Project Overview

February 2025

ARTEMIS

IMAGING TECHNOLOGY FOR A FOOD SECURE FUTURE

Alliance Bioversity & CIAT

CGIAR

Gf

and

IITA Transforming African Agriculture

Colorado State University

LSE The London School of Economics and Political Science

In collaboration with

TARI

CIP International Potato Center

Google Research

CIMMYT

ARTEMIS

Content

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Classical Phenotyping

Human Observation → Qualitative Estimates

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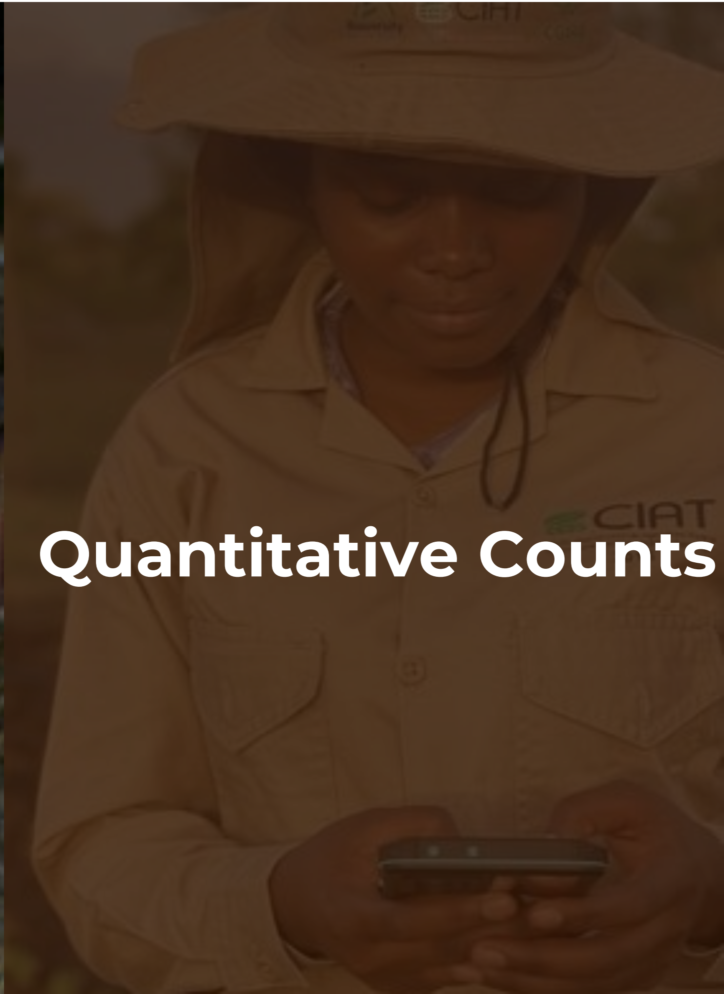

Machine Observation → Quantitative Counts

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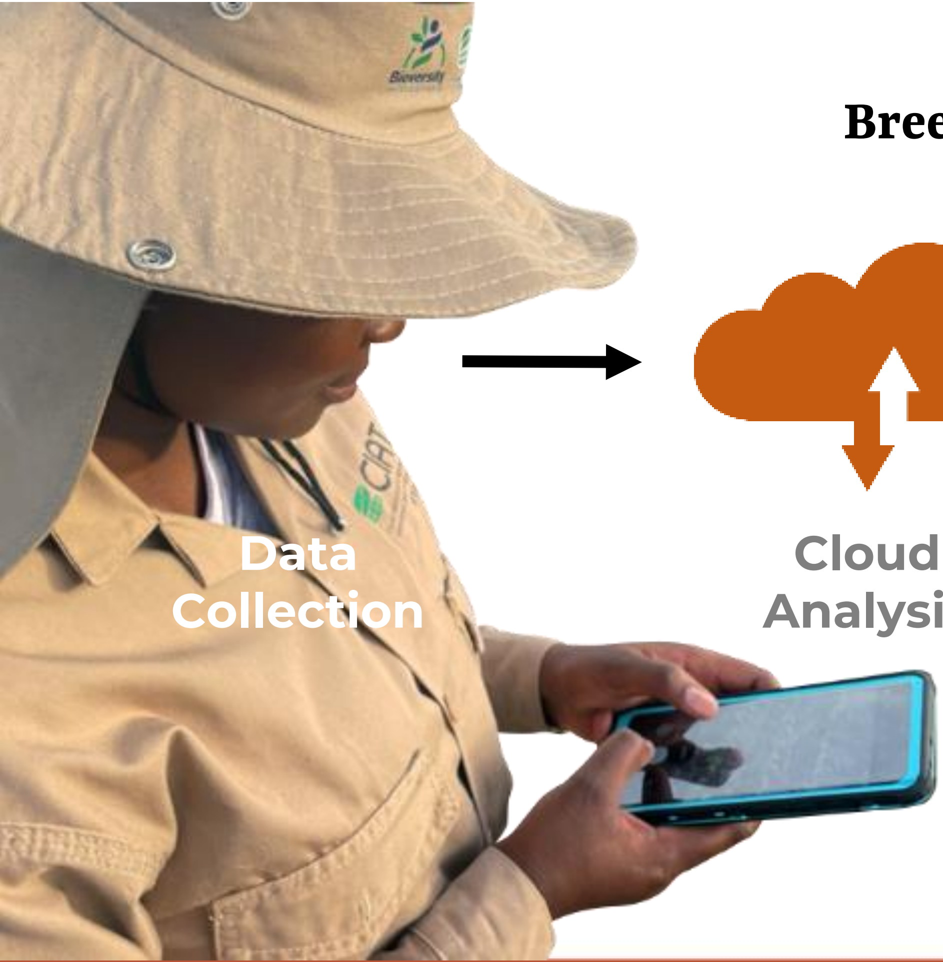
Breeding Pipeline Integration



Data Collection → Cloud Analysis → Enterprise Breeding System

Analytical System of Choice

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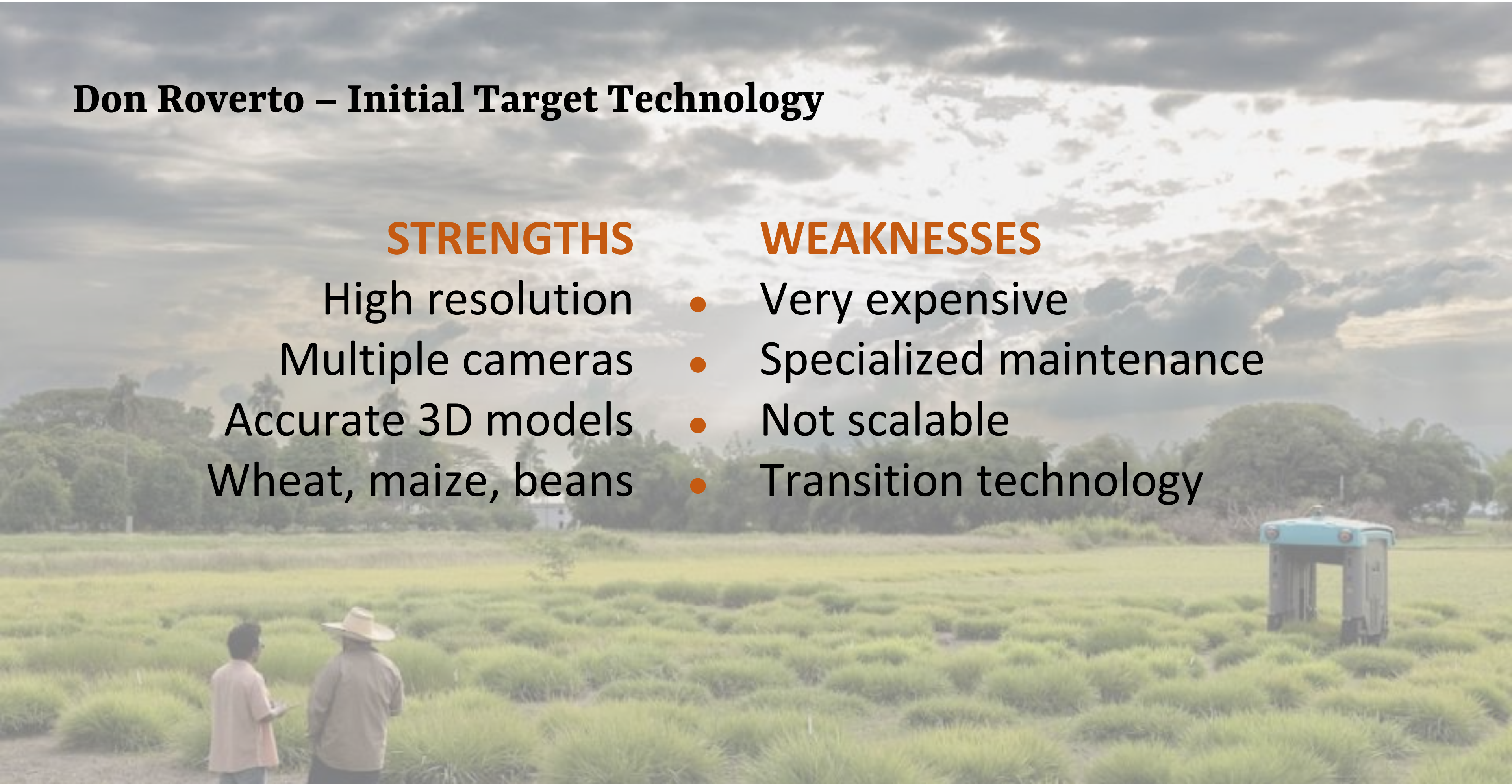


