just ND+MN: Farm Gate value: >$500 million USD!

Source: USDA-NASS



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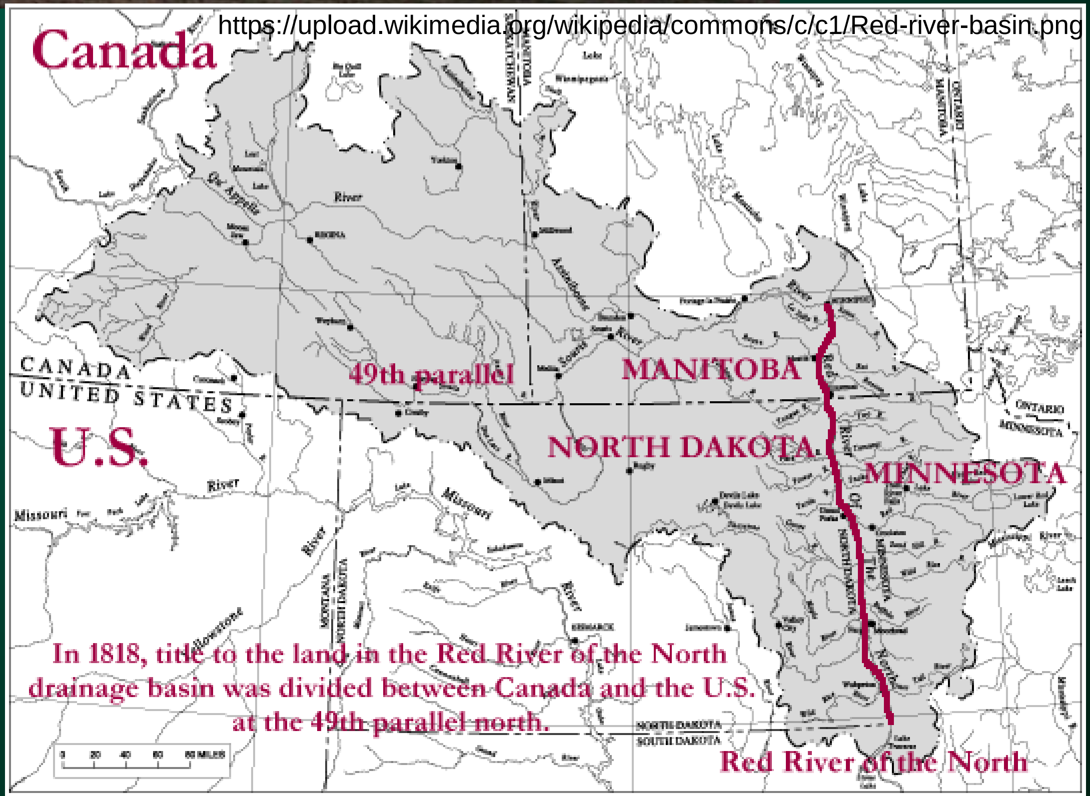
http://www.ndstudies.org/images/ag/ndregions.jpg

North Dakota Red River Valley

http://rrvsga.com/wp-content/uploads/2011/08/banner03.jpg

Average farm size: ~750 Has

http://www.airphotona.com/stockimg/images/10191.jpg



https://upload.wikimedia.org/wikipedia/commons/c/c1/Red-river-basin.png

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NDSU Released Varieties

- **Pinto:**
  - **ND Rodeo**
  - ND Falcon
  - ND Palomino
  - Lariat
  - Stampede
  - ND-307
  - Maverick
  - Frontier
  - Hatton
- **Great Northern:**
  - ND Pegasus
- **Navy:**
  - Avalanche
  - Norstar
  - Arthur
- **Black:**
  - Eclipse
  - ND Twilight
- Small Red:
  - Rio Rojo
- Kidney:
  - Talon DRK
  - Rosie LRK
  - ND Whitetail
  - **ND Redbarn**
- Several germplasm lines

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How is US Bean Research Addressing World Needs?

- **By Focusing Efforts on Key Target Traits:**
  - Overall Productivity
    - Seed Yield (many components)
    - Harvest Efficiency
    - Adaptation and Resilience
  - Biotic Stress (diseases/pests)
  - Abiotic Stress (heat, drought, flooding, soil fertility)
  - Quality
    - Visual (seed color, shape, size, etc.)
    - Cooking/canning
    - Health/Nutritional (protein, minerals, flavonoids, etc.)
    - Sensory (taste, texture, appearance, etc.)

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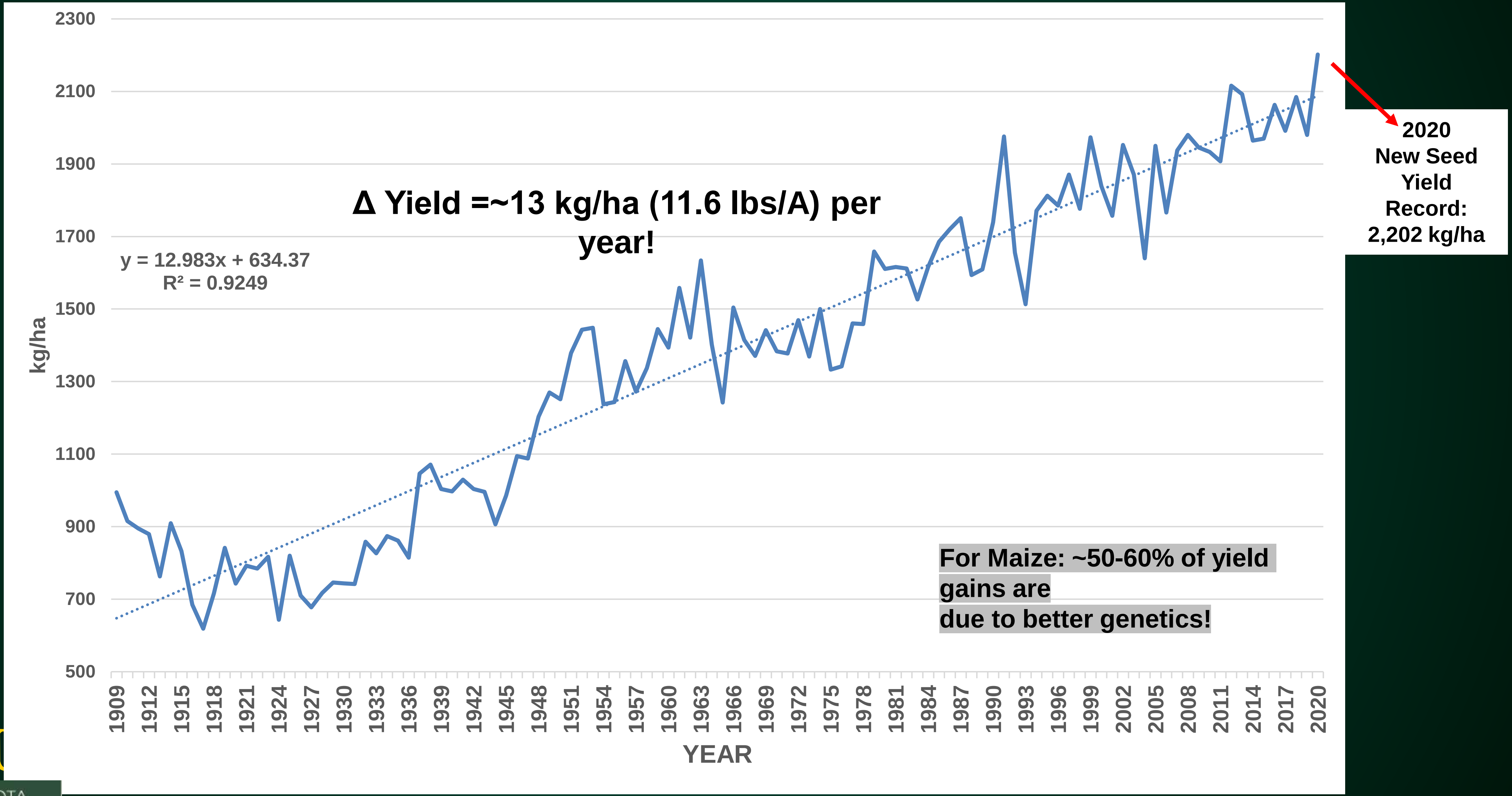
Impactful Examples of Bean Breeding to the Bean Value Chain (with a focus on breeding):

