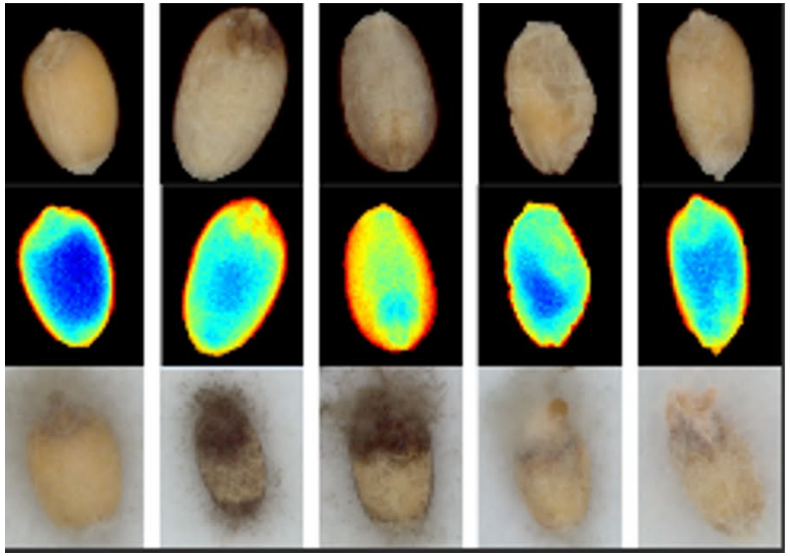
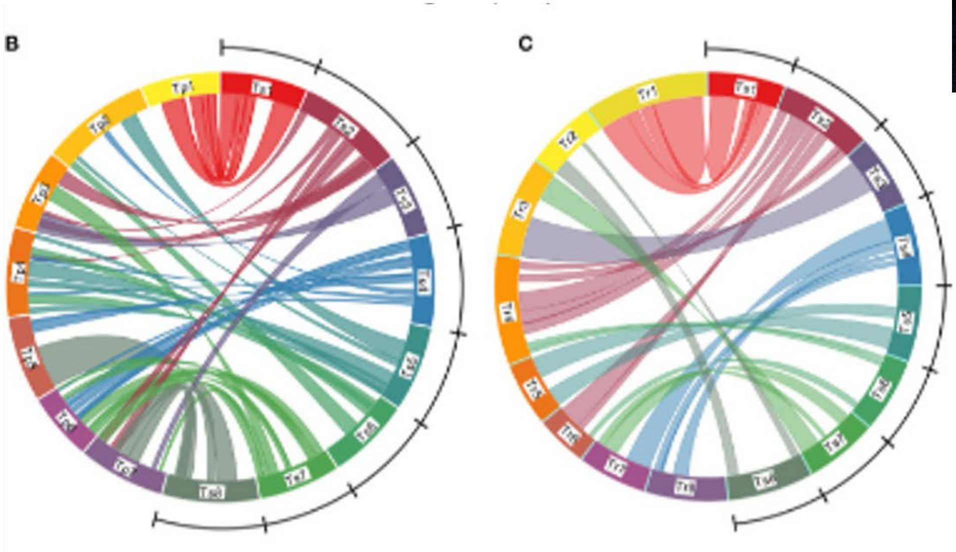
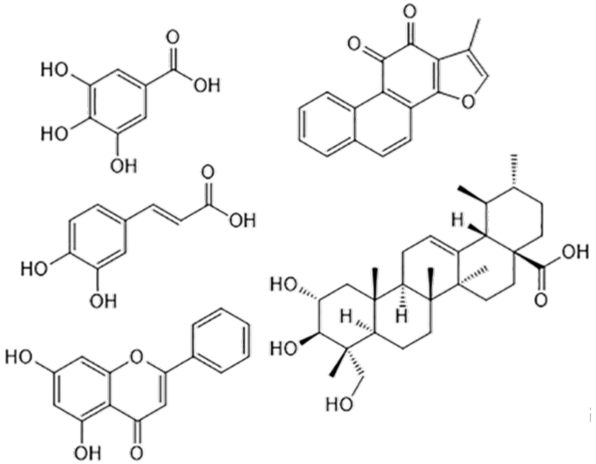
Unchaining genetic diversity by harnessing omics tools for genebank innovation and adaptive agriculture







Kioumars Ghamkhar
Director, Margot Forde Genebank, AgResearch
Co-chair, Academia Section, International Plant Phenotyping Network (IPPN)
Co-chair, Seed and Germpalsm Phenotyyping, IPPN

Margot Forde Genebank from AgResearch

agresearch

Grow webinar: 27 March 2025

Talk structure

Margot Forde Genebank from AgResearch

- New Zealand Agriculture and MFG
- Omics and “the book”
- It’s not just the book, walking the talk
- Seed phenomics/phenotyping
- IPPN and collaboration with genebanks
- Germplasm phenomics (form ground-based to aerial and satellite)
- Cost/value discussion
- Conclusion

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New Zealand

5.1 M people

- **268,000 km^2 land**
  - 50% woodland
  - 39% pastures
  - 9% arable & hort.
  - 800,000 ha irrigated

- **ag-R&D**
  - Government funded
  - levy paid
  - private

- **50% exports**
  - dairy products
  - meat & fish
  - fruits
  - timber

- **Billions/annum**
  - Ryegrass (14) and clover (3)
  - Pine (4.5)

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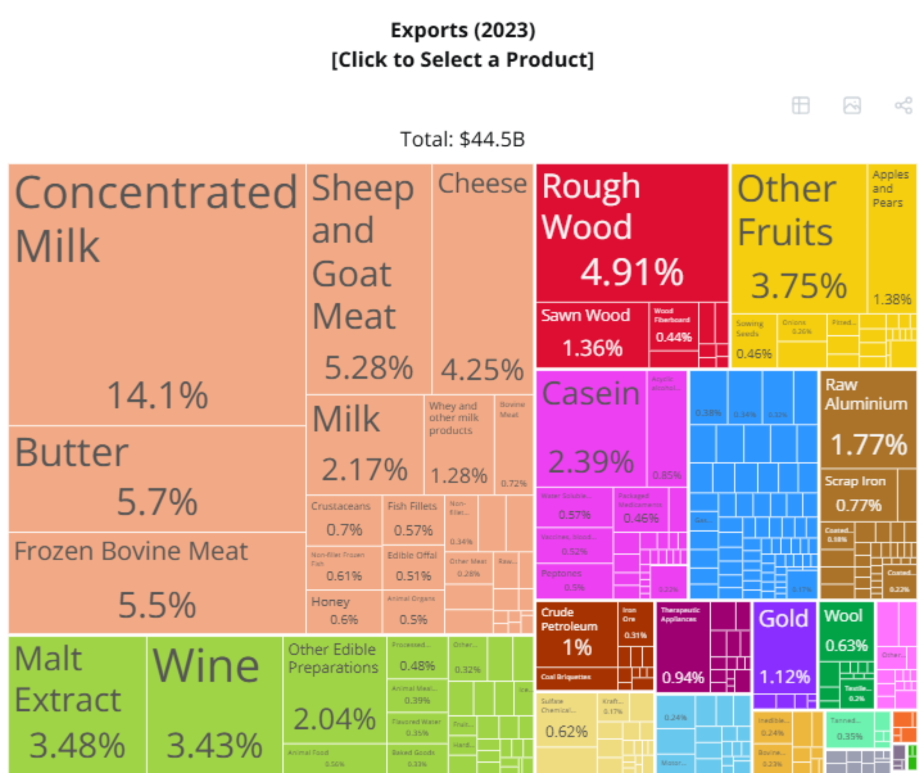
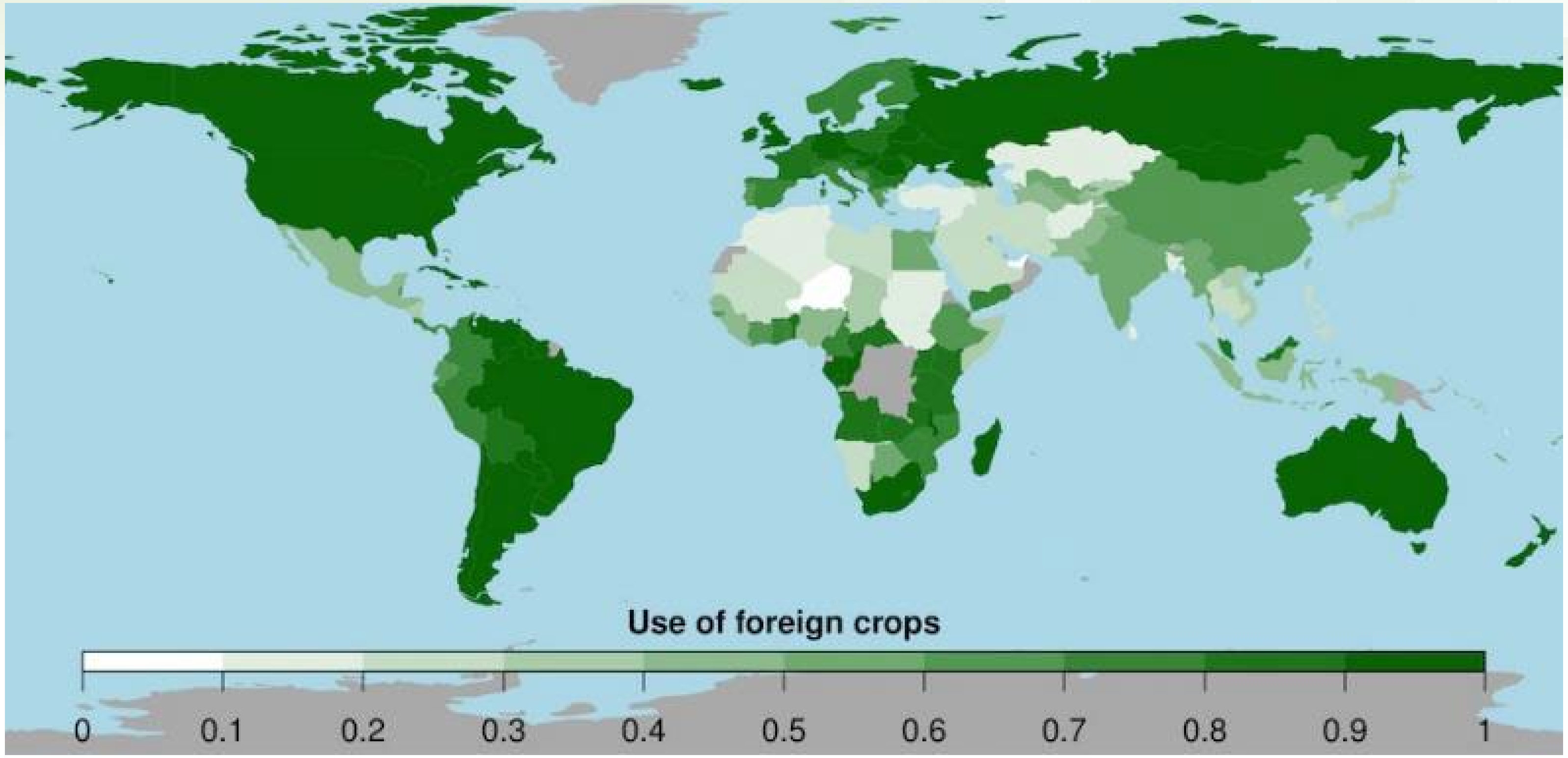
Why exotic forages