Don Roverto – Initial Target Technology

STRENGTHS

- High resolution
- Multiple cameras
- Accurate 3D models
- Wheat, maize, beans

WEAKNESSES

- Very expensive
- Specialized maintenance
- Not scalable
- Transition technology

Mobile Phone Deployment

Target was always mobile phones

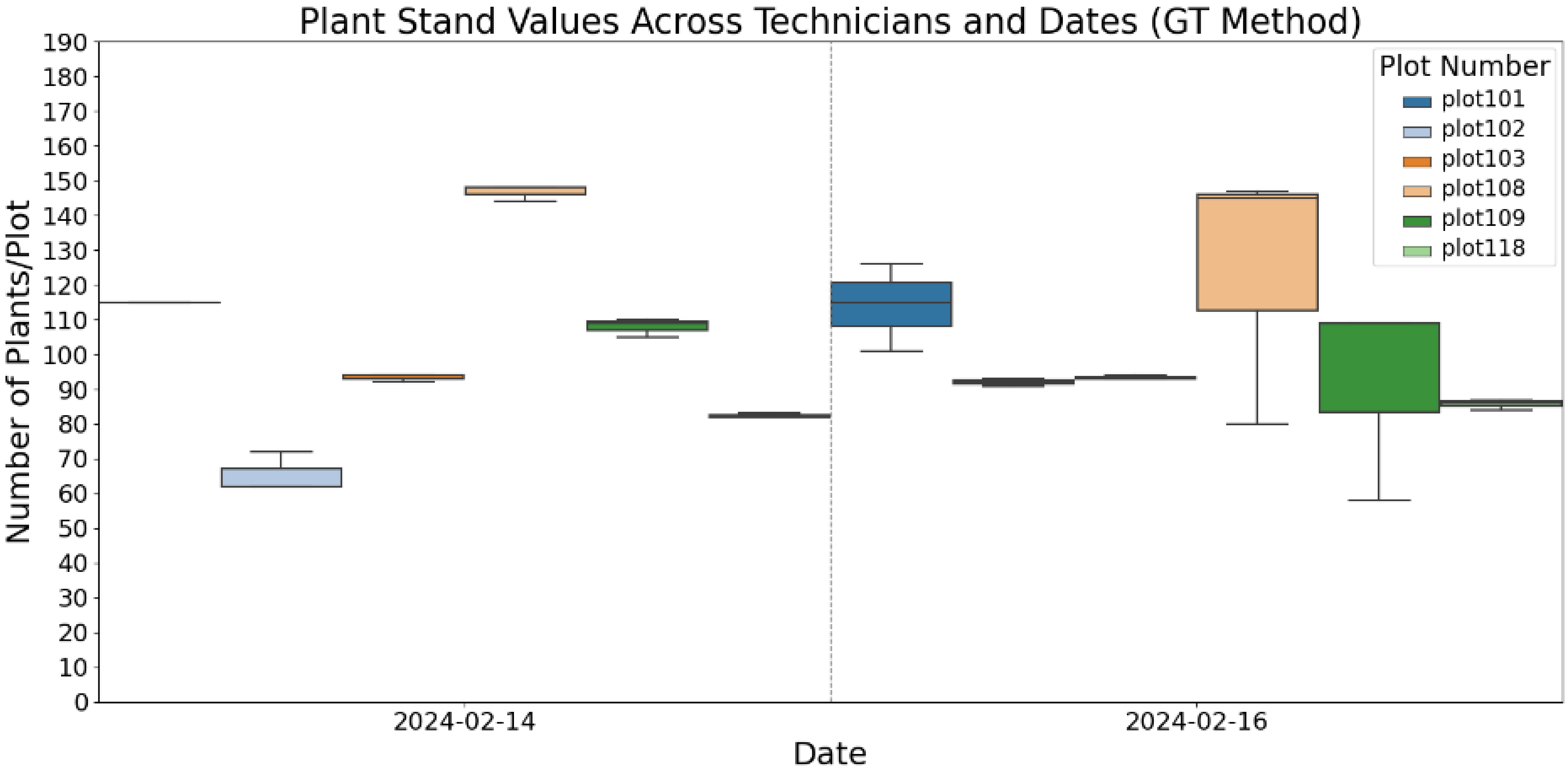
STRENGTHS

- Ubiquitous
- Affordable
- Scalable

WEAKNESSES

- Variable handset specs
- May be challenging for throughput efficiency

Accuracy of Computer vs Human Vision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Plant Stand Values Across Technicians and Dates (GT Method)
Number of Plants/Plot
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2024-02-14
2024-02-16
Date
Plot Number
plot101
plot102
plot103
plot108
plot109
plot118
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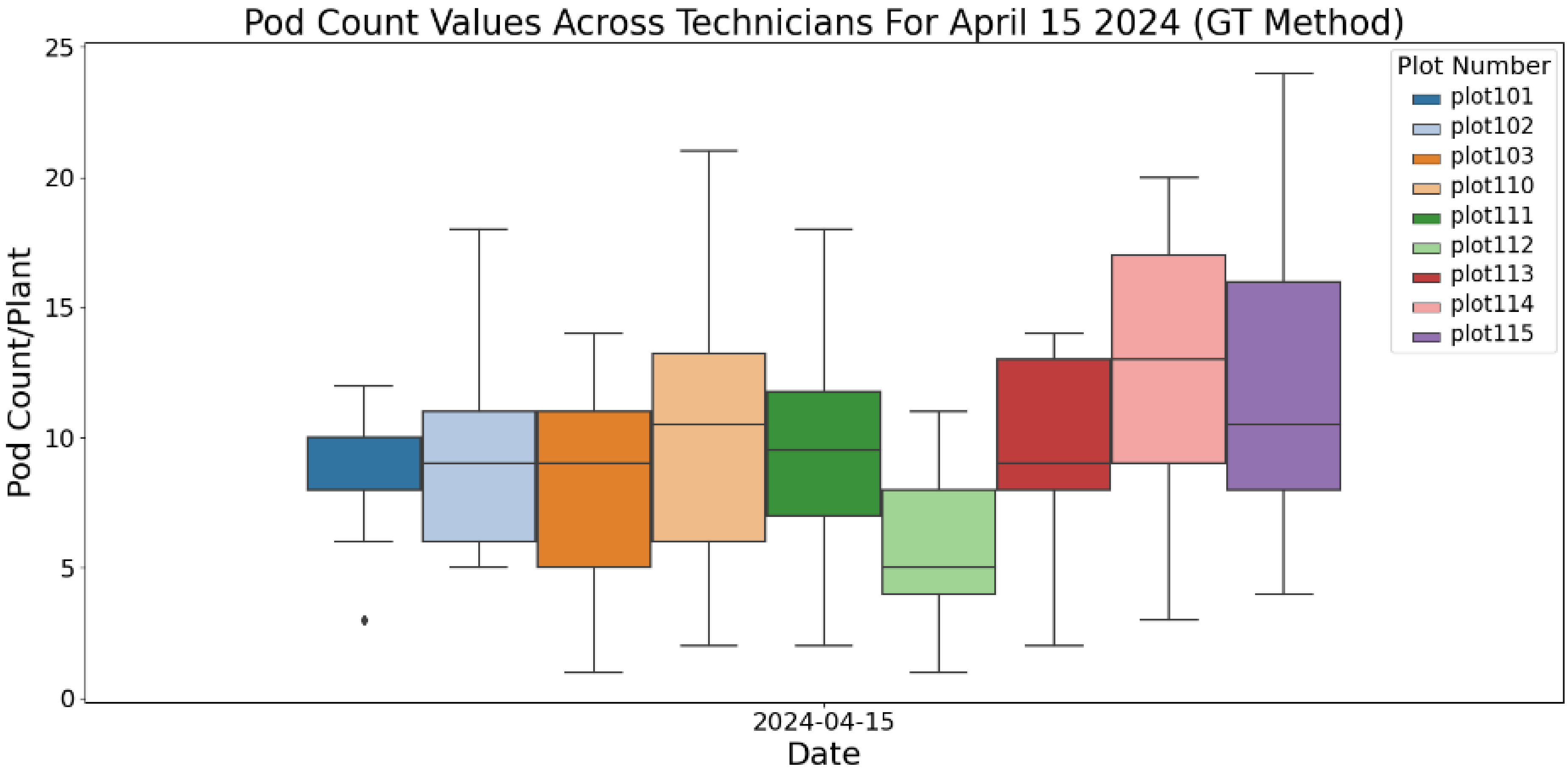
Pod Count Values Across Technicians For April 15 2024 (GT Method)
Pod Count/Plant
0
5
10
15
20
25
2024-04-15
Date
Plot Number
plot101
plot102
plot103
plot110
plot111
plot112
plot113
plot114
plot115

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Solving human error with Computer Vision