- Gains via conventional breeding:
  - Overall productivity (historic yield gains)
  - Upright plant architecture
  - Disease resistance
  - More recently: Slow Darkening Pintos

https://youtu.be/IkOxJDycRi4
https://youtu.be/wiMl-uGcslk

Today, we produce more beans per area unit!
On-Farm Seed Yields (all classes) – U.S. 1909-2020



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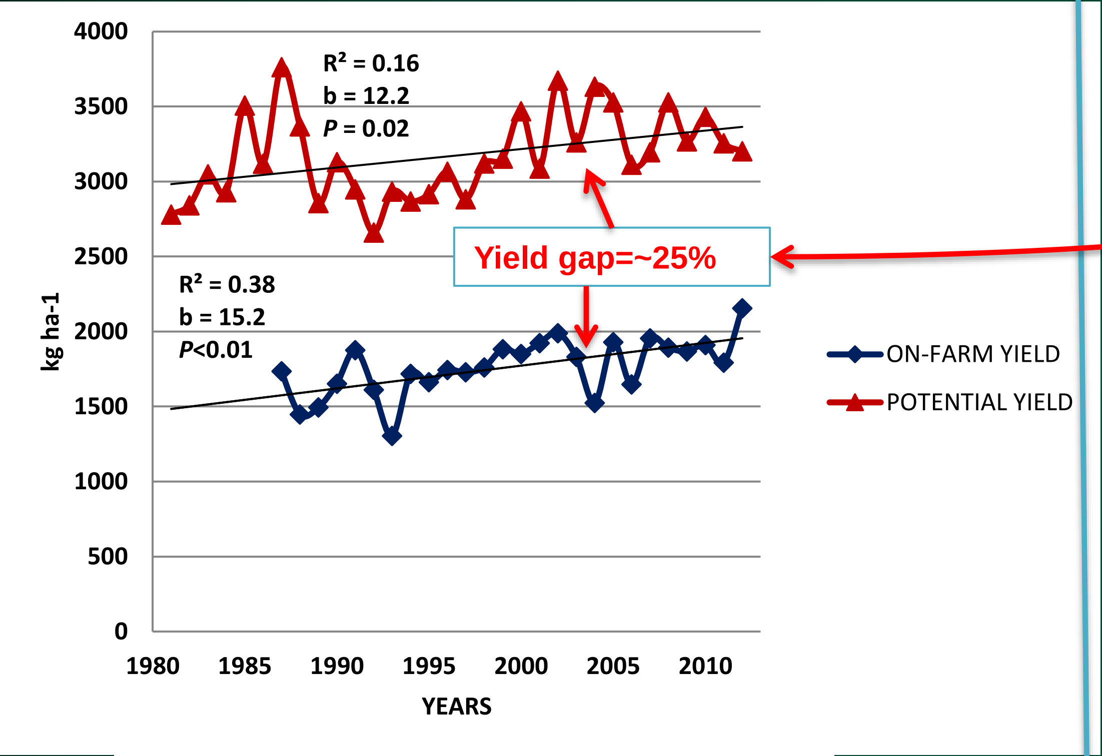
Sources: Vandemark et al., 2014 and USDA-NASS Quickstats (https://quickstats.nass.usda.gov/)

Seed Yield Gap
U.S. vs. Developing Regions



Pinto Seed Yields (1980-2012)
Source: Vandemark et al., 2014

Region	Avg. Yield (2008-10 avg.)	Potential Yield	Yield Gap	
	kg ha^{-1}			%
Latin America and Caribbean	**856**	**1800**	**944**	**52**
East and South Africa	**675**	**2020**	**1345**	**67**
West and Central Africa	**840**	**2125**	**1285**	**60**

Source: CGIAR Collaborative Research Program for Grain Legumes (CRP 3.5 - 2012)

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Disease Resistance

- Identification and deployment of resistance genes have reduced the threat of bean diseases in the U.S.
  - Reduces production costs via reduced use of chemicals
  - Environmental benefits
- Examples:
  - Bean Common Mosaic Virus (BCMV)
    - Virtually all current U.S. varieties are resistant
  - Common Bacterial Blight
    - Modern varieties more tolerant than older.
  - Rust
    - Incidence/severity varies by region but several resistant varieties available
  - Anthracnose
    - Few resistant varieties have been released

Susceptible Resistant

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Upright Bean Plant Architecture

Effect on Bean Production

Pre-2000

Cutting …

…then combining

Early 2000s

Direct combining

Reduces

- **Disease (white mold)**
- **Harvest time**
- **Harvest costs**

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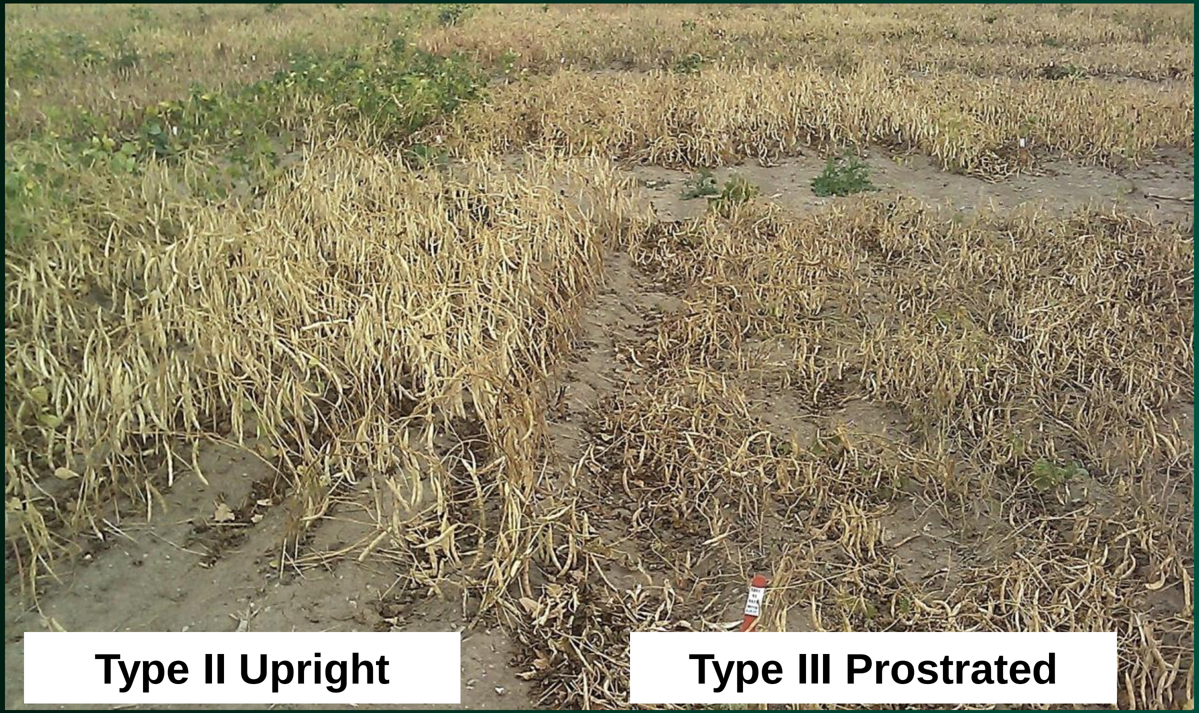
Breeding effort: Transition from Type III to Type II Architecture
Growth Habit & Maturity Differences



J. Kelly

- Most growers (>85%) in ND are doing direct harvest.
- Direct harvest gives them flexibility in their harvest timing for all crops.
- New upright varieties + improved harvest equipment = more efficiency.
- Reduced labor and breakdowns= lower production costs.