Margot Forde Genebank from AgResearch

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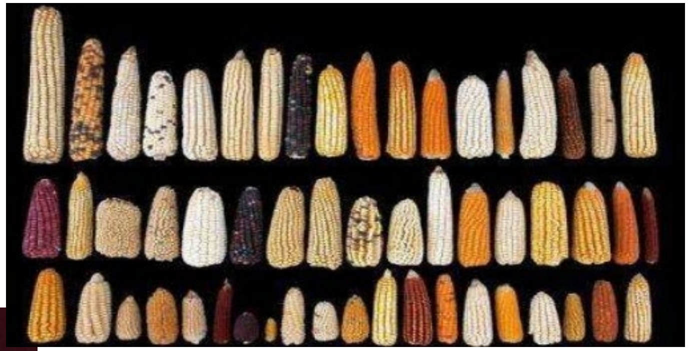
Margot Forde Genebank from AgResearch

Genetic diversity

- Foundation of resilient and productive agriculture
- Variation is essential not only for the survival and reproduction of populations, but also for the very existence and the preservation of species diversity.
- Critical for climate adaptation, pest resistance, and yield improvement



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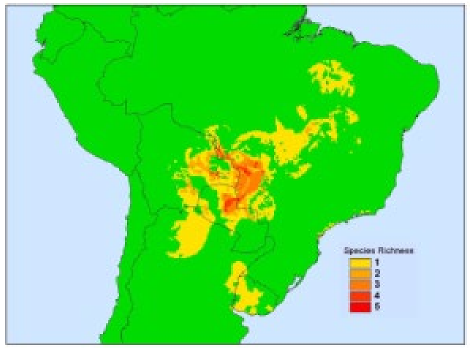
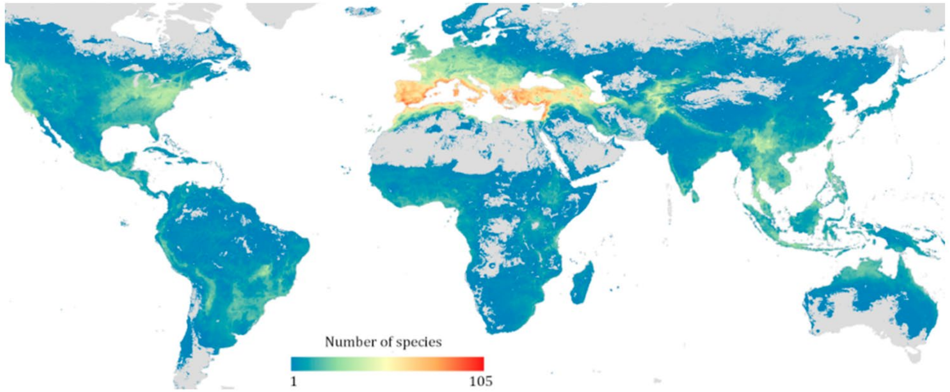
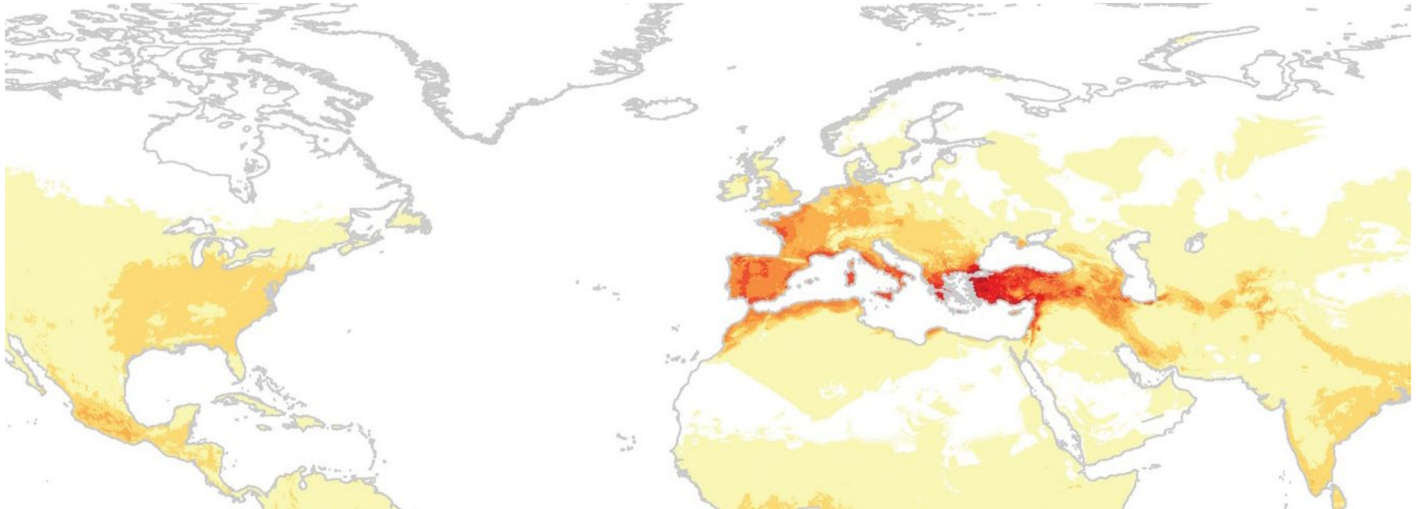
Climate change and human footprint is having a negative impact on wild relatives



Arachis



(a)



Role of genebanks

Diversity within subterranean clover and biserrula for persistence traits with potential use in New Zealand hill country

K. GHAMKHAR[1, 2, 3], T. FAITHFUL[4], P.G.H. NICHOLS[4, 5] and M. H. RYAN[4]

Future forage plants for hill country systems

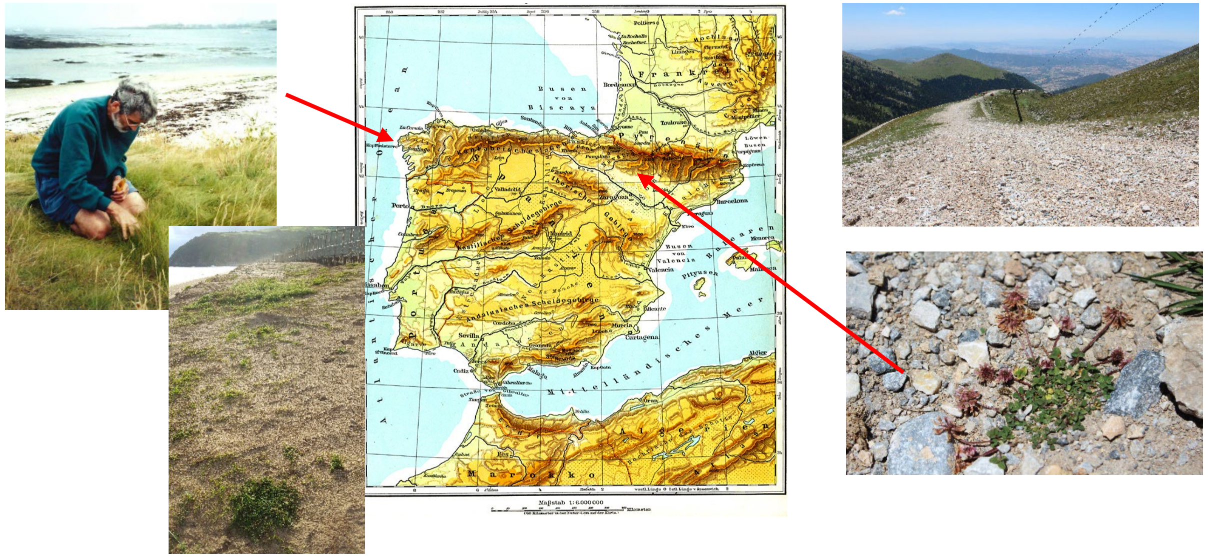
S.N. NICHOLS[1], J.R. CRUSH[1], C.C. EADY[2], M.J. FAVILLE[3], K. GHAMKHAR[3] and D.R. WOODFIELD[3,4]

frontiers in Plant Science — REVIEW

Prospects for *Trifolium* Improvement Through Germplasm Characterisation and Pre-breeding in New Zealand and Beyond

Lucy M. Egan[1,2], Rainer W. Hofmann[2], Kioumars Ghamkhar[3] and Valerio Hoyos-Villegas[4]*

- Find, collect, preserve and provide access to plant genetic resources
- Support breeding programs, research, and conservation efforts
- Initiate and introduce work on new crops/forages



Need for collections

- 1,700 genebanks worldwide, 7 m accessions
- These are strategic global assets
- Safety net against the loss of valuable germplasm
- Conserve rich gene pools and help feed the world
- Priceless genes can be lost even if only collecting but no characterisation, regeneration and maintenance.

Margot Forde Genebank
from AgResearch

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Margot Forde Genebank

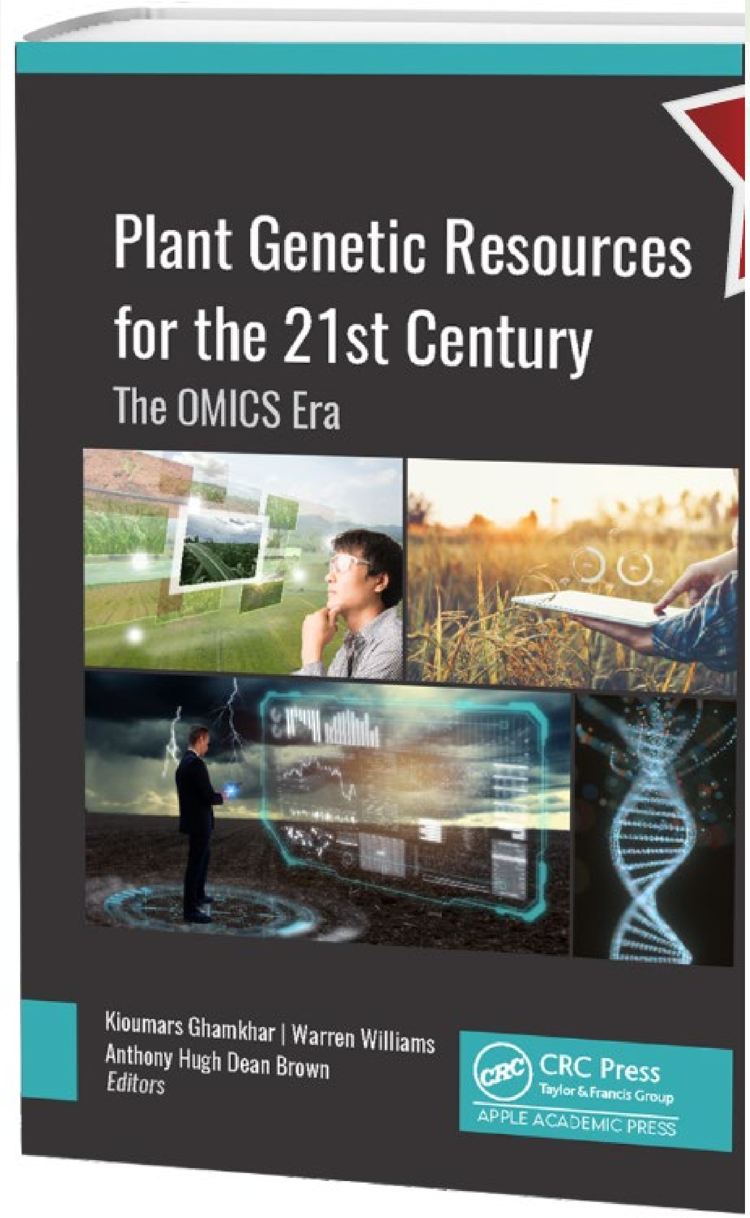
- >175,000 accessions, mostly forage species
- Over 2,600 different species from 590 genera
- Sourced from over 120 different countries
- >420 named fungal endophyte populations
- Oldest population is from 1940
- Over 8,000 wild populations collected in the last 5 years
- 3300 accessions of ryegrass plus many other breeding lines
- 2500 accessions of white clover plus breeding lines

Collections

https://www.genesys-pgr.org

In brief, we need:

- Agri-diversification
- Intensifying trait discovery
- Efficiency (core collections to whole collection and vice versa)
- Fast characterisation (all omics and computomics)
- Collaboration
- Investment (national and international)



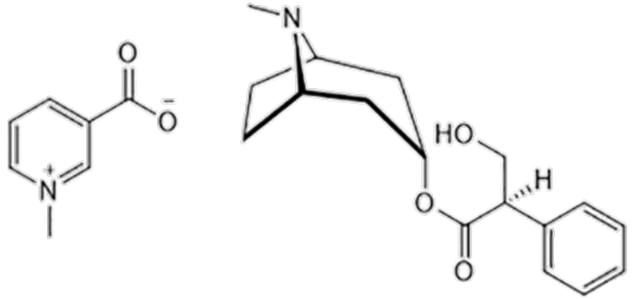
Why omics technologies?