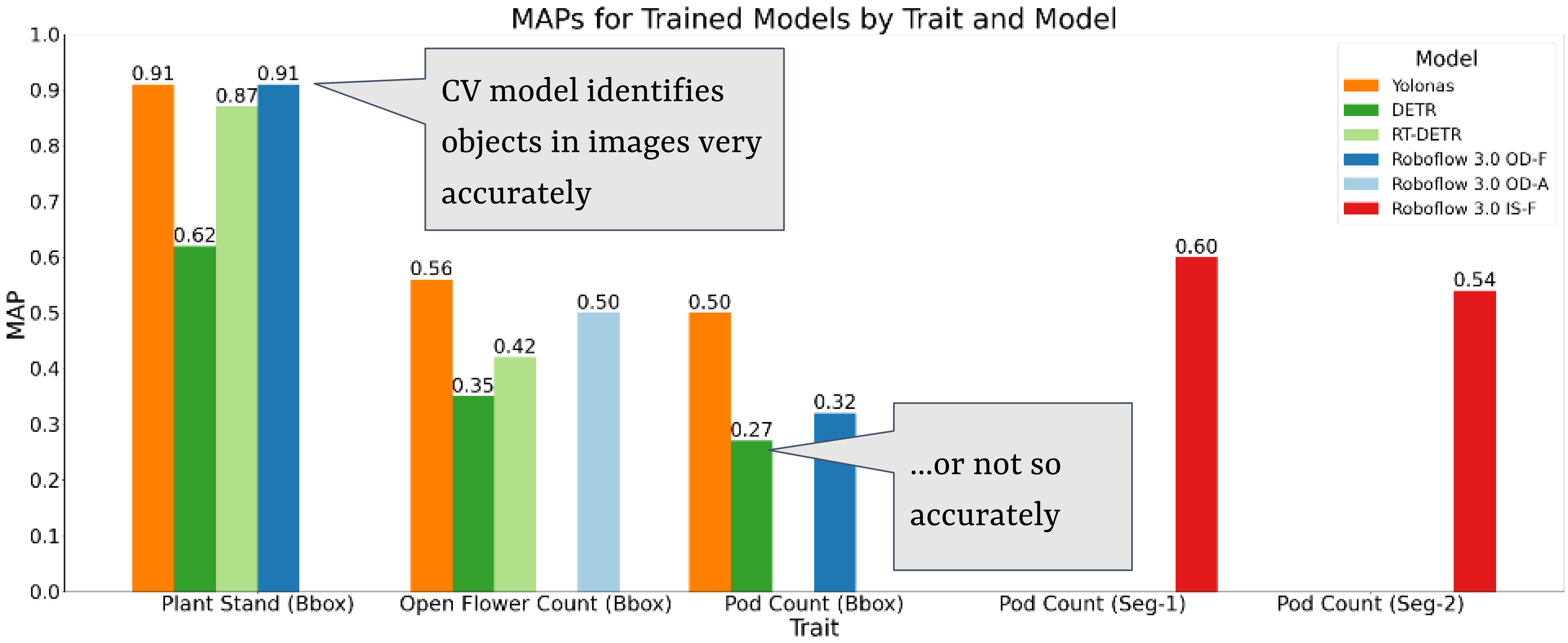
Accuracy AND Efficiency

Meet Bruno

Bruno images a plot (4x5m) <30 sec

Trait Group	Digital Method SOP	Handheld Capture Only Time Taken Per Plot (person-time)	Bruno Capture Only Time Taken Per Plot (person-time)	Visual Methods	Visual Traits Time Taken Per Plot (person-minutes)	Reduction	Difference (time)	% Difference
Plant Stand	Panorama	2m	30 s	Plant Stand Count	2	Yes	- 1m30s	-75.0
	Multiple Plant Ruler	3m			2	Yes	- 1m20s	-66.5
Flowering	Close Up Single Plant	4m 42s		Days to 50% Flowering	1	Yes	- 6s	-9.0
	Close Up Multiple Plant				1	Yes	- 31s	-53.0
	Under Canopy Multiple Plant	5m 12s	35s		1	Yes	-25s	-42.0
Podding	Under Canopy Multiple Plant	5m 12s	35s	Number of Pods per Plant at Harvest (5 plants)	1 min and 5 sec	Yes	-30s	-46.3
	Under Canopy Multiple Plant	5m 12s	35s	Number of Pods per Plant at Harvest (10 plants)	2 min and 20 sec	Yes	- 1min5s	-75.0

....+/- 1 hour to image 10 plots....



Choosing the right computer vision task for each trait is critical to getting the best model performance.

Stand Counts- beans is easier….