More Recently: Slow Darkening Pintos

- ~ 5 years since first varieties were released.
- Initial mixed reactions (as expected with any new technology!).
- 2020: SD pintos were ~35% of the total pinto area in ND.
- 2021: Seed of ND Palomino is sold out!
- Brazil: SD Carioca (BRSMG Madreperola).
- Recent research:
  - **SD pintos cook faster!**
  - **4-7 times more bioavailable iron!**

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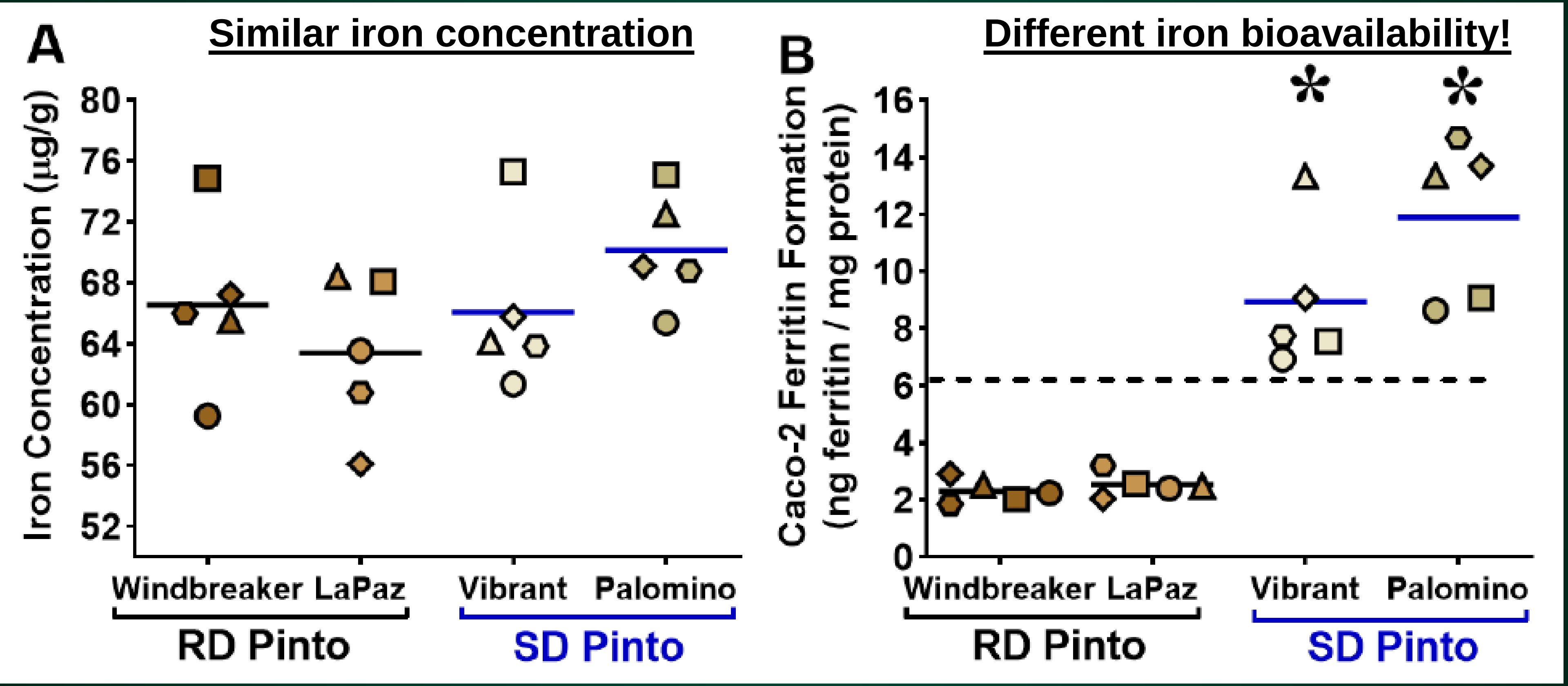
SD Pintos have more bioavailable iron compared to regular pintos!



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Wiesinger et al., (*2021*)

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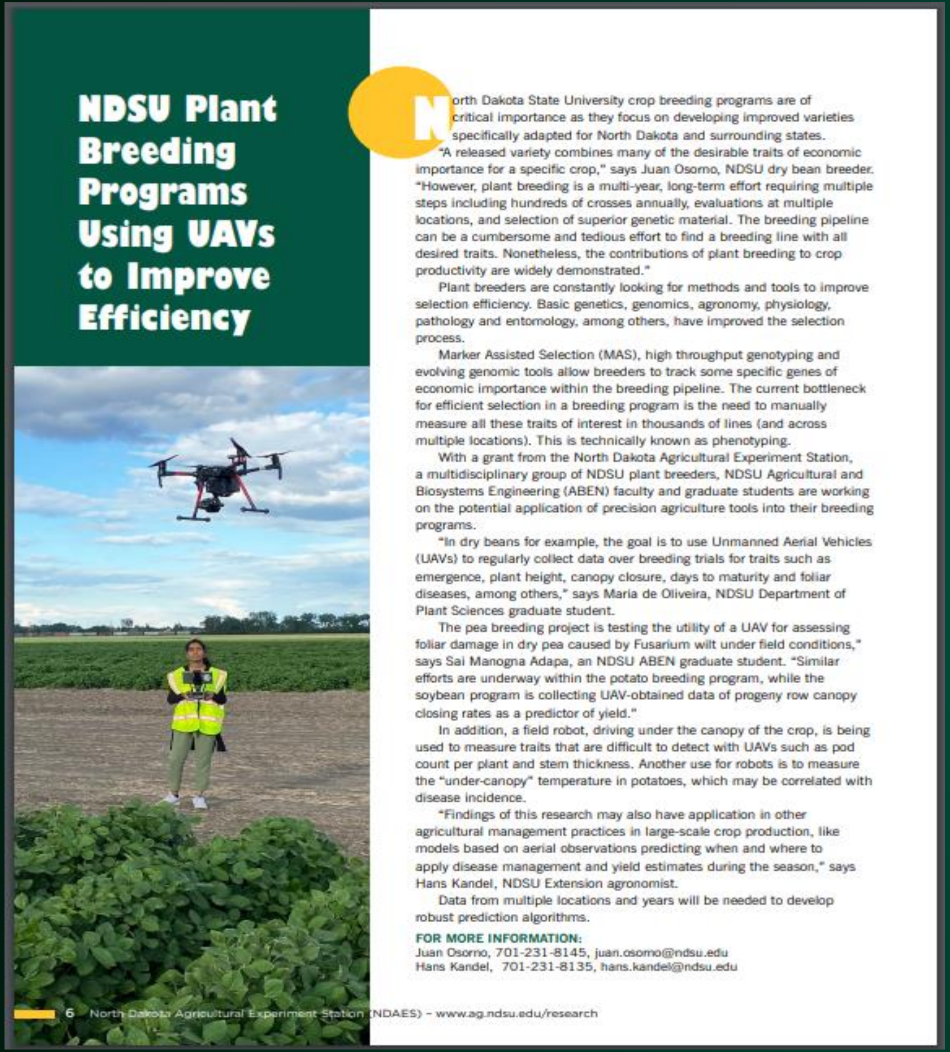
To be continued….



NDSU Plant Breeding Programs Using UAVs to Improve Efficiency

North Dakota State University crop breeding programs are of critical importance as they focus on developing improved varieties specifically adapted for North Dakota and surrounding states.

"A released variety combines many of the desirable traits of economic importance for a specific crop," says Juan Osorno, NDSU dry bean breeder. "However, plant breeding is a multi-year, long-term effort requiring multiple steps including hundreds of crosses annually, evaluations at multiple locations, and selection of superior genetic material. The breeding pipeline can be a cumbersome and tedious effort to find a breeding line with all desired traits. Nonetheless, the contributions of plant breeding to crop productivity are widely demonstrated."

Plant breeders are constantly looking for methods and tools to improve selection efficiency. Basic genetics, genomics, agronomy, physiology, pathology and entomology, among others, have improved the selection process.

Marker Assisted Selection (MAS), high throughput genotyping and evolving genomic tools allow breeders to track some specific genes of economic importance within the breeding pipeline. The current bottleneck for efficient selection in a breeding program is the need to manually measure all these traits of interest in thousands of lines (and across multiple locations). This is technically known as phenotyping.

With a grant from the North Dakota Agricultural Experiment Station, a multidisciplinary group of NDSU plant breeders, NDSU Agricultural and Biosystems Engineering (ABEN) faculty and graduate students are working on the potential application of precision agriculture tools into their breeding programs.