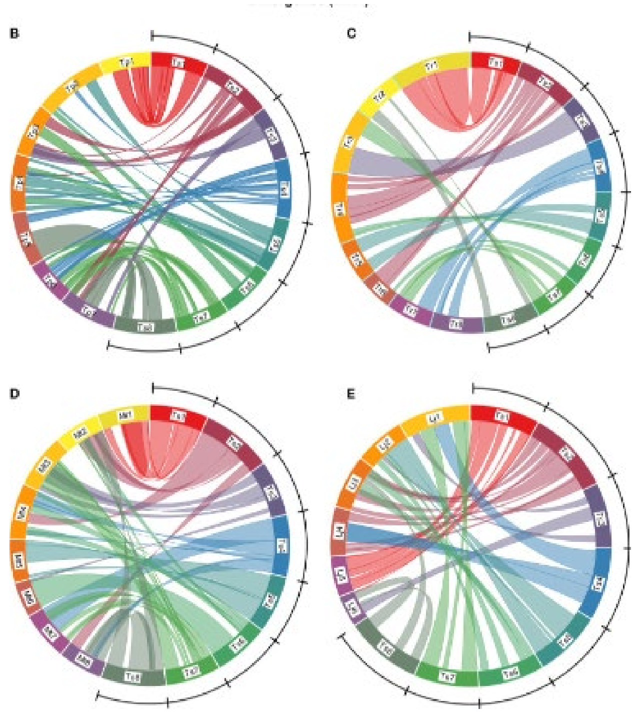
- Enable deep insights into genetic potential
- Accelerate breeding and conservation strategies

CHAPTER 3

Omics Technologies for Genetic Resources: Review and Prospects

KIOUMARS GHAMKHAR[1] and CHRISTOPHER M. RICHARDS[2]





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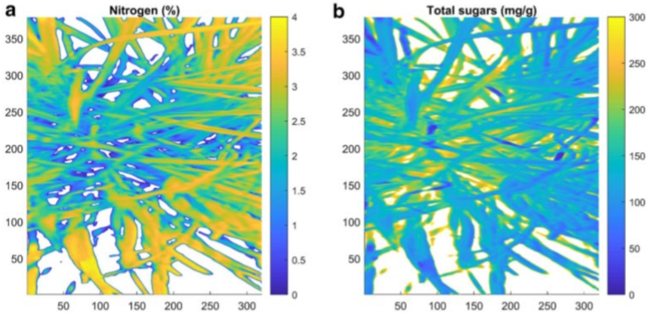
Challenges in genebank utilisation

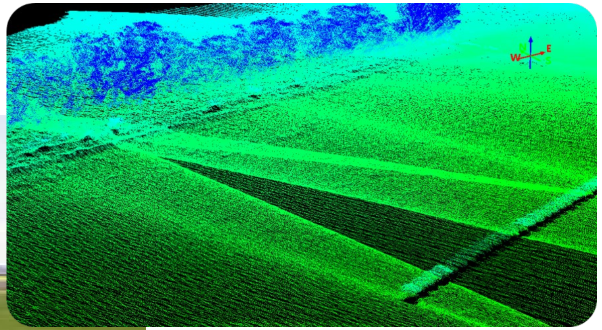
CHAPTER 2

Evolving Research Themes in Plant Genetic Resources

ANTHONY H. D. BROWN

- **Data gaps and limited characterisation**
  - Most genebanks rely on traditional phenotypic data, limiting efficiency
- **Slow integration into breeding programs**
  - Challenges in translating genetic diversity into applied outcomes
- **Environmental uncertainty and climate change**
  - Need for better predictive tools for adaptive agriculture





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Omics in action – to boost MFG utilisation

- **Genomics**
  - Whole-genome sequencing for diversity mapping in subterranean clover
  - Pangenomics: re-sequencing in 4 clover species (populations and core collections)
  - Skim sequencing of the same species to augment the pangenome
  - GBS for core development in ryegrass and white clover
- **Metabolomics**
  - Functional insights into rumen methane mitigation in forages
  - Identification of bioactive compounds

CHAPTER 4

Genomics for Germplasm Improvement and Adaptation

KIOUMARS GHAMKHAR[1] and CHRISTOPHER M. RICHARDS[2]

JGI JOINT GENOME INSTITUTE A DOE OFFICE OF SCIENCE USER FACILITY

Community Science Program 2023 Proposal

Proposer's Name: Marnin D. Wolfe

Project Title: Clover Genomics for Sustainable Bioenergy Mixtures

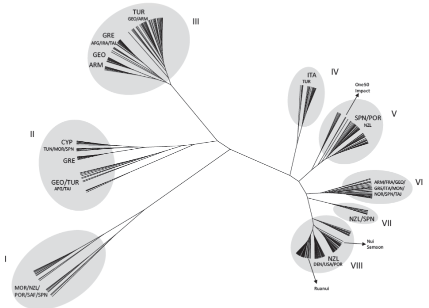
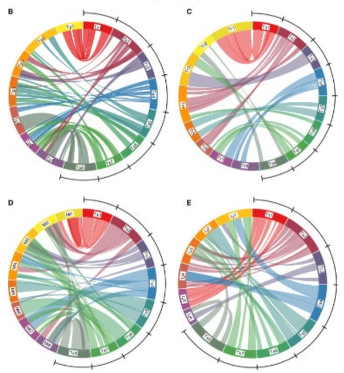


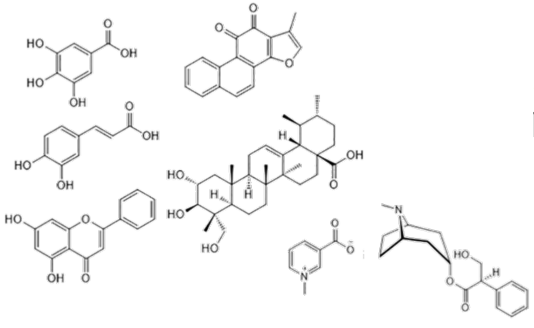
Figure 2 Dendrogram showing genetic relationships among 357 perennial ryegrass accessions and five cultivars ('One50',

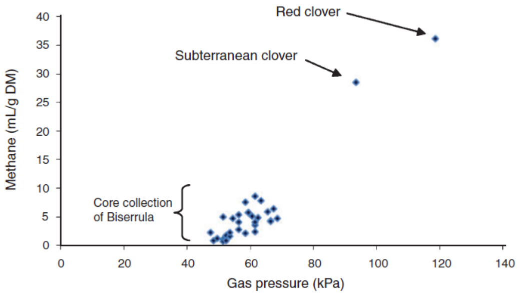


CHAPTER 7

Advances in Metabolomics Research for Germplasm Improvement and Adaptation

WARREN M. WILLIAMS and KIOUMARS GHAMKHAR



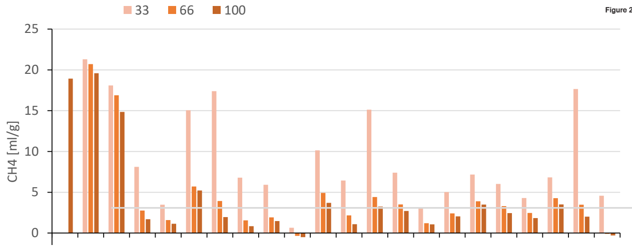


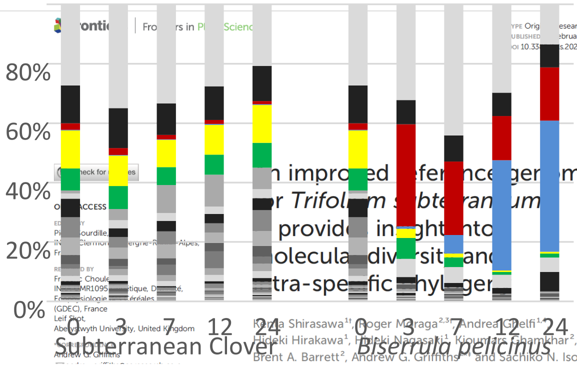
Agronomy for Sustainable Development (2018) 38:30
https://doi.org/10.1007/s13593-018-0510-x

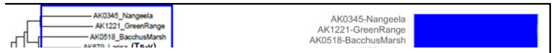
RESEARCH ARTICLE

Candidate metabolites for methane mitigation in the forage legume biserrula

Kioumars Ghamkhar[1,2,3] · Simone Rochfort[4,5] · Bidhyut Kumar Banik[2,6] · Clinton Revell[2,7]







CSIRO PUBLISHING
Crop & Pasture Science
http://dx.doi.org/10.1071/CP13073

Variability of *in vitro* ruminal fermentation and methanogenic potential in the pasture legume biserrula (*Biserrula pelecinus* L.)