COMMON BEANS r^2 0.94 from ~100 images

SORGHUM r^2 0.85 from ~500 images

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COMMON BEANS r^2 0.84 from ~500 images

COWPEAS r^2 0.83 from ~600 images

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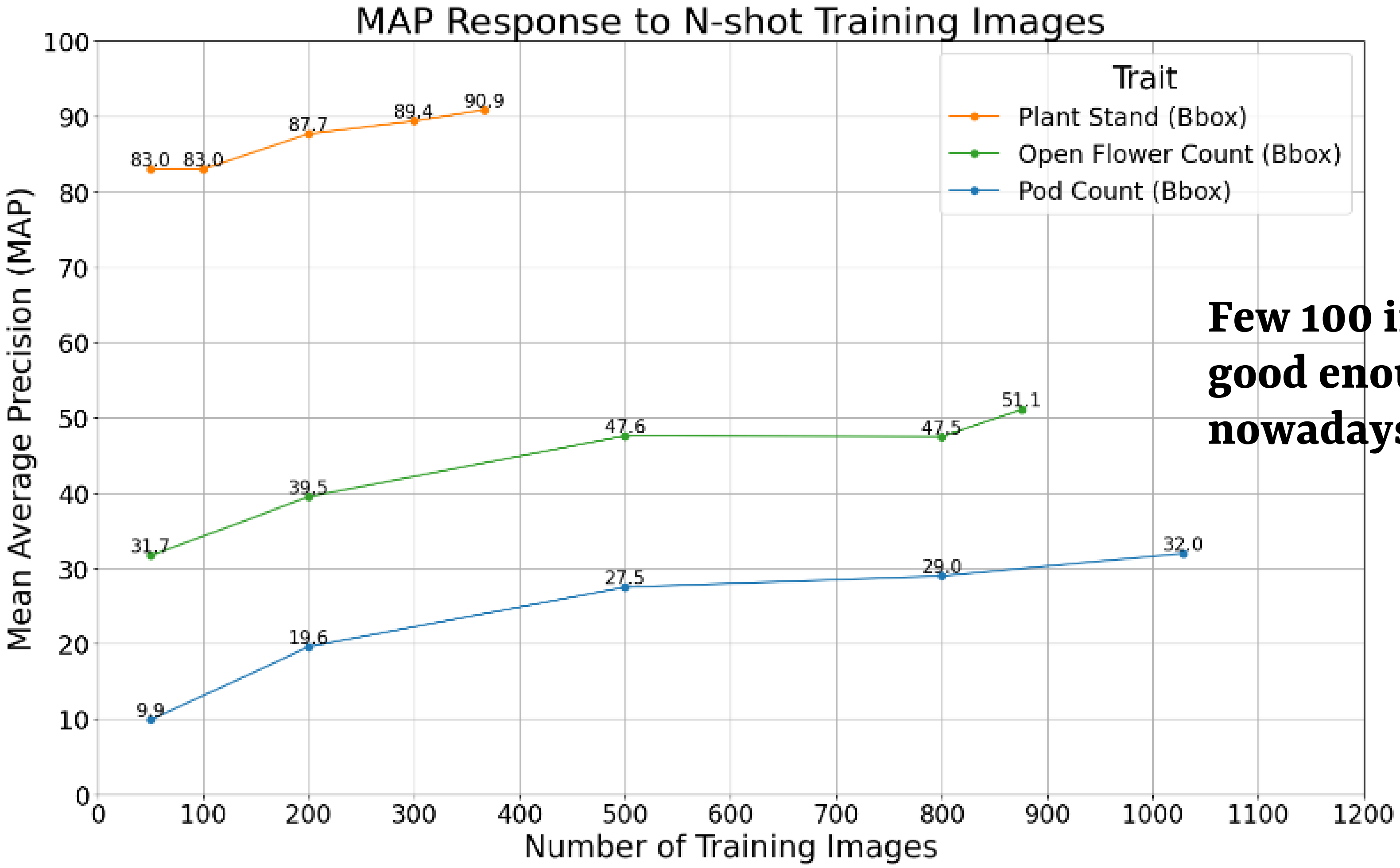

Few 100 images is good enough nowadays

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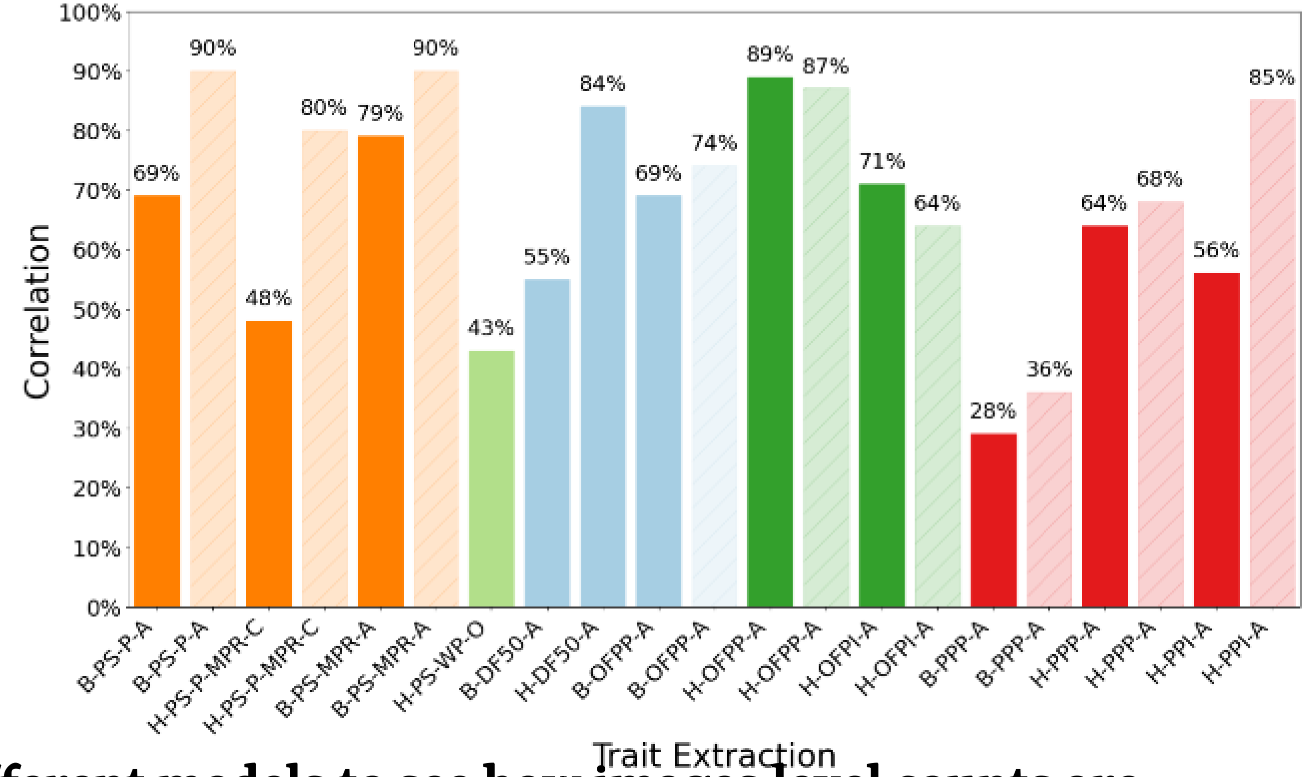
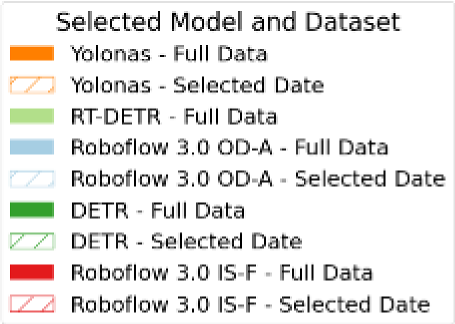
Correlation of Extracted Trait with Ground Truth for Model with Highest Correlation