"In dry beans for example, the goal is to use Unmanned Aerial Vehicles (UAVs) to regularly collect data over breeding trials for traits such as emergence, plant height, canopy closure, days to maturity and foliar diseases, among others," says Maria de Oliveira, NDSU Department of Plant Sciences graduate student.

The pea breeding project is testing the utility of a UAV for assessing foliar damage in dry pea caused by Fusarium wilt under field conditions," says Sai Manogna Adapa, an NDSU ABEN graduate student. "Similar efforts are underway within the potato breeding program, while the soybean program is collecting UAV-obtained data of progeny row canopy closing rates as a predictor of yield."

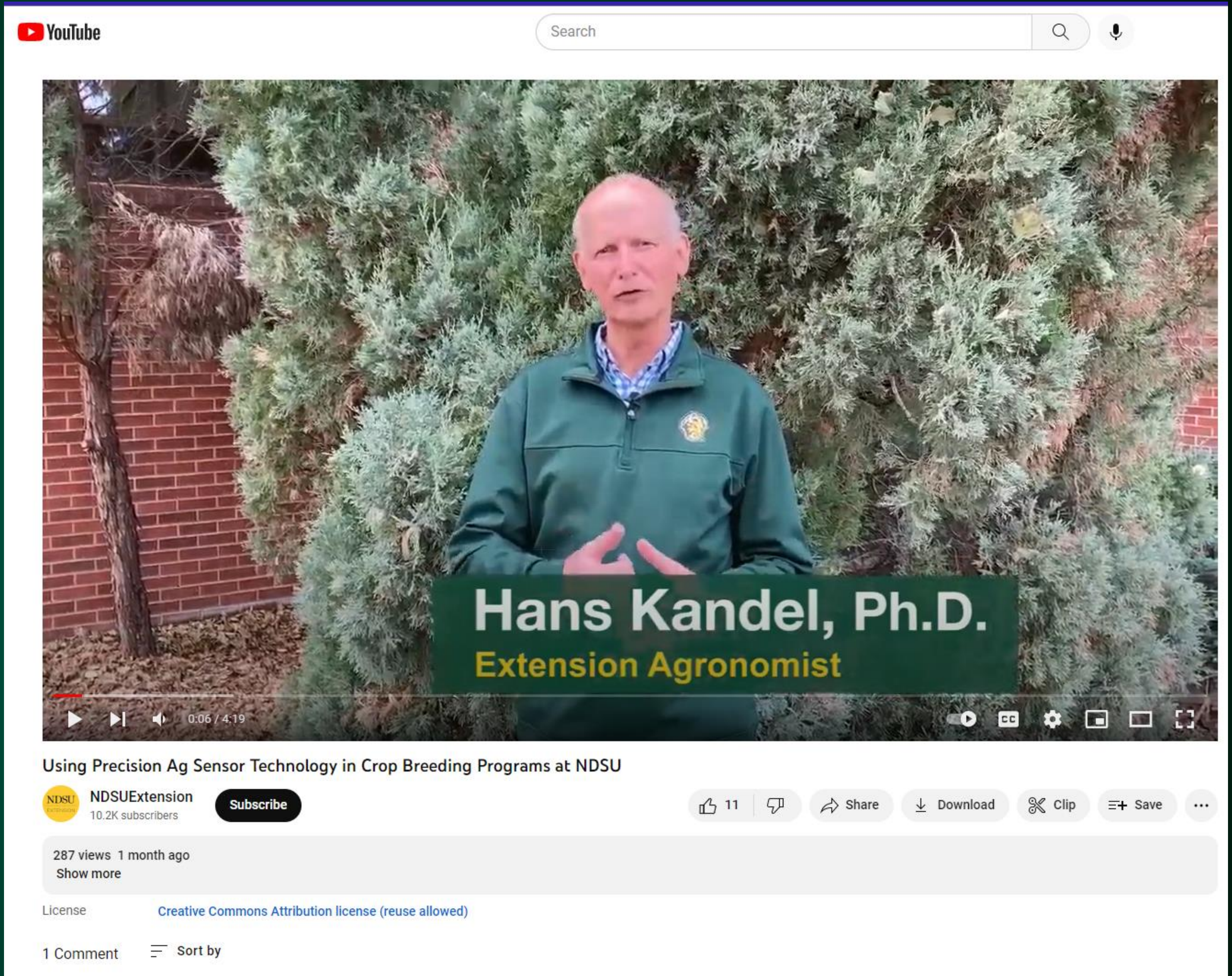
In addition, a field robot, driving under the canopy of the crop, is being used to measure traits that are difficult to detect with UAVs such as pod count per plant and stem thickness. Another use for robots is to measure the "under-canopy" temperature in potatoes, which may be correlated with disease incidence.

"Findings of this research may also have application in other agricultural management practices in large-scale crop production, like models based on aerial observations predicting when and where to apply disease management and yield estimates during the season," says Hans Kandel, NDSU Extension agronomist.

Data from multiple locations and years will be needed to develop robust prediction algorithms.

FOR MORE INFORMATION:
Juan Osorno, 701-231-8145, juan.osorno@ndsu.edu
Hans Kandel, 701-231-8135, hans.kandel@ndsu.edu

6 North Dakota Agricultural Experiment Station (NDAES) – www.ag.ndsu.edu/research



https://youtu.be/5rnsE45DjD0

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Helping Moving the Needle Up in Other Countries

- International projects (past+current):
  - China
  - Colombia
  - Costa Rica
  - Guatemala
  - Honduras
  - Mexico
  - Rwanda
  - Zambia/Malawi/Mozambique

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Guatemala

Additional Research Areas/Projects

- **Waterlogging** (M. Erfatpour)
- Rust (M. Erfatpour)
- **White Mold** (J. Figueroa-Cerna)
- Soybean Cyst Nematode (H. Kaur)
- Plant architecture (O. Rodriguez)
- Dicamba (herbicide) tolerance (A. Ali)
- Seed quality (E. Melgar)

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Innovation Lab for Legume Systems Research

Genetic Improvement of Dry Beans for Bruchid Resistance for Southern Africa

21st February 2023

USAID FROM THE AMERICAN PEOPLE
UNIVERSITY OF ZAMBIA
IIAM Instituto de Investigação Agrária de Moçambique
UNIVERSITY OF Nebraska Lincoln
NDSU
MICHIGAN STATE UNIVERSITY

Project Team

Juan – NDSU - US

Phil – NDSU - US

Carlos – UNL-US

Virginia - Malawi

Celestina - Mozambique

Kelvin - Zambia

Where is the resistance from?

- ✓ Pioneering work done by Drs. Paul Kusolwa, Jim Myers, Jim Beaver et. al
- ✓ Resistance controlled by APA locus originally from tepary bean
- ✓ Developed a variety AO-1012-29-3-3A that is being in the project as a source of resistance

Published April 15, 2016

JOURNAL OF PLANT REGISTRATIONS

GERMPLASM

Registration of AO-1012-29-3-3A Red Kidney Bean Germplasm Line with Bean Weevil, BCMV, and BCMNV Resistance

Paul M. Kusolwa, James R. Myers, Timothy G. Porch, Yulia Trukhina, Abiezer González-Vélez, and James S. Beaver*