Bidhyut Kumar Banik[A,B,C], Zoey Durmic[A], William Erskine[B,F], Phillip Nichols[C,E], Kioumars Ghamkhar[B,D], and Philip Vercoe[A]

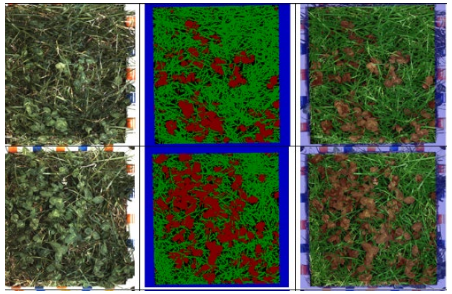
CSIRO PUBLISHING
Crop & Pasture Science, 2013, 64, 935–942
http://dx.doi.org/10.1071/CP13149

In vitro ruminal fermentation characteristics and methane production differ in selected key pasture species in Australia

B. K. Banik[A,B], Z. Durmic[B], W. Erskine[A,E], K. Ghamkhar[A,D], and C. Revell[A,C]

Omics in action – to boost MFG utilisation

- **Phenomics**
  - Insights into plant stress responses
  - Forage quality and yield
  - Combined and individual yield by species ID in forage mix

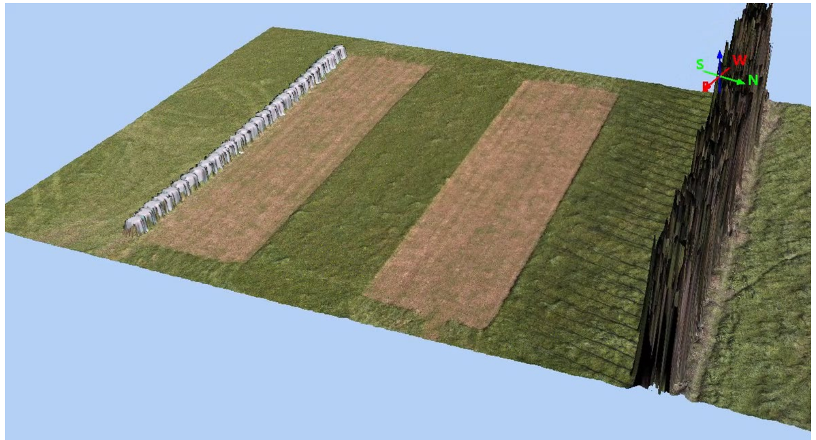


frontiers in Plant Science
ORIGINAL RESEARCH
published: 27 February 2020
doi: 10.3389/fpls.2020.00159

Check for updates

Assessment of Mixed Sward Using Context Sensitive Convolutional Neural Networks

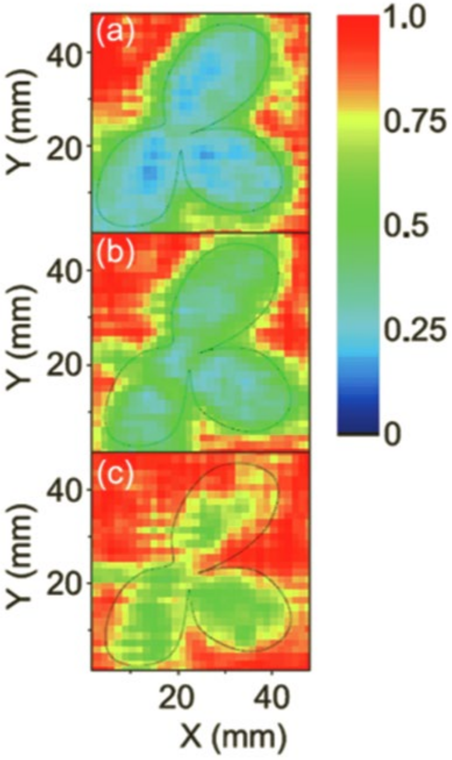
Christopher J. Bateman[1*], Jaco Fourie[1], Jeffrey Hsiao[1], Kenji Irie[2], Angus Heslop[3], Anthony Hilditch[3], Michael Hagedorn[2], Bruce Jessep[3], Steve Gebbie[3] and Kioumars Ghamkhar[4]

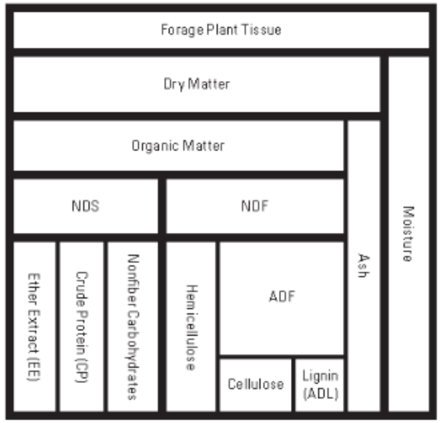


CHAPTER 8

Phenomics for the Improvement of Crop Adaptation

KIOUMARS GHAMKHAR





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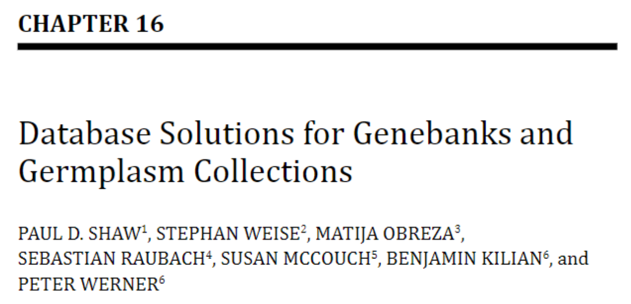
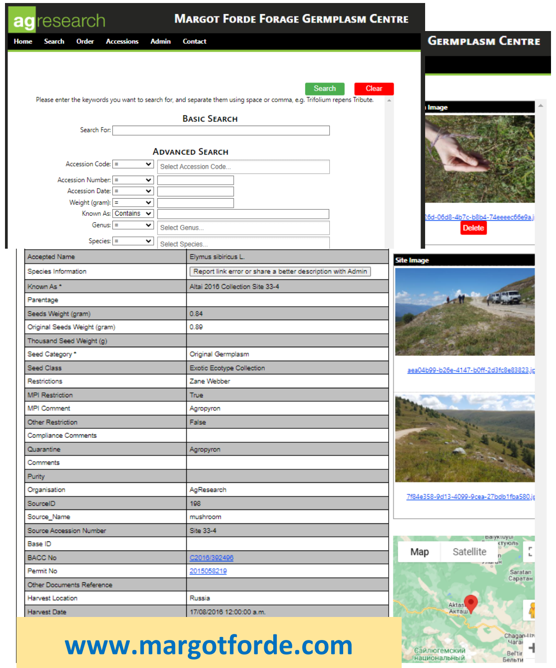
Digitisation turns genebanks to innovation hubs

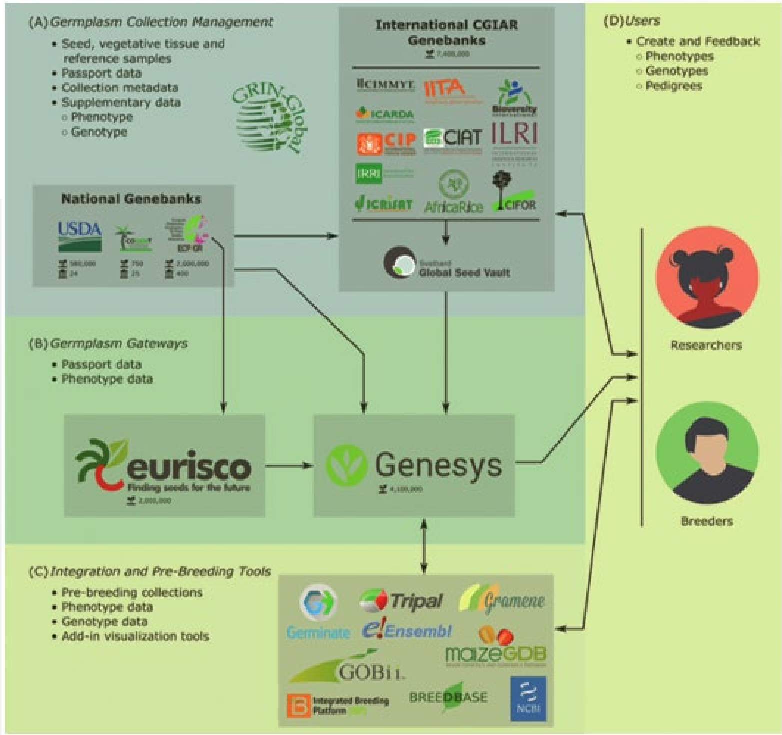
- **Digital genebanks**
  - Global initiatives integrating omics data with germplasm repositories
  - GRIN Global? Genesys?
- **AI and Machine Learning in genebank management**
  - Predictive modeling for optimal
    - seed conservation and utilization
    - germplasm selection


CHAPTER 16

Database Solutions for Genebanks and Germplasm Collections

PAUL D. SHAW[1], STEPHAN WEISE[2], MATIJA OBREZA[3], SEBASTIAN RAUBACH[4], SUSAN MCCOUCH[5], BENJAMIN KILIAN[6], and PETER WERNER[6]





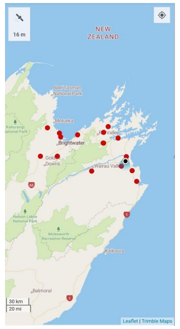
Impacts on Adaptive Agriculture

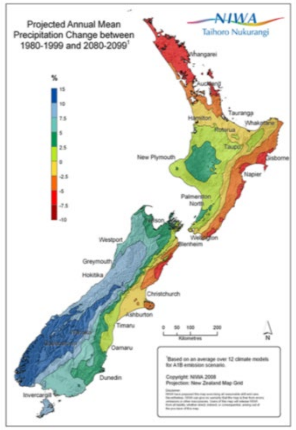
- **Climate prediction and climate match**
  - Predictive and more targeted collecting missions
    - seed conservation and utilization
    - germplasm selection
- **Climate-resilient Crops and forages**
  - Leveraging genetic resources to develop stress-tolerant varieties
  - Integrating omics with agroecological principles

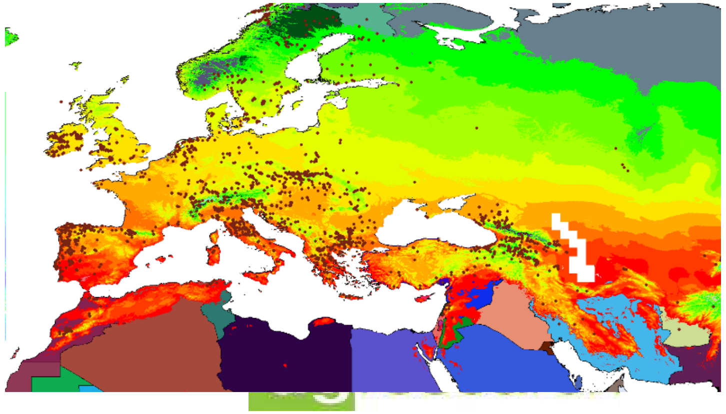
CHAPTER 5

Genomic Approaches to Using Diversity for the Adaptation of Modern Varieties of Wheat and Barley to Climate Change

KERSTIN NEUMANN[1], ALBERT W. SCHULTHESS[1], FILIPPO M. BASSI[2], SIDRAM DHANAGOND[1], ELENA KHLESTKINA[3], ANDREAS BÖRNER[1], ANDREAS GRANER[1] and BENJAMIN KILIAN[4]







CHAPTER 15

Drought, Omics, and Genetic Resources

SHIRLEY N. NICHOLS[1] and KIOUMARS GHAMKHAR[2]

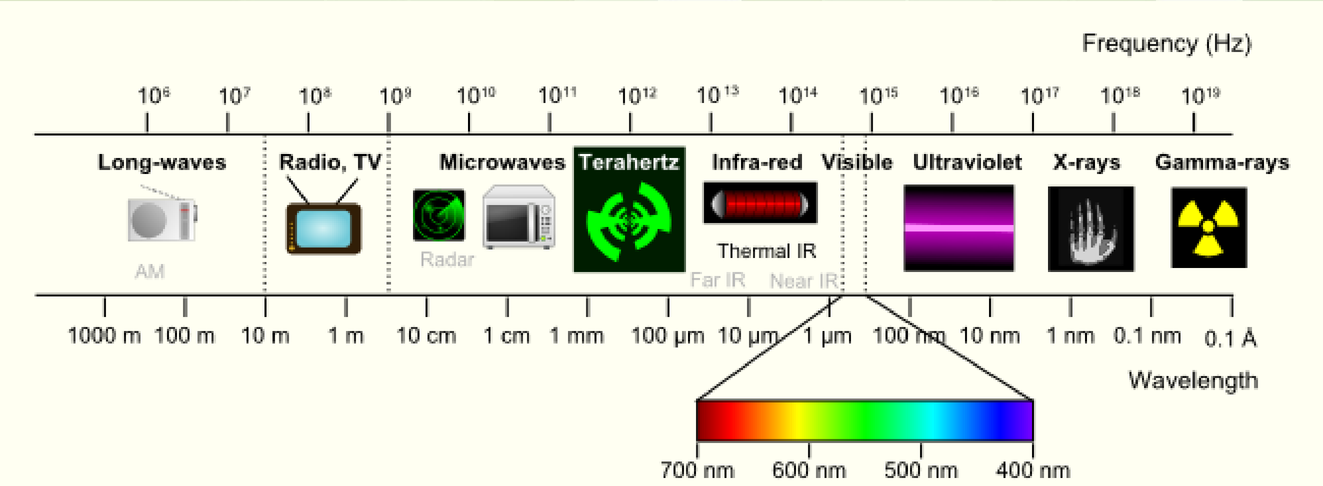
Journal of Agricultural Science (2015), 153, 1069–1083. © Cambridge University Press 2014
doi:10.1017/S0021859614000793

CROPS AND SOILS RESEARCH PAPER

Hotspots and gaps in the world collection of subterranean clover (*Trifolium subterraneum* L.)