Trait Extraction Long Name	In Plot
Bruno Plant Stand Panorama Arusha	B-PS-P-A
Handheld Plant Stand Panorama and Multiple Plant Ruler Colombia	H-PS-P-MPR-C
Bruno Plant Stand Multiple Plant Ruler Arusha	B-PS-MPR-A
Handheld Plant Stand WholePlot On-farm	H-PS-WP-O
Bruno Days to 50% Flowering Arusha	B-DF-A
Handheld Days to 50% Flowering Arusha	H-DF-A
Bruno Average Number of Open Flowers per plant Arusha	B-OFPP-A
Handheld Average Number of Open Flowers per plant Arusha	H-OFPP-A
Handheld Number of Open Flowers per image Arusha	H-OFPI-A
Bruno Average Number of Pods per Plant Arusha	B-PPP-A
Handheld Average Number of Pods per Plant Arusha	H-PPP-A
Handheld Average Number of Pods per Image Arusha	H-PPI-A

Different models to see how images level counts are translated to plot level values for breeders

Heritability phenotypic variation thats due to genetics and not random error goes up

	Plant Stand		Average Number of Open Flowers per Plant			Average Number of Pods per Plant		
Metric	*Bruno*	*Ground Truth*	*Bruno*	*Handheld*	*Ground Truth*	*Bruno*	*Handheld*	*Ground Truth*
H2 Standard	0.88	0.90	0.96	0.71	0.97	0.85	0.34	0.46
Genetic variance component	824.88	105.55	0.99	2.57	1.65	13.85	1.05	4.24
Error variance component	343.45	35.67	0.13	3.08	0.15	7.09	6.04	14.65

Basic Linear Unbiased Predictions (BLUPs) CV models track well with ground thuth

Genotype	Plant Stand		Average Number of Open Flowers per Plant			Average Number of Pods per Plant		
	Bruno	*Ground Truth*	*Bruno*	*Handheld*	*Ground Truth*	*Bruno*	*Handheld*	*Ground Truth*
Jesca	7.123	-0.300	0.985	1.436	1.066	3.821	0.627	1.597
Lyamungo 90	22.636	9.886	-0.018	-0.177	0.334	-0.971	-0.059	-1.038
Selian 13	-29.759	-9.587	-0.967	-1.258	-1.400	-2.850	-0.568	-0.559

BLUP Correlations for Different Collection Methods is high→ usable data for breeding decisions

Trait	Values	Correlation
Plant Stand	Bruno vs Ground Truth	0.967
Open Flowers per Plant	Bruno vs Handheld	0.995
Open Flowers per Plant	Bruno vs Ground Truth	0.970
Open Flowers per Plant	Handheld vs Ground Truth	0.941
Pods per Plant	Bruno vs Handheld	0.987
Pods per Plant	Bruno vs Ground Truth	0.901
Pods per Plant	Handheld vs Ground Truth	0.820

Translating this into Artemis Value Proposition: Efficiency

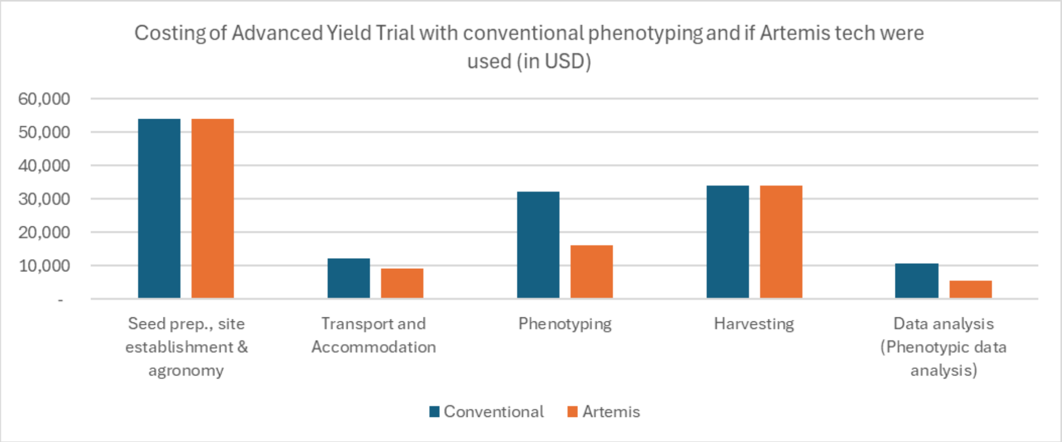
Case of AYT on 6 sites throughout Nigeria

- More efficient: scientist saves 54% of time, data collectors save 39%
- Cost savings: 50% on phenotyping , 17% on one season AYT trial (140,000 to 110 000 USD/AYT)

- Allows +1 trial location

  And +1 replication!

Data from: Uni Queensland / CGIAR



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IMPROVING ACCURACY

Higher inter-rater reliability and correlation with ground truth.

IMPROVING EFFICIENCY

Cheaper and faster phenotyping per plot.

Reduce percentage of repeat trials due to poor data quality

-20%

Reduce error variance term in phenotyping data

-50%

More replications per trial

+1

More environments

+1

Shorten breeding cycle

-1yr

Increase Heritability via reduced environmental variance

x2

Increase correlation between heritability on farm and on station

Improved varieties in farmer field, and **earlier**

Increase genetic gain (eg for podcount)

x2

Increase correlated response to selection (i.e. genetic gain on farm)

Higher yield on farm from one breeding cycle using Artemis vs manual

+5%

Higher value per acre of land where new variety is adopted (compared to variety developed with manual phenotyping)

Impact: by **increasing genetic gain** from one breeding cycle, and **decreasing the time** between initial cross until the variety is adopted, digital phenotyping using the **Artemis tool increases the net present value (NPV)** of the breeding cycle, through **higher yield gains** and **reduced discounting** as gains are incurred sooner

Cowpea example: 5% yield gain -> ~840,000USD per year in value added from one breeding cycle