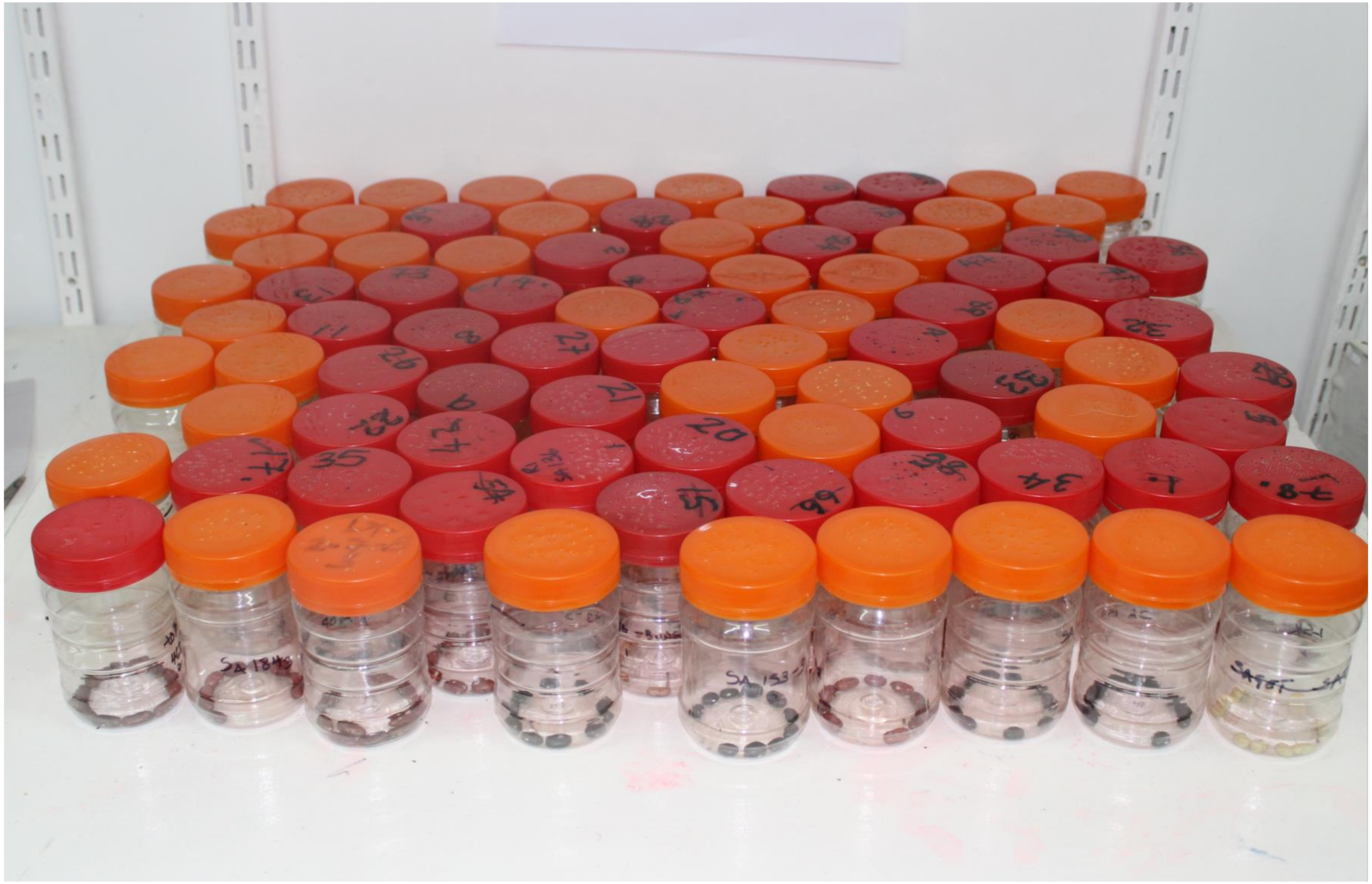
Development of Bruchid Resistant Breeding Lines

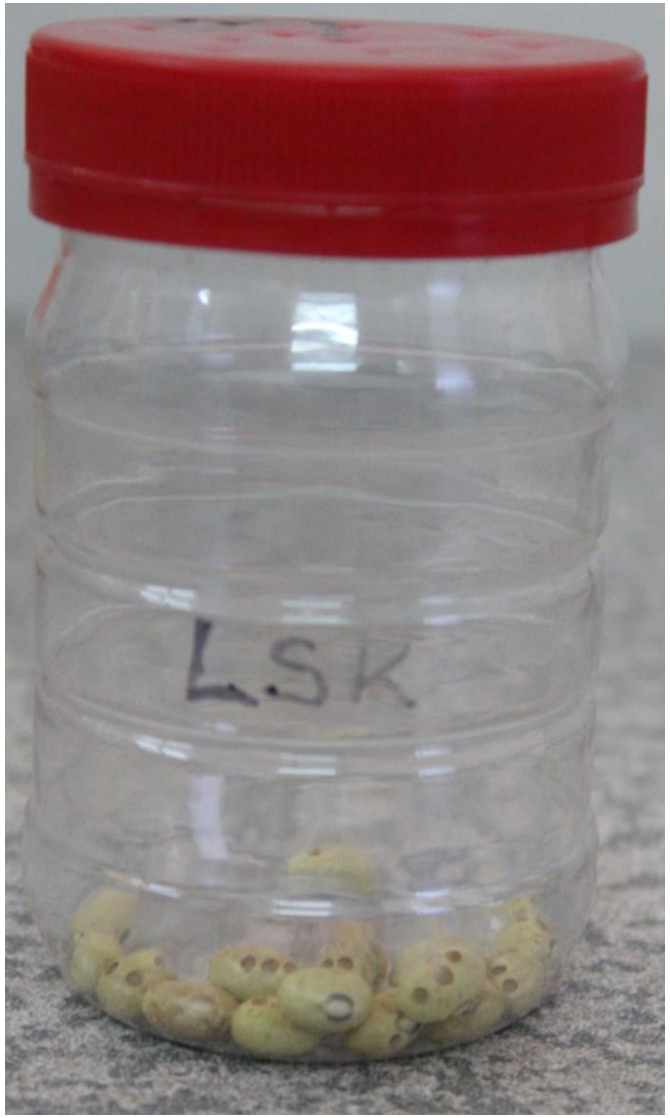
Bruchid Resistant Variety
"AO-1012-29-3-3A"

- Red's — ADP777
- Red Mottled — ADP1
- Pink Mottled — Solwezi
- Purple — ADP763, ADP466
- Cranberry — ADP725, ADP392

Total of 1,991 (F6:7) Breeding Lines developed

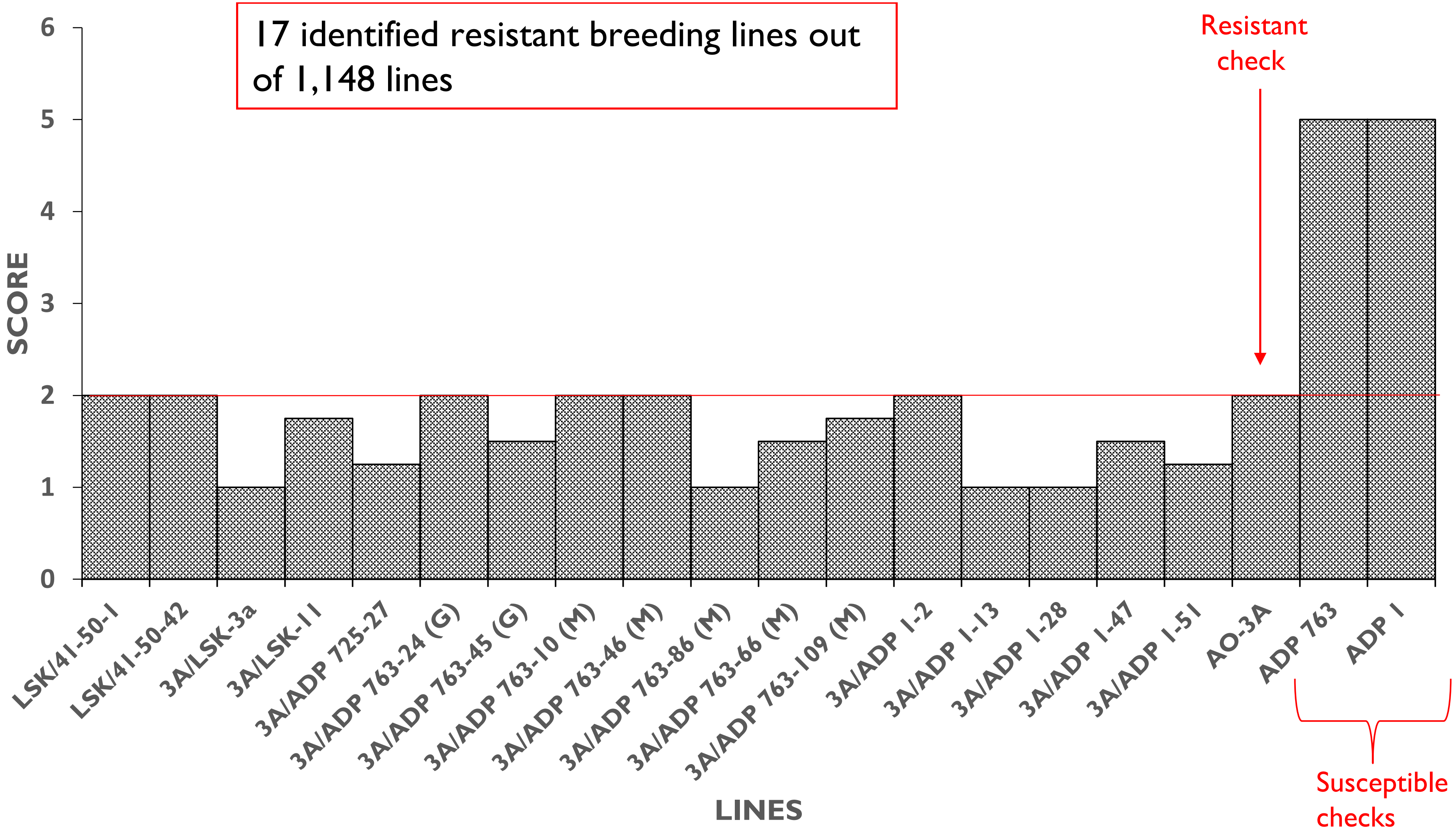
Screening for Bruchid Resistance –(Lab-based Protocol)