K. GHAMKHAR[1,2,3]*, P. G. H. NICHOLS[4,5], W. ERSKINE[1], R. SNOWBALL[4], M. MURILLO[6], R. APPELS[7] AND M. H. RYAN[5]

The electromagnetic spectrum



- **Gamma rays (> 0.1nm)**
  - To create mutations
- **X-rays (0.2-2 nm)**
  - See-through
- **UV (8-110 nm)**
  - Activation of chemicals
  - sterlisiation
- **Visible light (400-700nm)**
  - RGB
  - photosynthesis
- **Near Infrared (NIR) (700 – 1100nm)**
- **Infra-red (1100-8000 nm)**
  - SWIR (hyperspec) (1100 – 2700nm)
  - Thermal (Far infra-red) (3200-8000nm)

- **Terahertz (0.08- 1.2mm)**
- **Microwaves (1.2- 120mm)**
  - Shortwaves (penetrating)
  - Radar (reflective)
- **Wi-Fi (120-150mm)**
  - potentially see through

Radiowaves (0.5-10m)

- TV
- FM
- AM

Margot Forde Genebank from AgResearch

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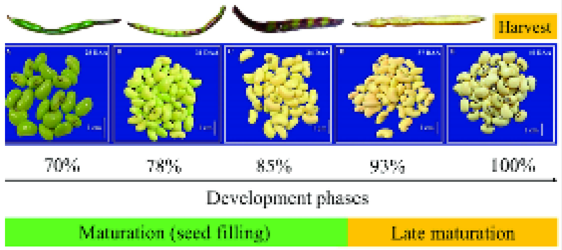
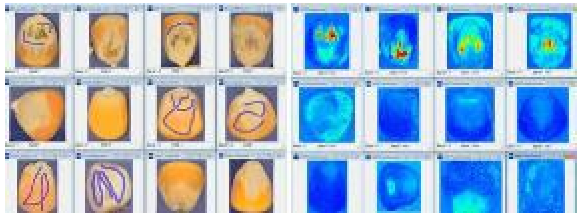
Important seed traits

- **Physical quality**
  - No damage
  - Uniformity
  - Purity (weeds, other crops)
- **Physiological quality**
  - Germination
  - Vigor
  - Viability
- **Health quality**
  - Disease free
  - Durability at storage
- **Content quality**
  - Moisture
  - Biochemical
  - Embryological
  - Microbiome
- **Genetic purity**



Aguila Moreno *et al.* **2022** *Plos ONE , 17(10)*



Sa *et al.* **2023** *Food Research International*, *169*

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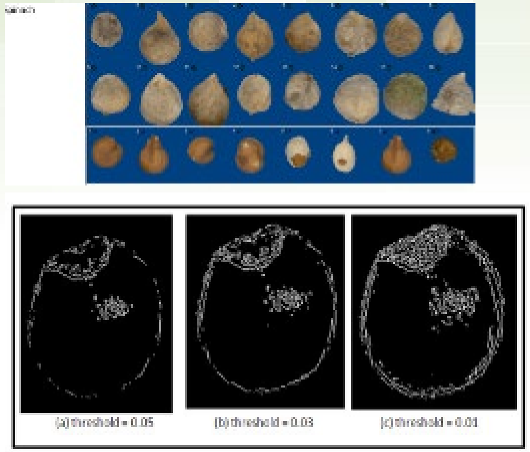
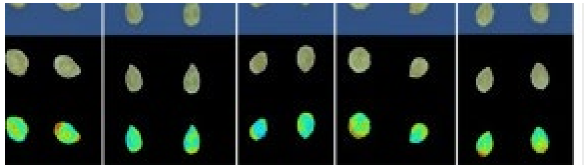
Physical quality traits

- **Physical Quality**
  - **Intact**
- **RGB imaging**



Lurstwut and Pornpanomchai **2011** *IJET* , *3(6)*, 600

- **Uniform**
  - **Size**
  - **Shape**
  - **Colour**
- **Muti-spectral imaging**



Shrestha et al **2016** *JSI* , *5*, 1

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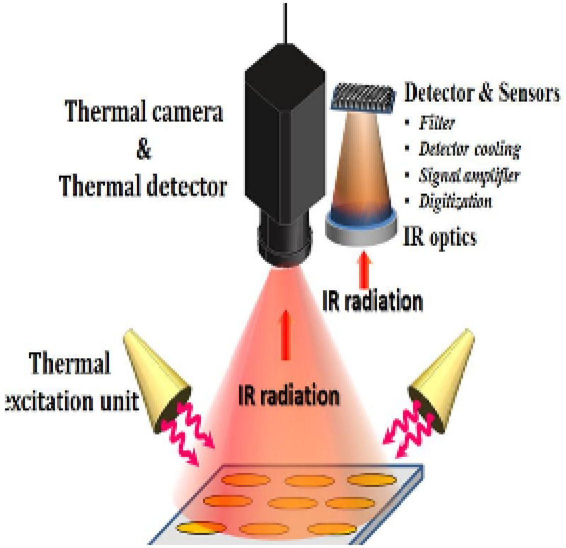
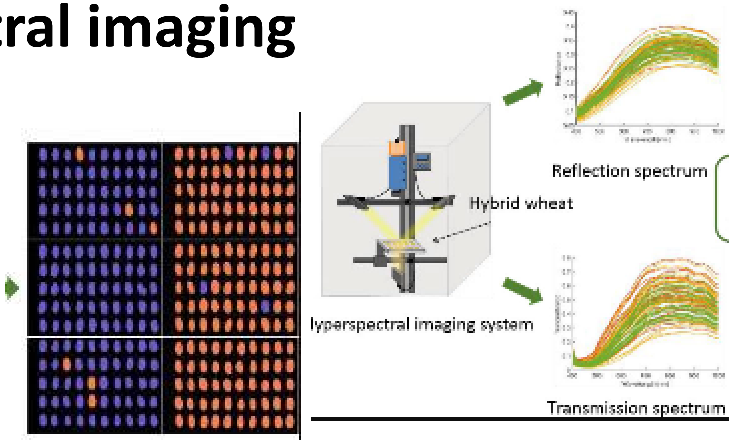
Physical quality traits

- No contamination (analytical purity)
  - Weeds
  - Other crops

ElMasry et al **2020** *FSI* , *131* 1



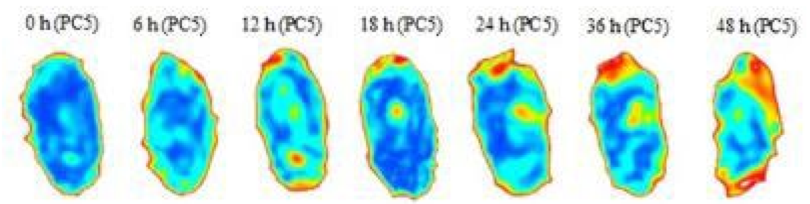
- RGB imaging (using different filters) – multispec
- Thermal imaging
- Hyperspectral imaging



Zhang et al **2022** *Frontiers* , *131* 1

Physiological quality traits

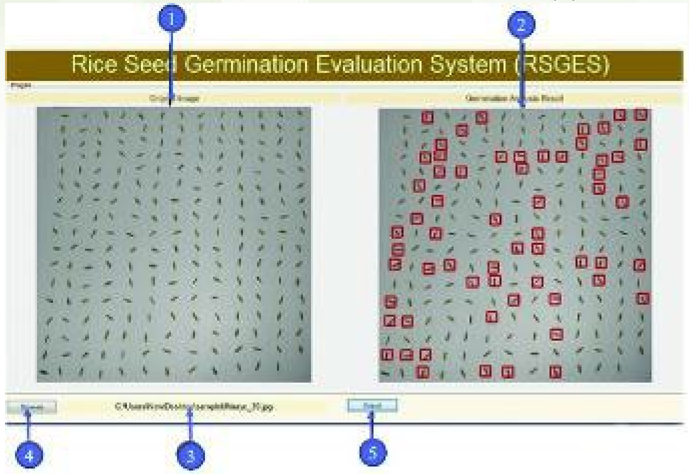
- **Physiological Quality (regeneration capacity)**
  - **Germination**



Jiang et al. **2016** *Scientific Reports , 6, 21299*

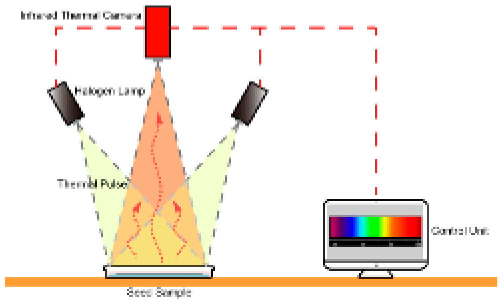
- **RGB imaging**
- **THz imaging**
- **Thermal imaging**

Lurstwut and Pornpanomchai **2017** *ANR* , *51(5)*



- **Vigor**
  - **Longevity**
  - **Stress tolerance**

- **Thermal imaging**



Liu et al **2020** *Plants* , *9 (6)*, 768

Margot Forde Genebank from AgResearch

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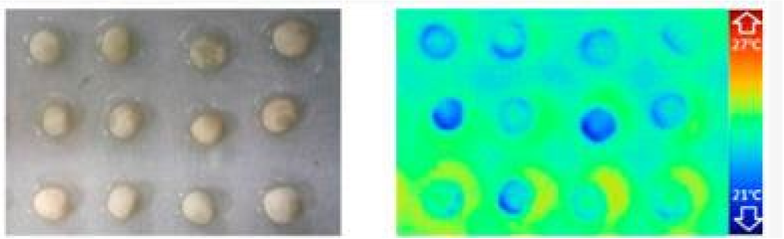
Physiological quality traits

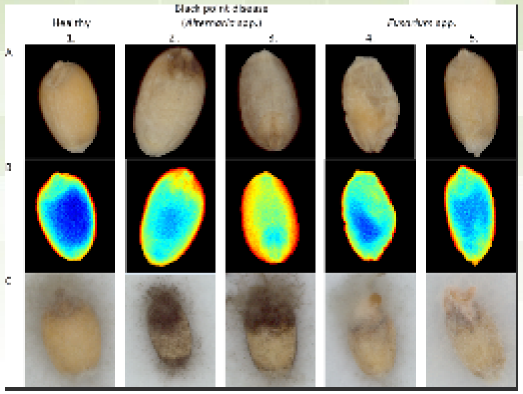
- **Physiological Quality (regeneration capacity)**
  - **Viability (reproducibility)**
  - **RGB imaging (using different filters) – multispec**
  - **Thermal imaging**