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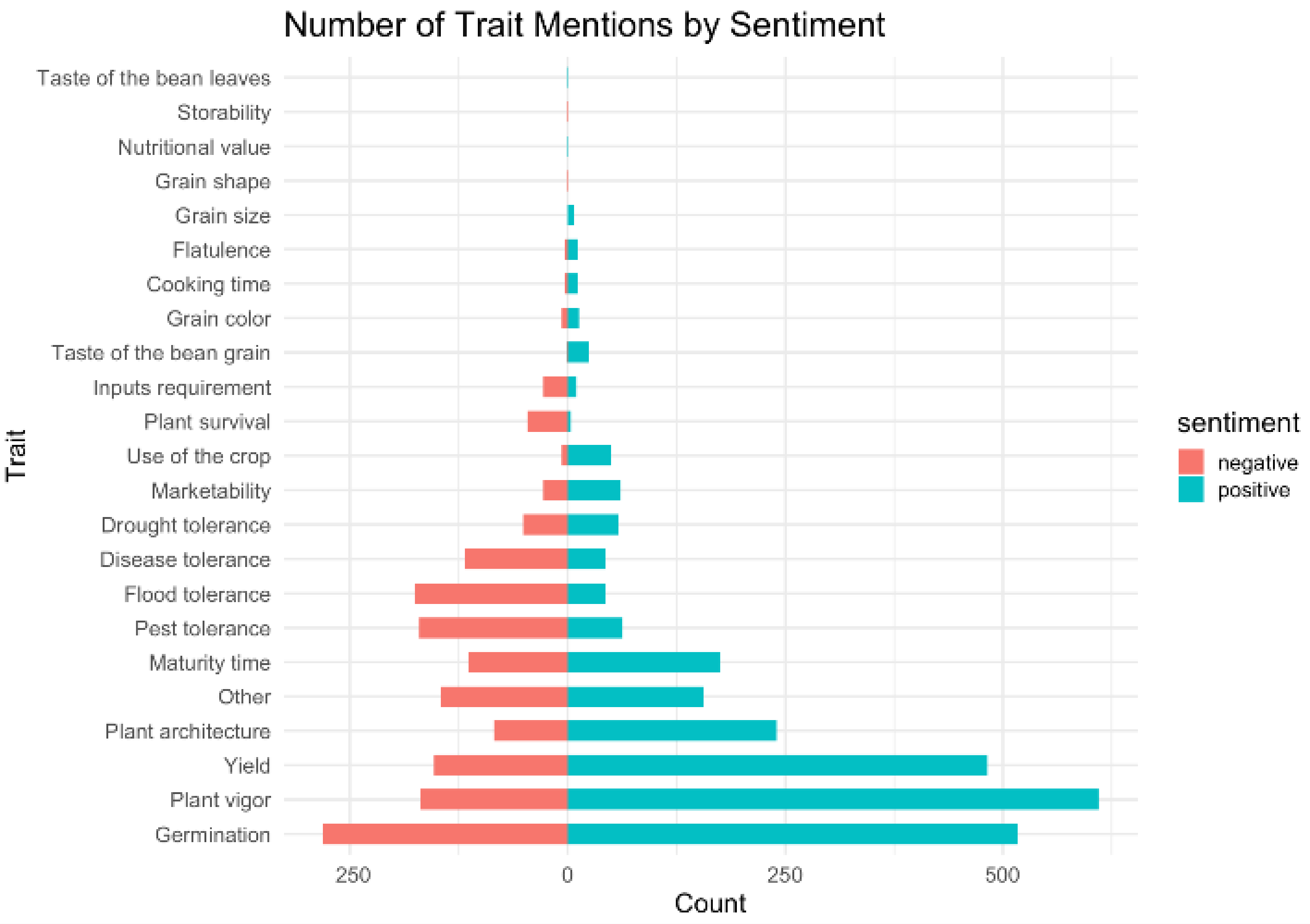
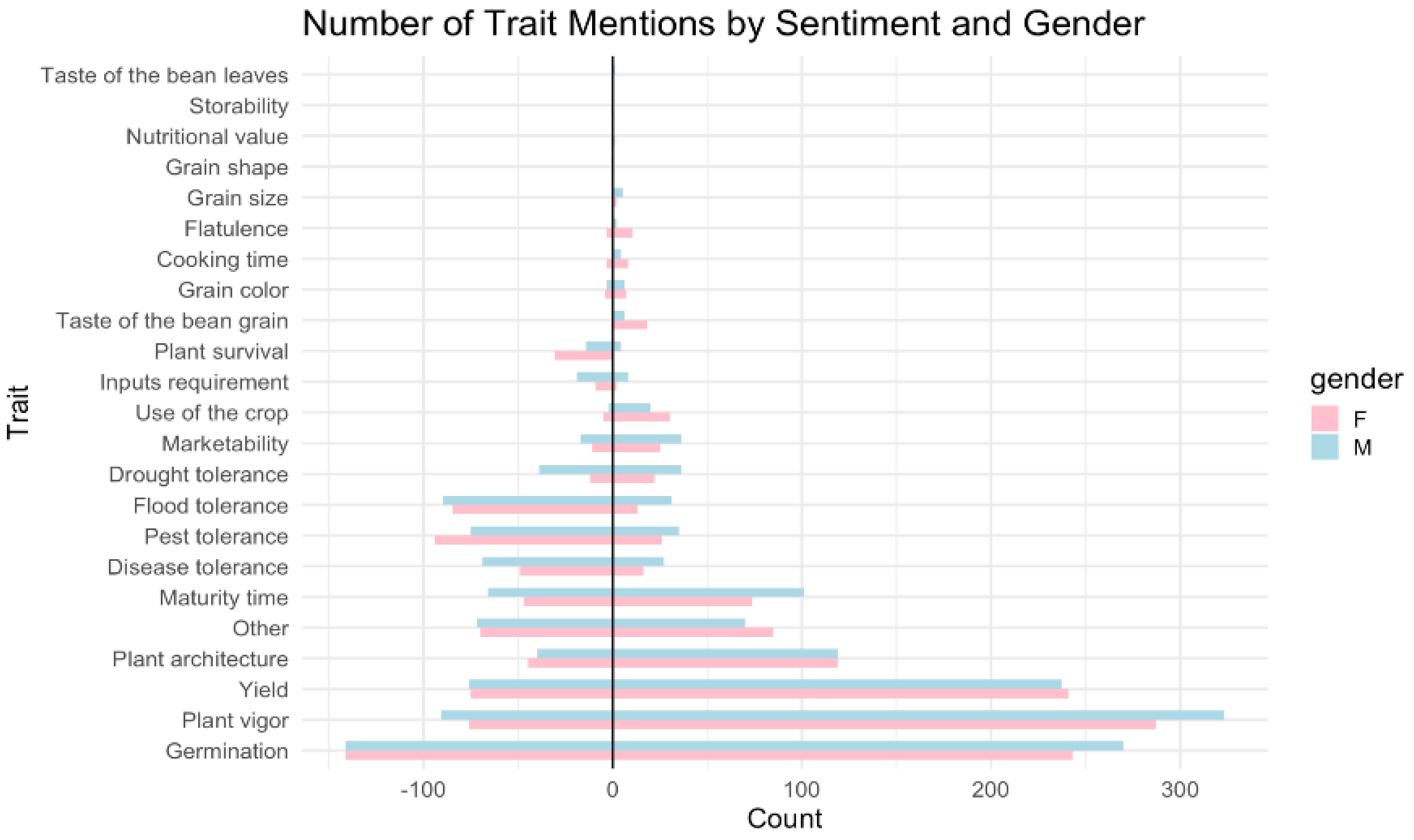
Moving from station to on-farm

Correlation between h2 on-station and on-farm: 0.07 -0.40

0.5 km



Note: we have not processed all the data from post-harvest, so these traits (eg marketability, grain size, etc) are under-represented in the figure and throughout the following analysis



Number of Trait Mentions by Sentiment and Gender
Taste of the bean leaves
Storability
Nutritional value
Grain shape
Grain size
Flatulence
Cooking time
Grain color
Taste of the bean grain
Plant survival
Inputs requirement
Use of the crop
Marketability
Drought tolerance
Flood tolerance
Pest tolerance
Disease tolerance
Maturity time
Other
Plant architecture
Yield
Plant vigor
Germination
Trait
-100
0
100
200
300
Count
gender
F
M