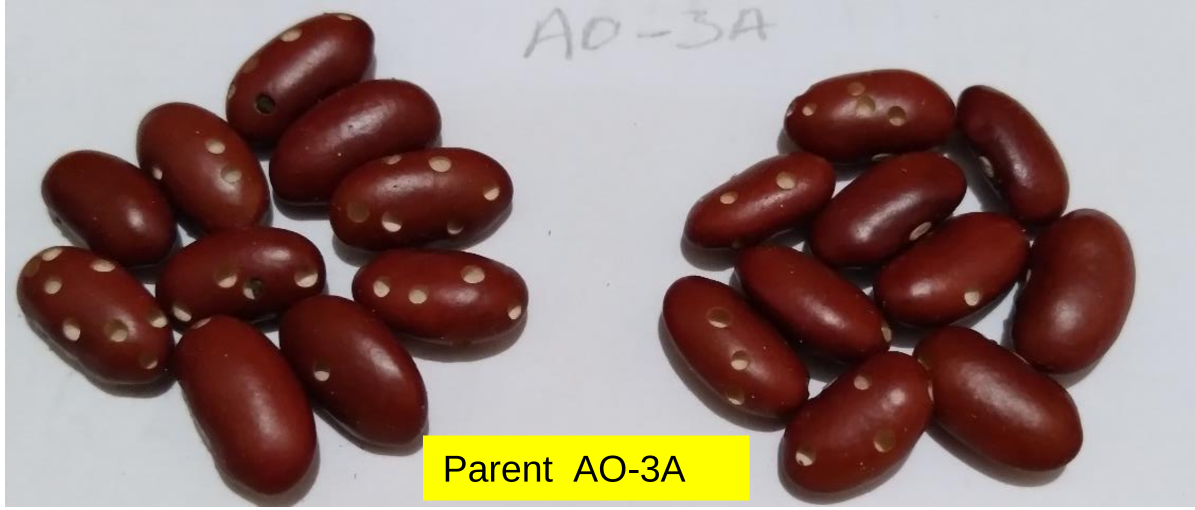


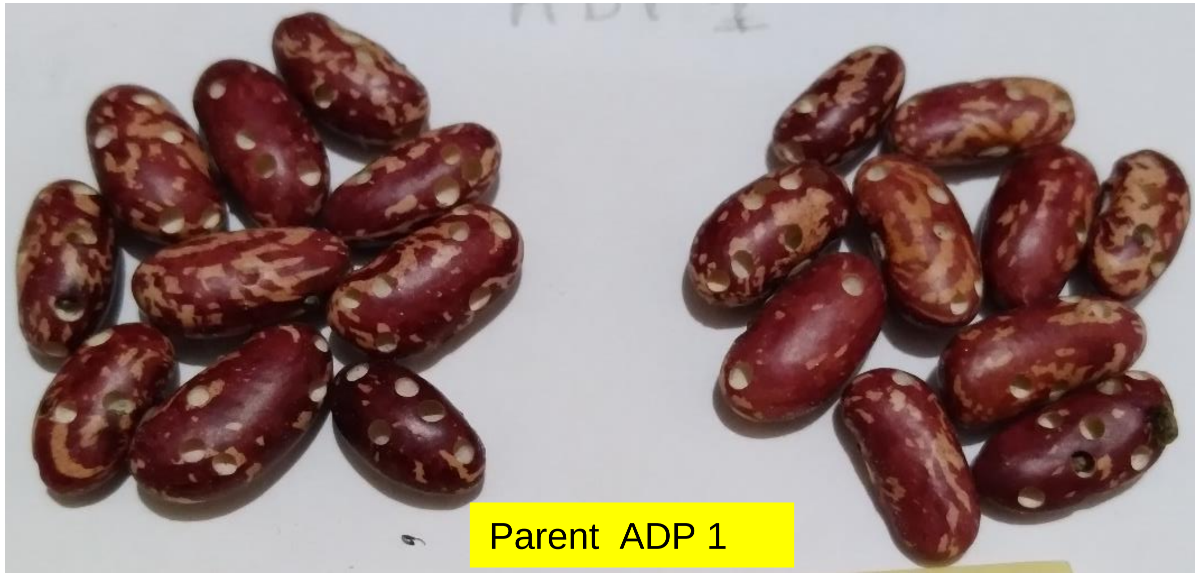
Screening for Bruchid Resistance in the Lab at University of Zambia