Men et al **2017** *Sensors* , 17 (4), *845*



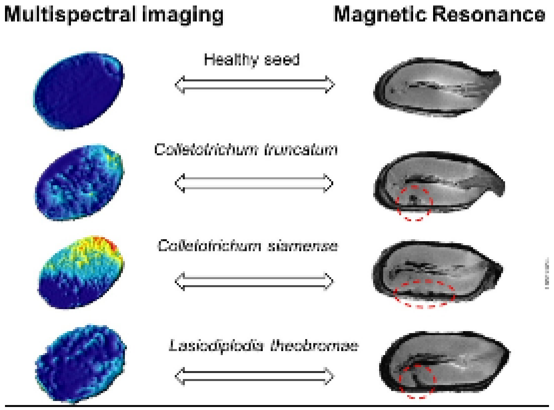
Seed health traits

Vrešak et al. **2016** *Plos One* , *11 (3)*

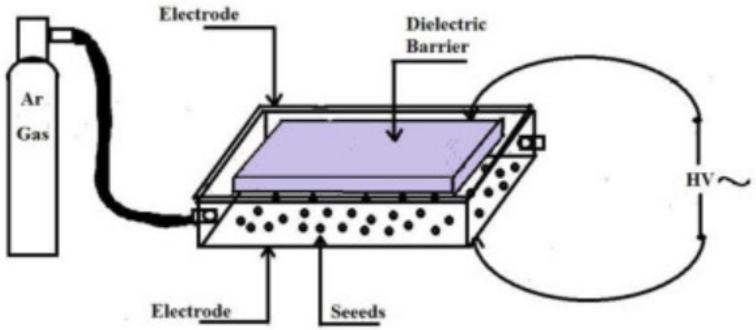


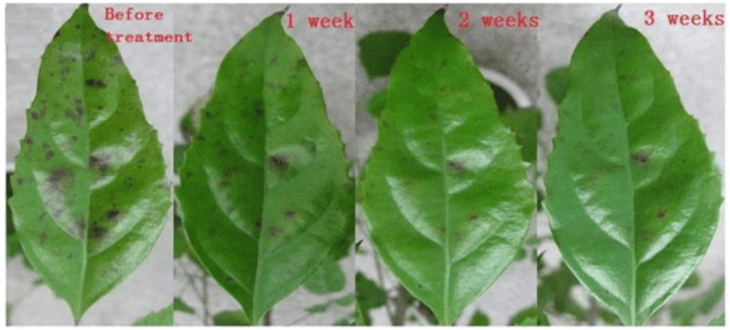
- **Health**
  - **Disease free**

- **RGB imaging**
- **Mutispectral imaging (need health indices for accuracy)**
- **Thermal imaging (needs high sensitivity)**
- **MRI (expensive and slow)**
- **Cold plasma**



da Silva et al **2021** *ICP* , *161*





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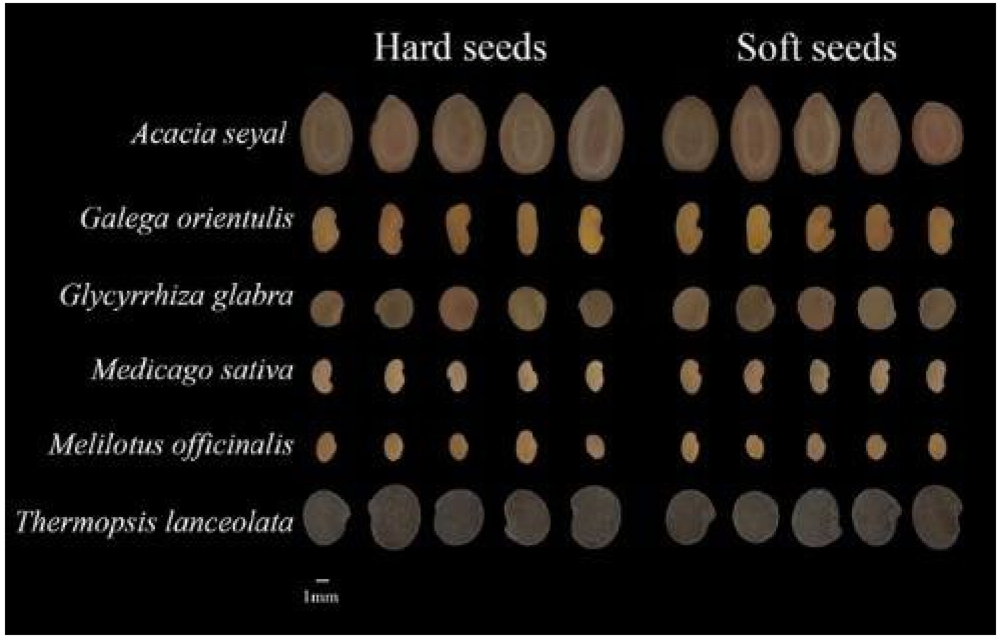
Seed health traits

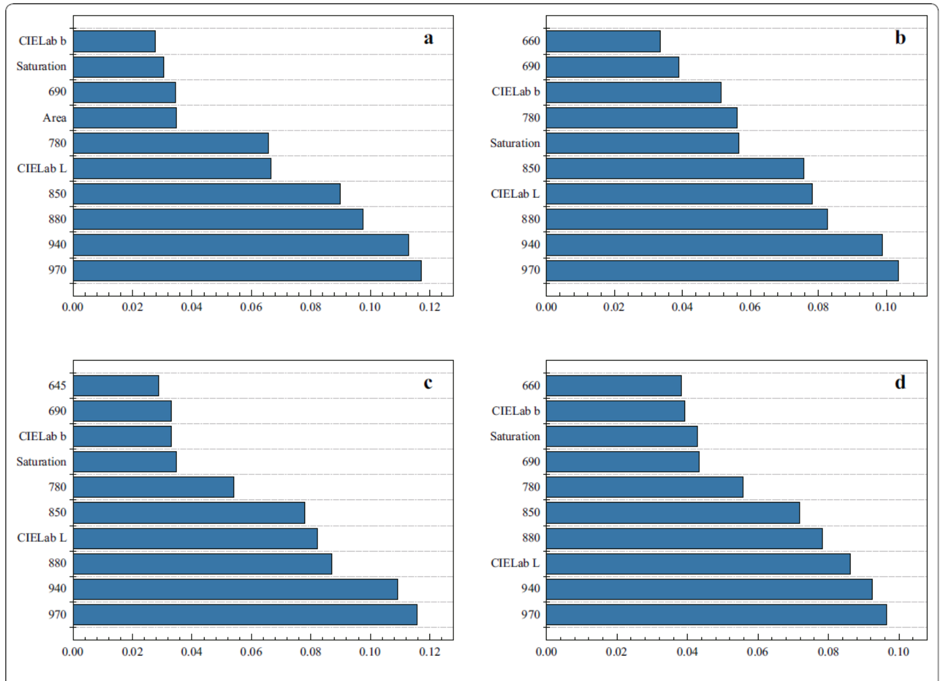
- **Health**

  - **Durability at storage**
    - **Longevity**
    - **Hardseedness (dormancy)**
    - **Other physical factors**

- **Multispectral imaging (VNIR)**

Hu et al **2020** *Plant methods* , 16 *(1)*, 1





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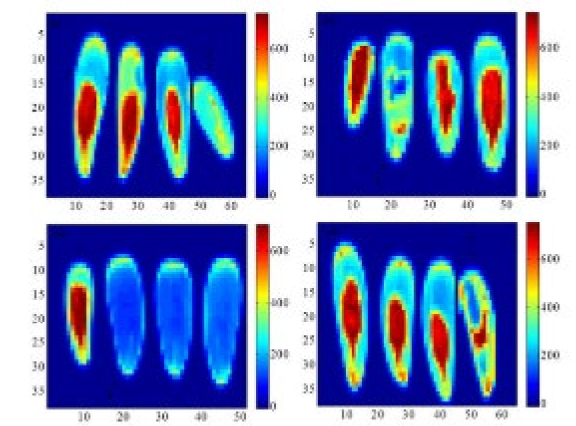
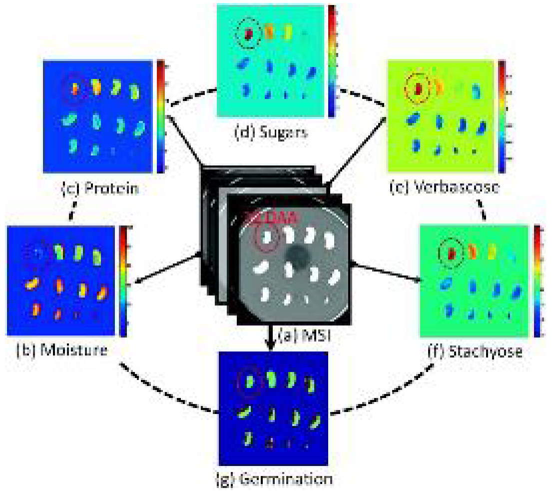
Seed quality - contents

Sun and Liu **2020** *JIMTW*, *41, 307*

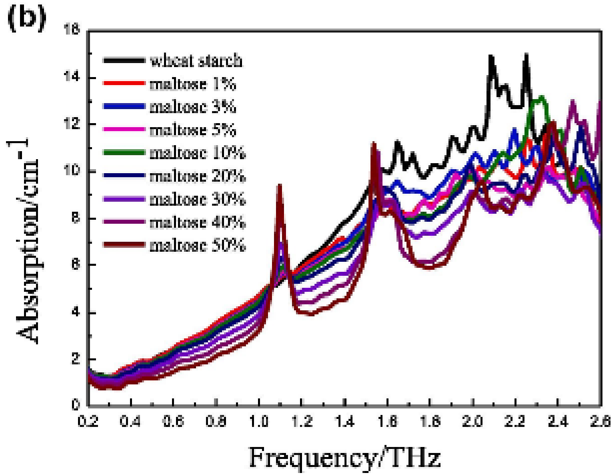


- **Moisture**
  - **Terahertz imaging**
  - **Thermal imaging (high sensitivity)**
  - **Hyper-multispectral imaging**



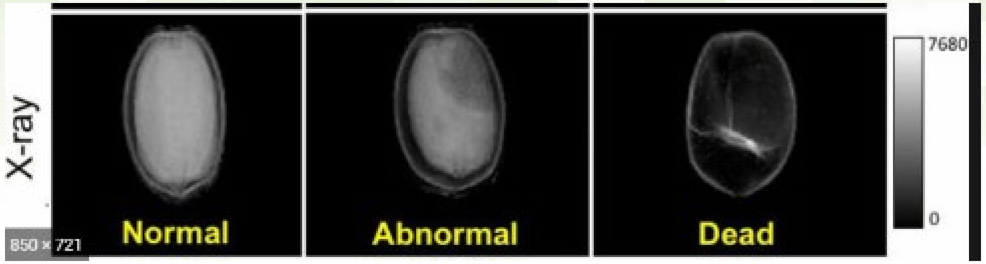
ElMasry et al. **2022** *The Crop Journal*, *10 (5), 1399*

- **Biochemical**
  - **Hyper-multispectral imaging**
  - **THZ/laser imaging**



Jiang et al **2020** *Food Chemistry* , 307, 125533

Seed quality - contents



- Embryological
  - X-ray
  - Wi-Fi
- Microbiome
  - MRI
  - Hyper/multispectral imaging