Participants identified 14 traits

Germination & Survival	Plant Vigor	Yield & Performance	Maturity & Flowering	Disease Tolerance	Pest Tolerance	Weather & Environmental	Plant Architecture	Market & Economic V	Consumption & Cooking	Grain & Pod Character	Other Issues & Challenges
Good germination	Good growth	High yield	Early maturity	Disease tolerant	Pest tolerant	Weather tolerant	Good plant architecture	Good marketability	Good for consumption	Good grain color	Late drying
Poor germination	Poor growth	Low yield	Late maturity	Not disease tolerant	Not pest tolerant	Not weather tolerant	Compact plant architecture	Not marketable	Not good for consumptio	Not good grain color	Burnt leaves
Early germination	Plant vigor	Moderate yield	Short maturity time	Disease resistant	Pest resistant	Weather resilient	Good branching	Low marketability	Good taste	Yellow grains	New experience
Late germination	Good plant vigor	Average yield	Long maturity time	Not disease resistant	Not pest resistant	Cold tolerant	Many branches	High marketability	Not good taste	Red color	Good inputs
Difficult germination	Poor plant vigor	Unknown yield	Fast maturity	Not disease affected	Pest attacked	Not cold tolerant	Few branches	Good for business	Sweet taste	Green color	Good project
Uneven germination	Weak growth	Easy yielding	Slow maturity	Disease presence	Pest damage	Drought tolerant	Many leaves	Not suitable for busine	Tasty when cooking	Shiny color	Good education
Weak germination	Stunted growth	Direct yield	Timely maturity	Disease challenges	Pest attack on leaves	Not drought tolerant	Few leaves	High income	Good cooking quality	Good seed quality	Research potential
Not germinated	Not vigorous	Delayed yield	Not early maturing	Wilts and has mold	Pest attacked seeds	Flood tolerant	Broad leaves	Low income	Not good cooking	High quality seeds	
Problematic germination	Overly vigorous	Not yielding	Quick maturity	Shrivelled beans	Pest challenged	Not flood tolerant	Small leaves	Easy market access	Average cooking	Average seed quality	
High germination rate	Expanding growth	Anticipated high yield	Early flowering	Frost tolerant	Insect attack on roots	Not rain tolerant	Green leaves	Market problem	Short cooking time	Shrivelled beans	
Easy germination	High plant vigor	Performed well	Late flowering	Not frost tolerant	High pest attack	Rain tolerance	Yellow leaves	Low market price	Fast cooking	Few pods	
Somewhat satisfactory germinat	Grown well	Good performance	Slow flowering		Early pest attack	High water requirement	Nice leaves	High price	Not good food quality	Many pods	
Not good germination	Not growing	Not good performance	Uneven flowering		Good pest control	Moderate rain requirement	Weak leaves	Not available in marke	No consumption challeng	Good pod carrying	
Poor plant survival	Not thriving well	Good fertility	Long flowering period		Not heavily attacked by	Requires sole planting	Curling leaves		Good for eating	Not good carrying	
Low plant survival	Good development	Not very much liked	Many flowers			Not suitable for intercroppi	Perforated leaves		Good for cooking with ric	Continuous pod development	
Not good plant survival	Not resilient	No yield	Few flowers			Not inputs requirement	Leaves with holes		Not flatulent	Not long pods	
Poor emergence	Thrives well		Flower shedding			High inputs requirement	Leaves dried up		No gas	Mixed grain size	
	Not thriving well		Late pod production			Not soil tolerant	Wilting leaves		Clean food	Stunted seeds	
	Can thrive in region		Slow reproduction			Soil tolerance	Wilting stems		Preferred by children	Dried beans	
	Good fertility		Poor flower setting			Climate tolerant	Drying leaves		Plump beans when cooke	Burnt beans	
	Good expansion		Poor flowering				Plant withering		Good beans		
	Many offspring		Late offspring production				Quick leaf shedding				
	Not green leaves		Late planting				Wide leaves				
	Good health		Early planting				Beautiful leaves				
			Delayed flowering				Attractive leaves				
							Tall growth				
							Not tall				
							Short plants				
							Thin stem				
							Thick stems				
							Thick variety				
							Short seed				
							Large grains				
							Small grains				
							Long beans				
							Long tails				
							Long leaves				
							No strings				
							Many strings				
							No tendrils				
							Not climbing vines				
							Ove[illegible] growth				
							Excessive vine growth				
							Not well spread stems				

LEGEND:	
(orange)	Traits we knew about but still good to identify
(green)	Novel traits that add information of potential interest to breeders
	Unhighlighted = synonyms or items that lack clear meaning

(New) traits that matter to farmers (in green)

ARTEMIS

Enable On-Farm Breeding

Conversational Data

Speaker

Automatic Speech Recognition (ASR)

Natural Language Processing (NLP)

Speech Synthesis (TTS)

Farmers' Insights and Preferences

On-Farm and On-Station imagery

Artemis FM

Multi-Modal Analysis

Breeding Decisions

qed

Research at Google

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Scaling

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Mariam Kamau - Aspiring Agronomy Expert

"If you are not the person collecting the data, it becomes tricky for you to clean it and make sense out of it."

Demographics

Age:	26
Gender:	female
Education:	BSc Agronomy
Role:	Lead Technician
Station:	NARS
Location:	Uyole,Tanzania

Station Capacities

Team (size & roles)	●○○○○
Breeding Facilities	●●○○○
Digital Infrastructure	●●○○○
Breeding Software Licenses	●●○○○

Responsibilities

- Field preparation, management and coordination on-station and at remote sites
- Supervise data collection process (on-station and remote)
- Collect phenotypic data
- Train casual labor & junior technicians on germplasm evaluation
- Clean and pre-process phenotypic data in Excel

Skills

Screening & Crossing	●○○○○
Trial Management	●●●●○
Phenotyping	●●●●○
Data Analysis and Interpretation	●○○○○
Digital Literacy	●●○○○

Commonly Used Apps & Software

Communication · Data Collection · Data Pre-processing

Goal: **Provide reliable phenotyping data**

Needs

- Timely access to materials for field preparation and management (seeds, fertilizer, etc.)
- **Field layout and trial goal** outlining the required traits for efficient planning and complete evaluation
- **Phenotyping guideline** for **standardised evaluation** and for training purposes
- **(Digital) tools to collect phenotypic data timely and efficiently**
- Communication channels with remote stations
- **Computers** for data export, data review and cleaning
- **Collection of reliable and consistent phenotyping data**
- **Timely management** of trails in different locations, collecting all the needed data on time

Pain Points

- **Long days** (up to 8hrs) in the field under the sun, leading to **data entry errors** caused by exhaustion and lack of support
- **No barcodes** on plot marks increases risk for errors
- Field teams at remote locations require supervision to make sure trial objectives are understood
- Day-to-day activities leave **no time for immediate data review** after collection, which makes it difficult to distinguish mistakes from performance irregularities
- Tedious **process of data pre-processing** and cleaning, delaying the analysis by 4 to 8 weeks after harvest
- Lack of resources, or weather conditions forcing **collection on paper sheets**, which causes additional delays during processing

A Day On The Field

The day begins early. Mariam briefs the field team on today's work. Phenotyping is conducted in pairs, with one assessing traits while the other records values in Fieldbook. After 4-6 hours of data collection (depending on the trait and field size), Mariam regroups with the team for a quick error check. Back in the office, she reports the trial status back to the breeder and pursues various administrative tasks. If time allows, she and her team may proceed to another trial field in the afternoon for data collection.

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IITA - Cowpea Breeding Program Nigeria

Station Mandate

4 IITA centres in Nigeria
Ibadan, Kano, Abuja, Onne

Ibadan: Global coordination for cowpea seed development
Kano: Mandate for Nigeria, Mali, Ghana, Burkina Faso

Trial Scope

Seed Development, Yield & Adaptability Trials
6 trials per season
7-400 genotypes tested
up to 1.000 plots

Market Segments
1. home made flour
2. boiled grain
3. Dual purpose feed (fodder)
4. fresh pods
5. grain
6. margin segments

Research Focus
Research focus depends on breeding goal, but typically includes:
- Disease, pest, nematodes, parasitic weeds resistance
- Yield improvement
- Nutrition enhancement
- Soil fertility management options

Breeding Scheme

TPP → Crossing / Generation Development (Parent Selection, F1, F6) → Breeding (IET, PYT, AYT, PVS) → Release (CIT/RCT, NPT, Apply)

IITA is consulted by national centres and project partners during Target Product Profile generation. Due to their on-station capacities and access to genetic material (greenhouse, genetic markers) IITA selects donor material and conducts crossings to **develop varieties from F1-F6 generation**. They receive material from the IITA genebank in Ibadan, which holds the world's largest and most diverse collection of cowpeas.

IITA conducts multi-location testing (in up to 6 locations, also cross-country). Thereby they support and collaborate with NARS, who lack the required capacities and resources. NARS role here is to plant checks and validate the collected trial data. IITA hires field agents to manage and supervise remote fields, they try to visit each location once per month during trials.

IITA provides selected lines and supports network trials. They provide data and evaluations to NARS, who proceed with applications for release.

Agronomic Practices

Farm & Field Management ●●●◐○
- Planting machines and threshers are available, but not always in good conditions.
- Using manual labels for plot identification for yield trials. Barcodes for plot identification are used in Ibadan.
- Procedures are systematically documented. Limited control for remote / extension managed fields.
- Communication via WhatsApp or Email.