Advanced Resistant Breeding Lines from Different Populations

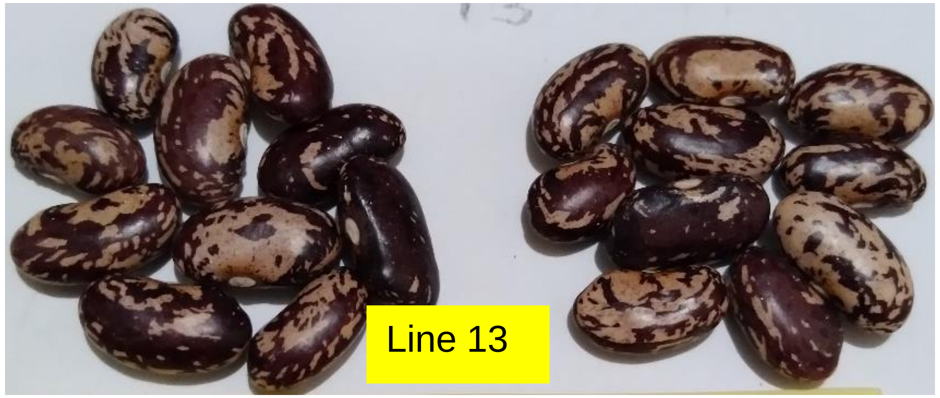


Parents

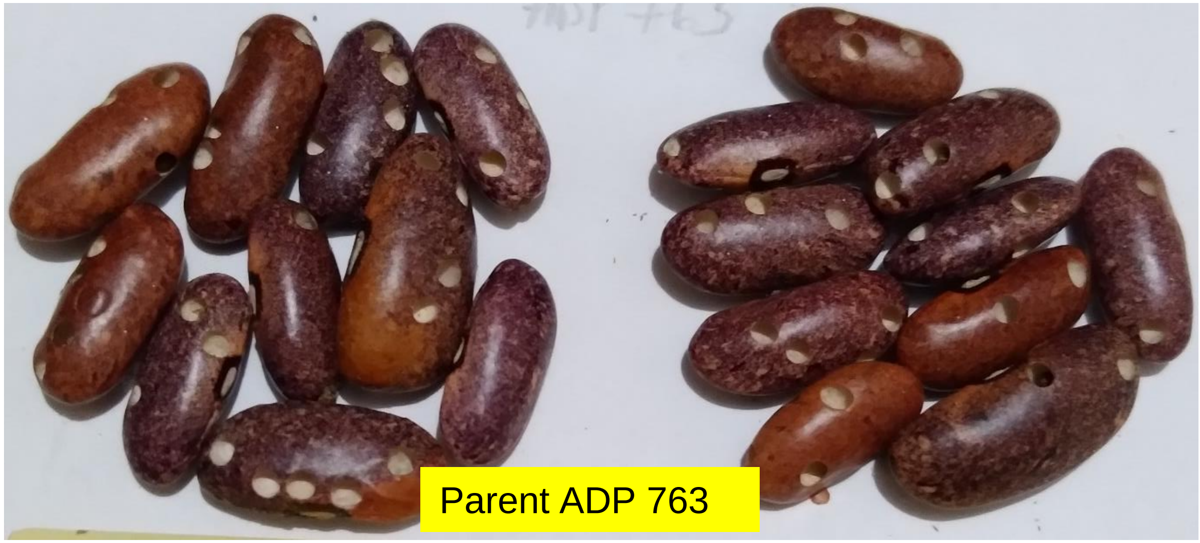




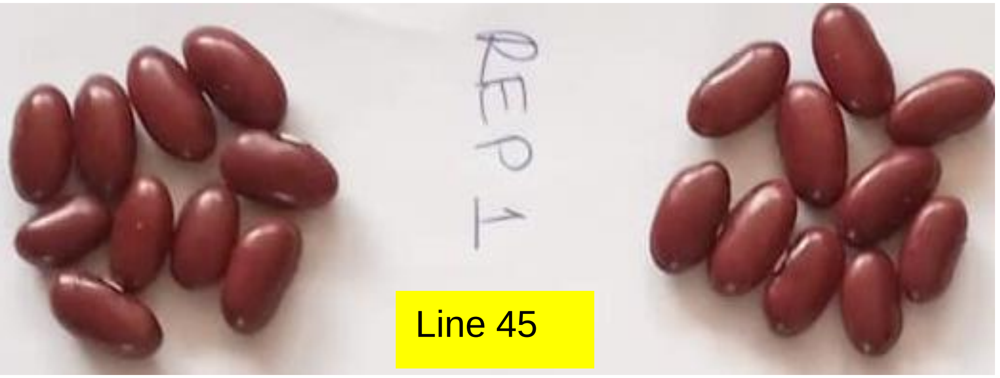
Resistant Breeding Lines

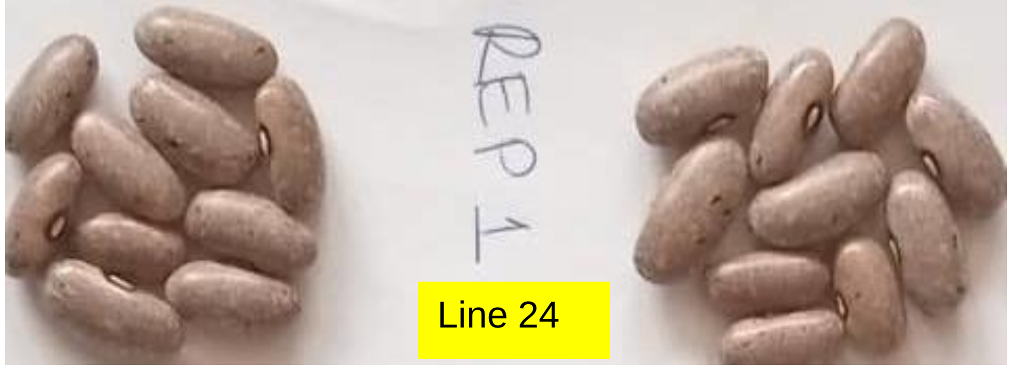


Parents

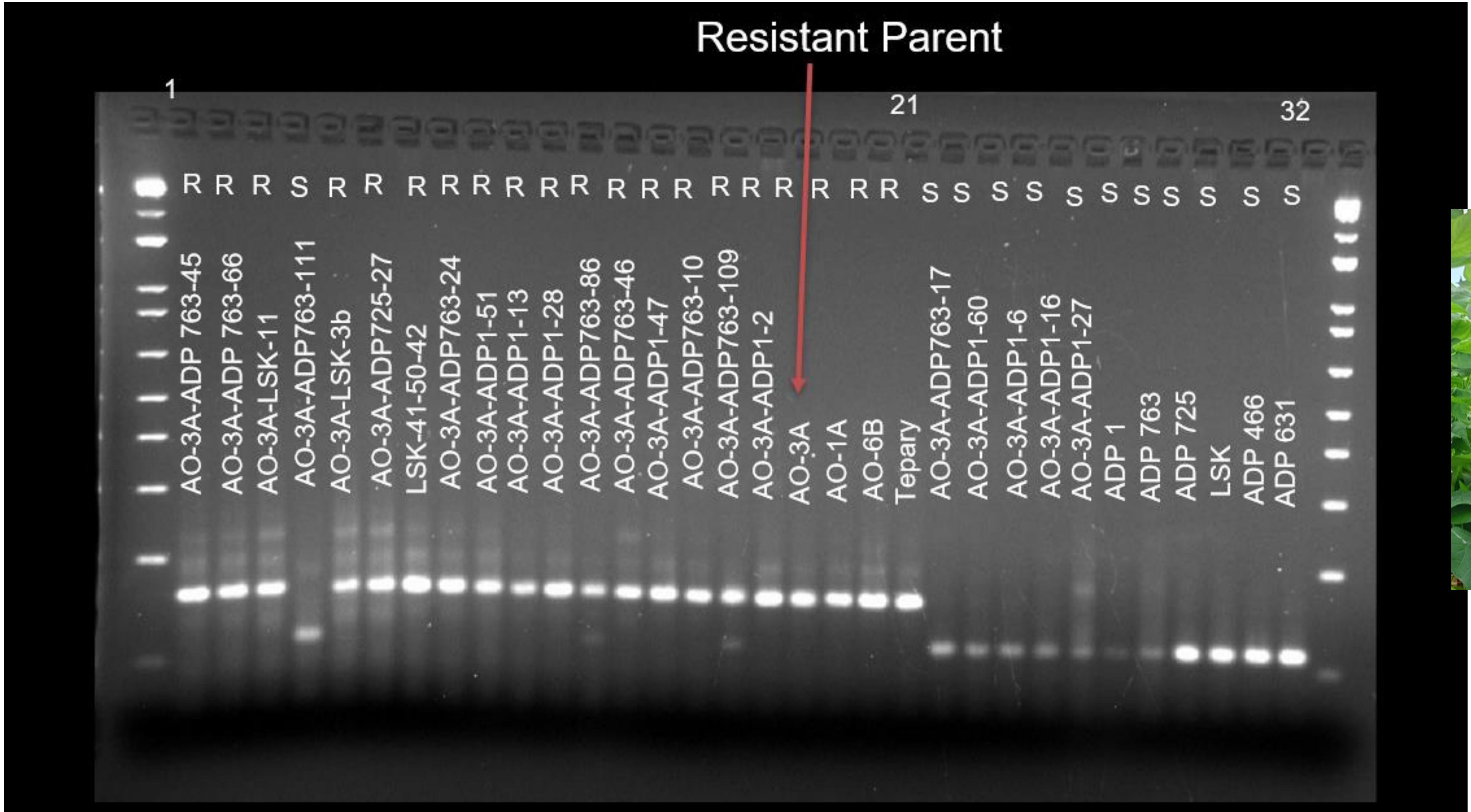


Resistant Lines





α-AI Marker Screening

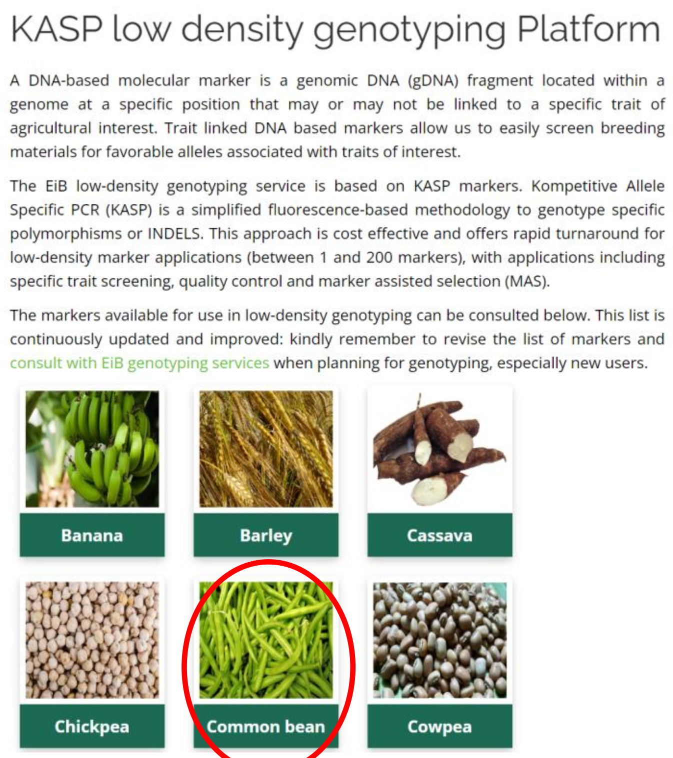


Differences in Resistant (1-21) and Susceptible (22-32) bands with α-AI Marker

Maria – NDSU (Zambian)

KASP marker assisted selection

-publicly available (Tm-shift or KASP-Intertek)



KASP low density genotyping Platform

A DNA-based molecular marker is a genomic DNA (gDNA) fragment located within a genome at a specific position that may or may not be linked to a specific trait of agricultural interest. Trait linked DNA based markers allow us to easily screen breeding materials for favorable alleles associated with traits of interest.

The EiB low-density genotyping service is based on KASP markers. Kompetitive Allele Specific PCR (KASP) is a simplified fluorescence-based methodology to genotype specific polymorphisms or INDELS. This approach is cost effective and offers rapid turnaround for low-density marker applications (between 1 and 200 markers), with applications including specific trait screening, quality control and marker assisted selection (MAS).

The markers available for use in low-density genotyping can be consulted below. This list is continuously updated and improved: kindly remember to revise the list of markers and consult with EiB genotyping services when planning for genotyping, especially new users.

https://excellenceinbreeding.org/module3/kasp
https://www.intertek.com/agriculture/agritech/

SNPs and INDELS converted to Tm-shift assays and KASP markers

	Intertek SNP ID	Customer SNP ID	Notes
1	snpPV0002	bc-3, Hart & Griffiths, 2013	Intertek verified marker
2	snpPV0003	bc-3, PveIF4E1,3,4 _PveIF4E2	Intertek verified marker
3	snpPV00032	ALSChr04_GC_43800347	Intertek verified marker
4	snpPV00038	CBB_SAP6_801	Intertek verified marker
5	snpPV00039	SU91, CB_00005	Intertek verified marker
6	snpPV00050	ANT_Co-3_ss715640025	Intertek verified marker
7	snpPV00066	bgm-1_03_2446460	Intertek verified marker
8	snpPV00072	I gene, 02.48.2799	Intertek verified marker
9	snpPV00083	ALS_Phg2M_08_AC_61470271_B	Intertek verified marker
10	snpPV00135	SD_07_TC_28765329	Intertek verified marker
11	snpPV00156	BGY8.1 QTL, S08_9202267	Intertek verified marker
12	snpPV00157	Ur-3, C11_50646133	Intertek verified marker
13	snpPV00158	Ur-11, C11_51904022	Intertek verified marker
14	snpPV00159	BGY4.1 QTL, S04_2531038	Intertek verified marker
15	snpPV00160	BGY8.1 QTL	Intertek verified marker
16	snpPV00162	bc-1, 03.04.0573	Intertek verified marker
17	snpPV00163	bc-u^d, 05.34.7830	Intertek verified marker