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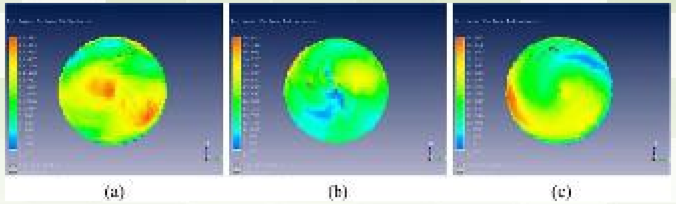
Genetic purity traits

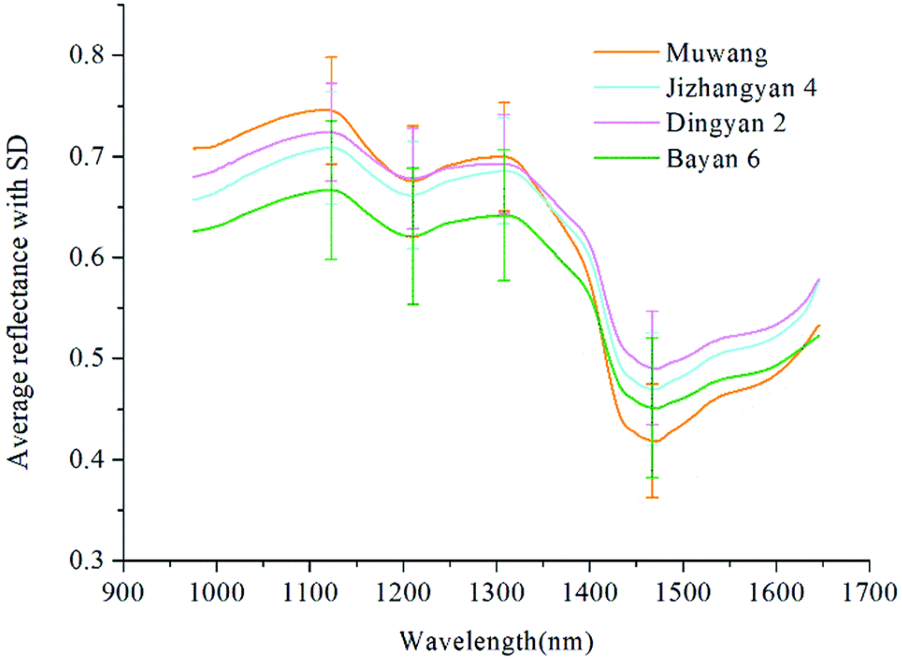
- **GM vs. non-GM**

- **THz imaging**



Liu et al. **2016** *Scientific Reports*, 6 *(1)*, 1

- **Variety discrimination**



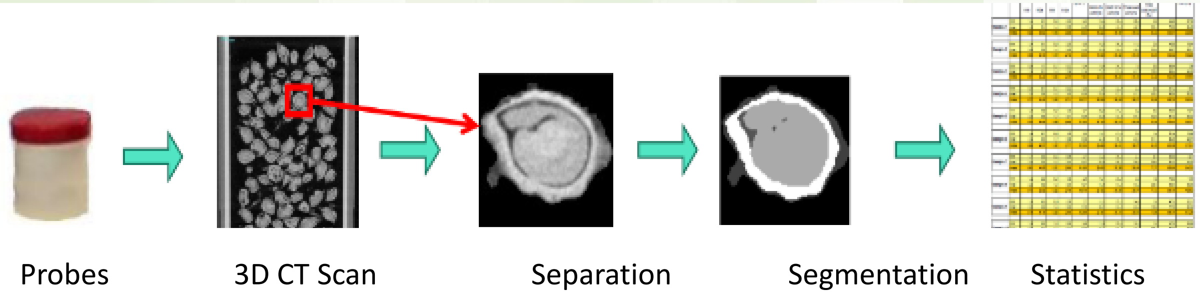
- **Hyperspectral imaging**

Wu et al. **2019** *RSC advances*, 9 *(22)*, 12635

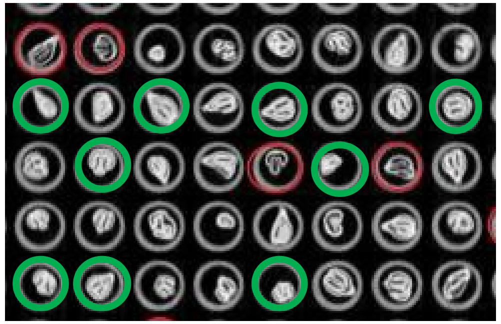
IPPN – International Plant Phenotyping Network

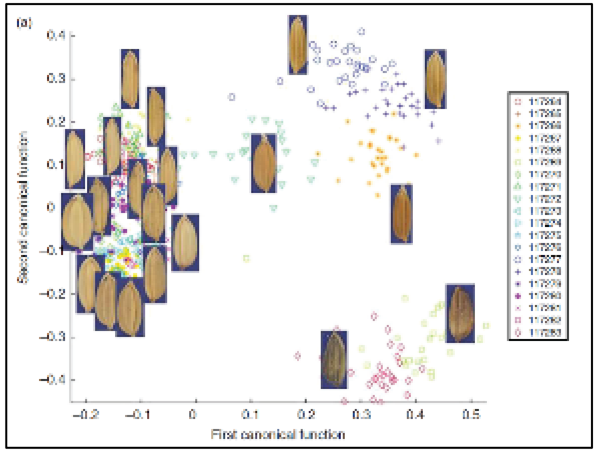
INTERNATIONAL PLANT PHENOTYPING NETWORK
IPPN

- **Examples**
  - **Seed quality testing**
  - **Physical seed assessment**



Fraunhofer
EZRT





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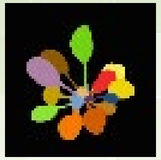
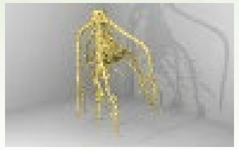
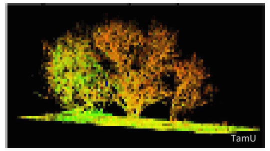
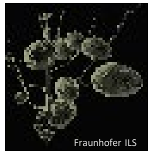
JÜLICH Forschungszentrum

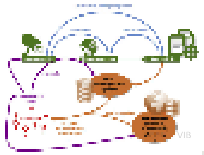
Working Groups

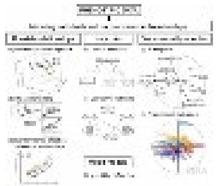
- Advanced Sensor Applications
- Affordable Plant Phenotyping
- Field Phenotyping
- Forest Phenotyping
- AI for Plant Phenotyping
- Controlled Environment Plant Phenotyping
- Root Phenotyping
- Seed and Germplasm Phenotyping







Contact
Uli Schurr or
Kioumars Ghamkhar

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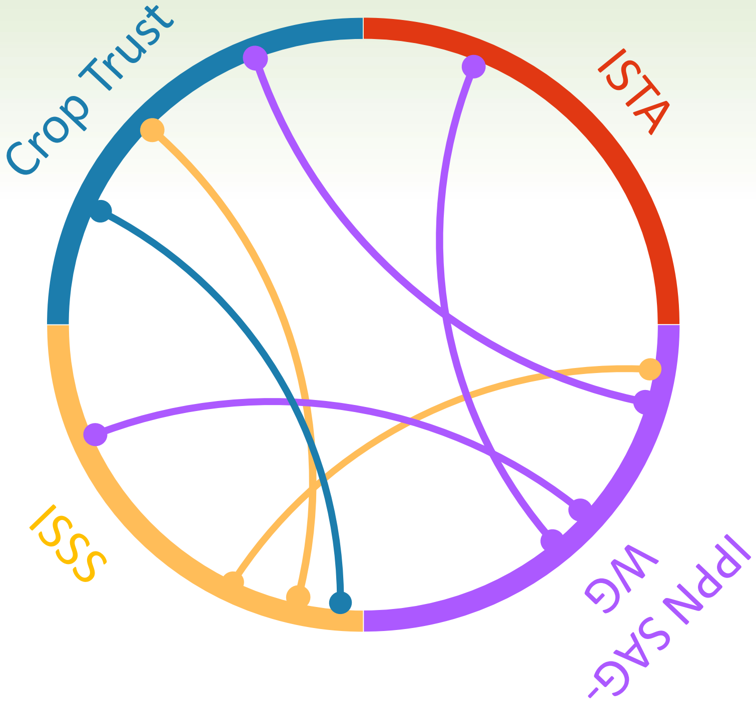
IPPN - Seed and Germplasm Phenotyping Working Group



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Challenges:

- Inexpensive high-throughput phenotyping in Genebanks
- Prioritisation of traits to phenotype
- Prioritisation of crops to phenotype
- Seed quality assessment
- Community phenotyping standards

Outcomes of WG:

- Suggest phenotyping solutions for genebanks
- Provide access to phenotyping methodologies & protocols
- Streamline use of technology and resources within the framework of quadrilateral relationships

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Taken a few steps so far

- Workshop held in 2022 (Wageningen)
- Results published
- A follow up workshop held in 2024 (Nebraska)

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IPPN Workshops & Satellite Meetings

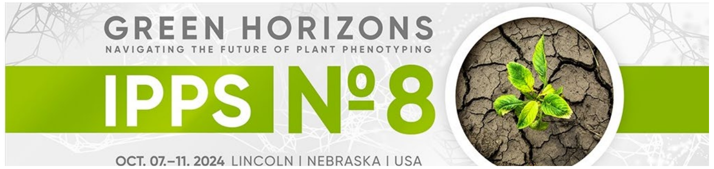
Phenomics for genebanks – future prospects (Seed and Germplasm Phenotyping Working Group – Workshop)

Summary: Gathering of genebanks and their frequent users interested in streamlining phenotyping of seeds and germplasm material using latest technologies and potentially set up global joint activities in this space

Contact: Uli Schurr, Kioumars Ghamkhar

Time: 9:00- 13:00

Location: Room: Atlas 2; Building: Atlas 104



6) **Phenomics for Genebanks: Leveraging diversity towards new phenotypes**

Keynote: TBD

Session topics include:

- Phenomic characterization of Germplasm: requirements & challenges
- Protocols & Technologies for Genebanks: Harmonization vs. Individual Approaches to Phenomics in Genebanks
- Phenomics for Faster Identification of Climate Resilient Crops
- Predictive Breeding: Utilizing Phenomics data for predictive modeling

ELSEVIER
Plant Science
Volume 282, May 2019, Pages 2-10

Review article

Review: New sensors and data-driven approaches—A path to next generation phenomics ☆

Thomas Roitsch [a h], Llorenç Cabrera-Bosquet [b], Antoine Fournier [c], Kioumars Ghamkhar [d], José Jiménez-Berni [e], Francisco Pinto [f], Eric S. Ober [g]

Show more

Received: 4 March 2024 | Revised: 30 July 2024 | Accepted: 31 July 2024
DOI: 10.1002/ppp3.10570
Plants People Planet PPP

OPINION

Realizing the potential of plant genetic resources: the use of phenomics for genebanks

Kioumars Ghamkhar [1] | Fiona R. Hay [2] | Marleen Engbers [3] | Hannes Dempewolf [3] | Ulrich Schurr [4]

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More recent outputs and activities

- A couple of more publications
- Upcoming third workshop to be held in September 2025 (Horsham, Australia)
- Results to be analysed and shared
- Many seed scientists present – unique opp.
- Invitation to join IPPN and our working group

INTERNATIONAL PLANT PHENOTYPING NETWORK
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AUSTRALASIAN SEED SCIENCE CONFERENCE 2025
22-25 September | Horsham, Vic

57%

Workshops & Tours

Date: Thursday 25th September
Time: TBC
Venue: TBC

Please indicate your interest in attending one or more workshops and tours. Once the conference program is finalised, you will be asked to re-confirm your selection based on scheduling and attendance caps.