Phenotyping ●●◐○○
- Data is recorded manually and digitally following standard processes.
- On-station trials use seed count and weight machines
- IITA offers in-season trainings to align data collection team, establishing clarity on traits and procedures (subjectivity to collector remains).
- Less control on data collection procedures at remote sites.

Data Management ●●●●○
- Data integration system for IITA centres using BMS, enabling data sharing and providing access to historical breeding data
- Access to advanced breeding software
- Dedicated data scientist roles responsible for efficient data management

Station Capacities

Human Resources ●●●●○
- Skilled breeding team with dedicated expert roles:
  - 2 Breeders
  - Physiologist, Entomologist, Pathologists (Ibadan)
  - Data Scientists (Ibadan)
  - Biometrician (Ibadan)
  - 10 Technicians
  - Students
  - Casual labour hired during planting and harvest

Station Facilities ●●●◐○
- Laboratory with specialised equipment (inoculation, genetic markers)
- Greenhouses, irrigation
- Field equipment: planting machine, threshers
- Funds and means for travelling
- Stable internet connection
- Computers for staff
- 1 tablet per trial for data collection

Breeding Software

Data Management System / Trial Design

Digital Data Collection

Data Analysis

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Apply Design Decisions

Plot registration | Data capture - camera | End collection

Designed for scale

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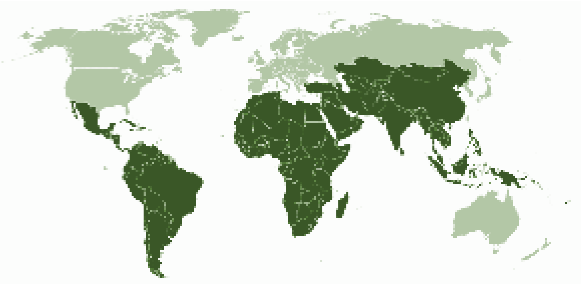
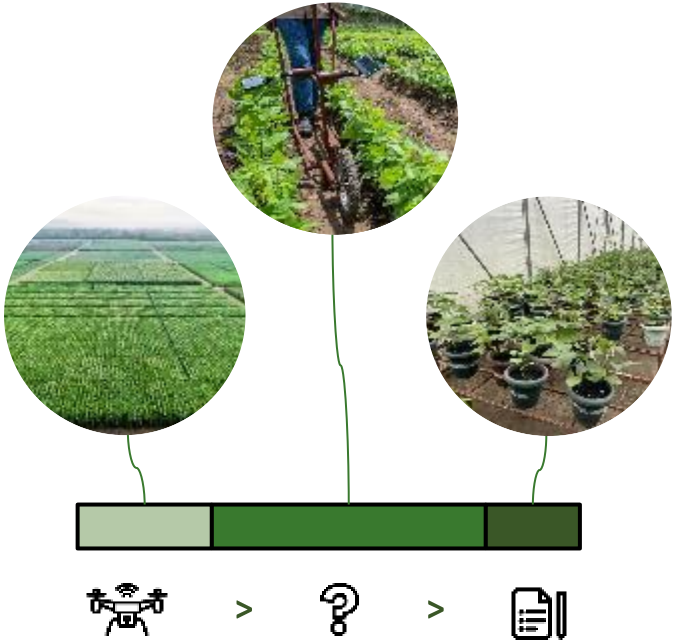
$100M/y in breeding



∑ $1b : 500m smallholder farmers



under-resourced

54% 17%

Efficient

Accessible

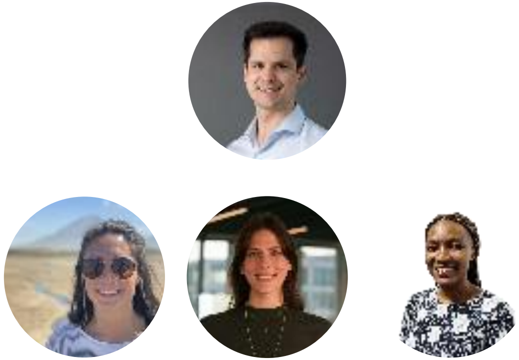
Easy & Practical

Compatible

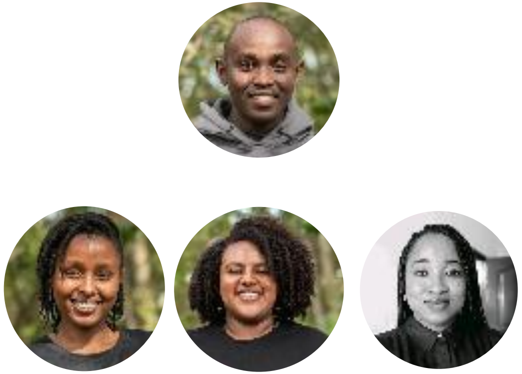
Fundable

Diverse Team

Product



MLOps

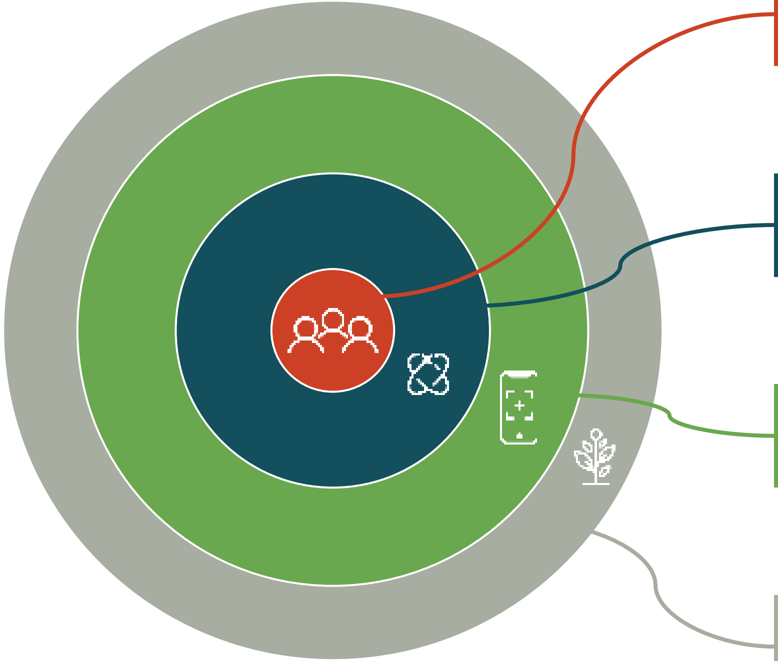


FieldOps

PM

Scaling and Market Research

The Artemis flywheel



ARTEMIS

Talented, diverse multidisciplinary team, based in Arusha, building tech to enable breeding better crops in a changing climate.

TATU Tech Stack

The base for building powerful products, featuring the AI-models, SOPs and HCD.

Products

Leveraging our Tech Stacks to develop and deploy practical, useful and scalable products into the field. ONA in beta.

Use-cases

Initial focus has been on phenotyping beans, cowpeas and sorghum for on-station breeding.

The next big thing…

ARTEMIS	Project →	Entity
TATU STACK	Phenotyping App →	ARTEMIS FM
PRODUCTS	Computer Vision →	Multimodal (SIKIA, ONGEA)
PROBLEM SPACE	Breeding →	Agronomy
TRIALS	On-station →	On-farm

Maize	**Potatoes**	**Millet**
Wheat	**Sweet potatoes**	**Pigeon peas**
Rice	**Lentil**	**Groundnut**
Beans	**Chickpea**	**Banana**
Cowpeas	**Sorghum**	**Cassava**

ARTEMIS

IMAGING TECHNOLOGY FOR A FOOD SECURE FUTURE

Alliance Bioversity & CIAT

CGIAR

BILL & MELINDA GATES foundation

Thanks!

IITA Transforming African Agriculture

Colorado State University

LSE The London School of Economics and Political Science

In collaboration with

TARI

CIP International Potato Center

Google Research

CIMMYT