18	snpPV00164	bc-4, Pvmit-1_T_G	Intertek verified marker
19	snpPV00177	Co-1, ss645251	Intertek verified marker
20	snpPV00178	bc-4^2, Pvmit-1_C_G	Intertek verified marker
21	snpPV00183	Co-4^2, S08_2443578	Intertek verified marker
22	snpPV00241	bgm-1, Indel, PvNAC1	Retry
23	snpPV00242	BCMV, Indel, bc-2(2)	Retry
24	snpPV00243	Ur-5, S04_523133v1	New
25	snpPV00244	APA, S04_46273822	New
26	snpPV00245	Phs, S07_5221126	New
27	snpPV00246	Ur-4, ss240	New
28	snpPV00247	Ur-7, S11_31536658	New
29	snpPV00248	SAP6, CB437	New
30	snpPV00249	Co-x, KTR23	New

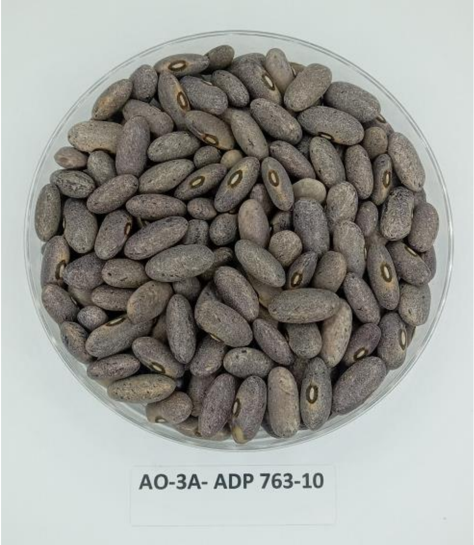
http://www.bic.uprm.edu/?page_id=91 (Soler-Garzón et al.)

Bruchid Resistant Lines Distribution to Collaborators

- Bruchid resistant lines identified and shipped to:
  - Dr. Juan Osorno - USA (North Dakota State University)
  - Dr. Celestina Jochua Mozambique
  - Virginia Chisale – Malawi
- For seed multiplication and agronomic evaluation

Field visit to Chokwe Research Station, Mozambique 2022

Weevil-Resistant Lines Developed by the Project



Thank you!

- NDSU colleagues (it takes a village!)
- Bean breeders
- Northarvest Bean Growers Assoc.
- NDDEBSG
- Many others…

BREEDING QUALITY BEANS FOR THE WORLD
A JOURNEY THROUGH THE BEAN BREEDING PROCESS

https://youtu.be/IkOxJDycRi4
https://youtu.be/wiMI-uGcsIk

Juan.Osorno@ndsu.edu

MINNESOTA NORTHARVEST BEANS NORTH DAKOTA

USDA ars Agricultural Research Service
www.ars.usda.gov

USAID FROM THE AMERICAN PEOPLE

US DRY BEAN Council

USDA Agricultural Marketing Service

NORTH DAKOTA DEPARTMENT of AGRICULTURE

USDA
United States Department of Agriculture
National Institute of Food and Agriculture

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Tiempo de Cocción: Frijoles Remojados

RD

~34 min

SD

~26 min

Ahorros potenciales no solo en tiempo sino también en energía!

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Miklas et al., 2020

Tiempo de Cocción: Frijoles sin Remojar

Table 1

Postharvest cooking times of regular-darkening and slow-darkening pinto bean varieties.[1]

	Variety	Darkening Pattern	Cooking Time (minutes)
RD	Windbreaker	regular-darkening	107 ± 4 [a]
	La Paz	regular-darkening	98 ± 3[b]
SD	Vibrant	slow-darkening	87 ± 2[c]
	ND Palomino	slow-darkening	63 ± 3 [d]

Wiesinger et al., 2021

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Cambios Mayores en Arquitectura de Planta
Han ayudado al Incremento de la Productividad

Volcamiento

Wheat
- *Rht* genes

Regulator of GA response

Rice
- *sd* and other
- genes

Multiple modes of action in hormone pathways

Angulo de hoja/ramificación

Sorghum
- *erl* genes

Unknown

Corn
- *lg* genes

Transcription regulation

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HUDSONALPHA INSTITUTE FOR BIOTECHNOLOGY

USDA ARS

USDA United States Department of Agriculture National Institute of Food and Agriculture