Workshops

- [ ] **Seed collecting and data management to optimise future utilisation**
- [ ] **Seed collecting, storage and propagation for First Nations communities**
- [ ] **Seed phenomics: technology, applications, and future directions (in association with IPPN)**

CHAPTER 8

Phenomics for the Improvement of Crop Adaptation

KIOUMARS GHAMKHAR

Molecular Plant

COMMENT · Volume 16, Issue 7, P1099-1101, July 03, 2023
Open Archive

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The power of phenomics: Improving genebank value and utility

Ezhilmathi Angela Joseph Fernando [1] · Michael Selvaraj [1] · Kioumars Ghamkhar [2]

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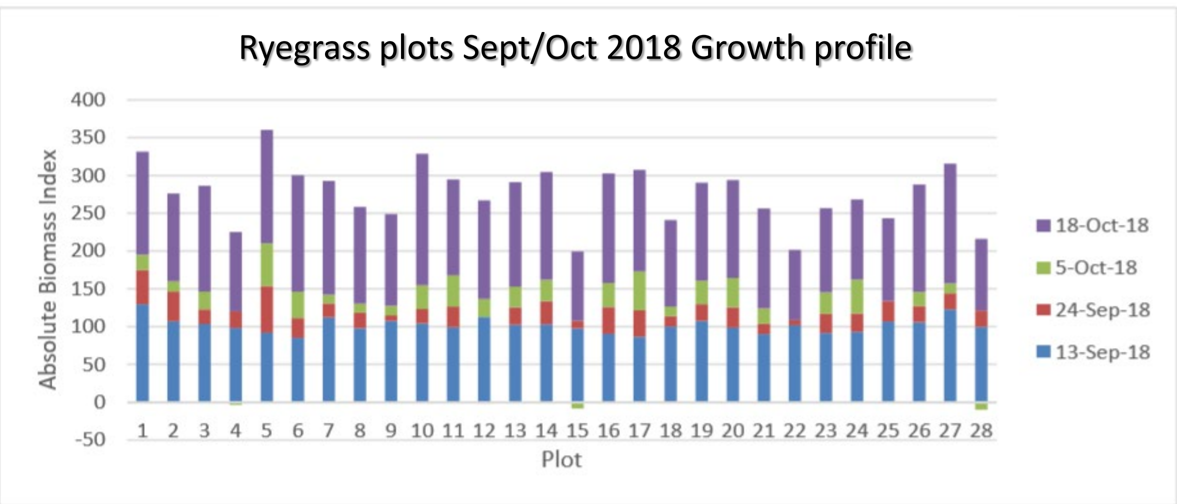
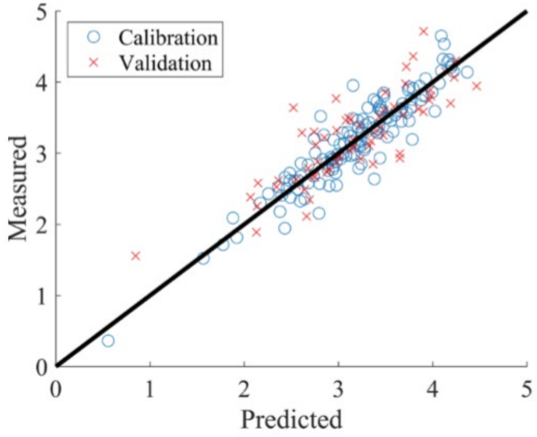
Ryegrass - High Throughput Phenotyping via *Proximal Sensing*

- AgResearch project
- **Monitoring growth in real time**
- **Forage quality**



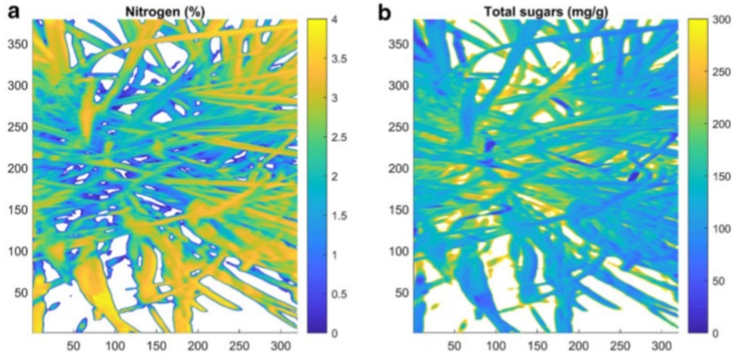


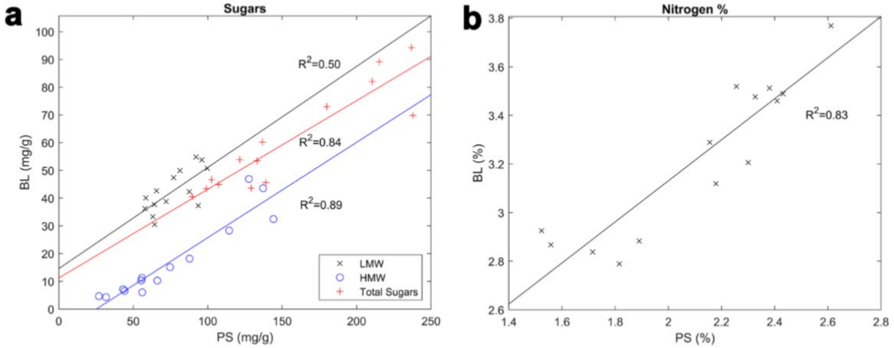
Total N (mg/g)

Shorten et al. Plant Methods (2019) 15:63
https://doi.org/10.1186/s13007-019-0448-2
Plant Methods
RESEARCH Open Access

Predicting the quality of ryegrass using hyperspectral imaging

Paul R. Shorten[1*], Shane R. Leath[1], Jana Schmidt[2] and Kioumars Ghamkhar[2]





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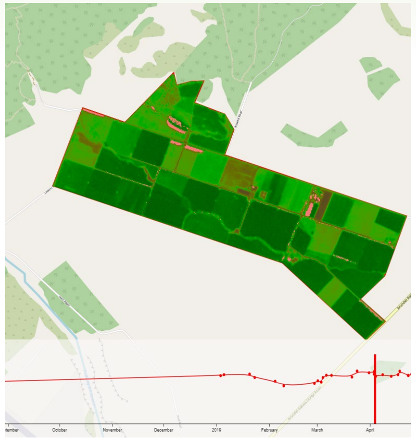
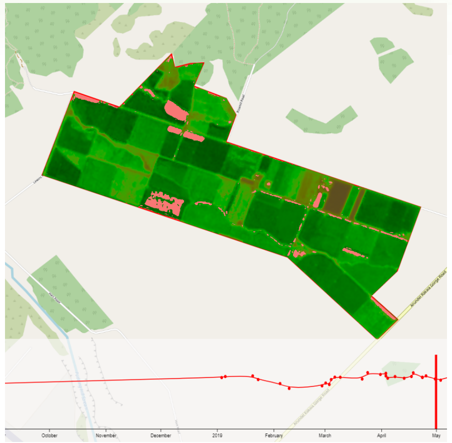
Remote sensing:
Aerial and satellite observation of growth over a short period


Callaghan Innovation BUSINESS TECHNOLOGY SUCCESS

AIRBUS

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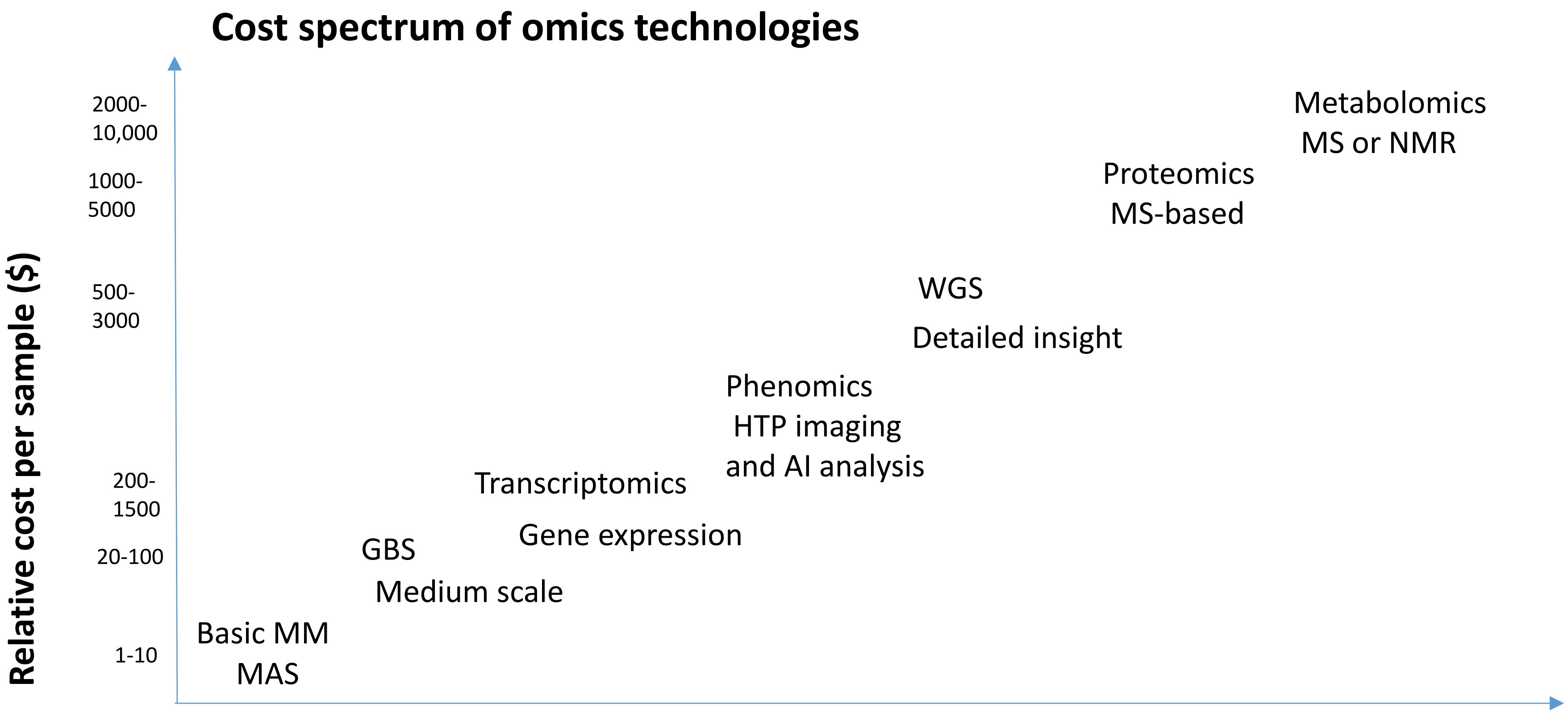
Which omics technologies should genebanks adopt?

- Omics technologies vary in cost and informativeness
- Investment and adoption depends on your priorities and budget



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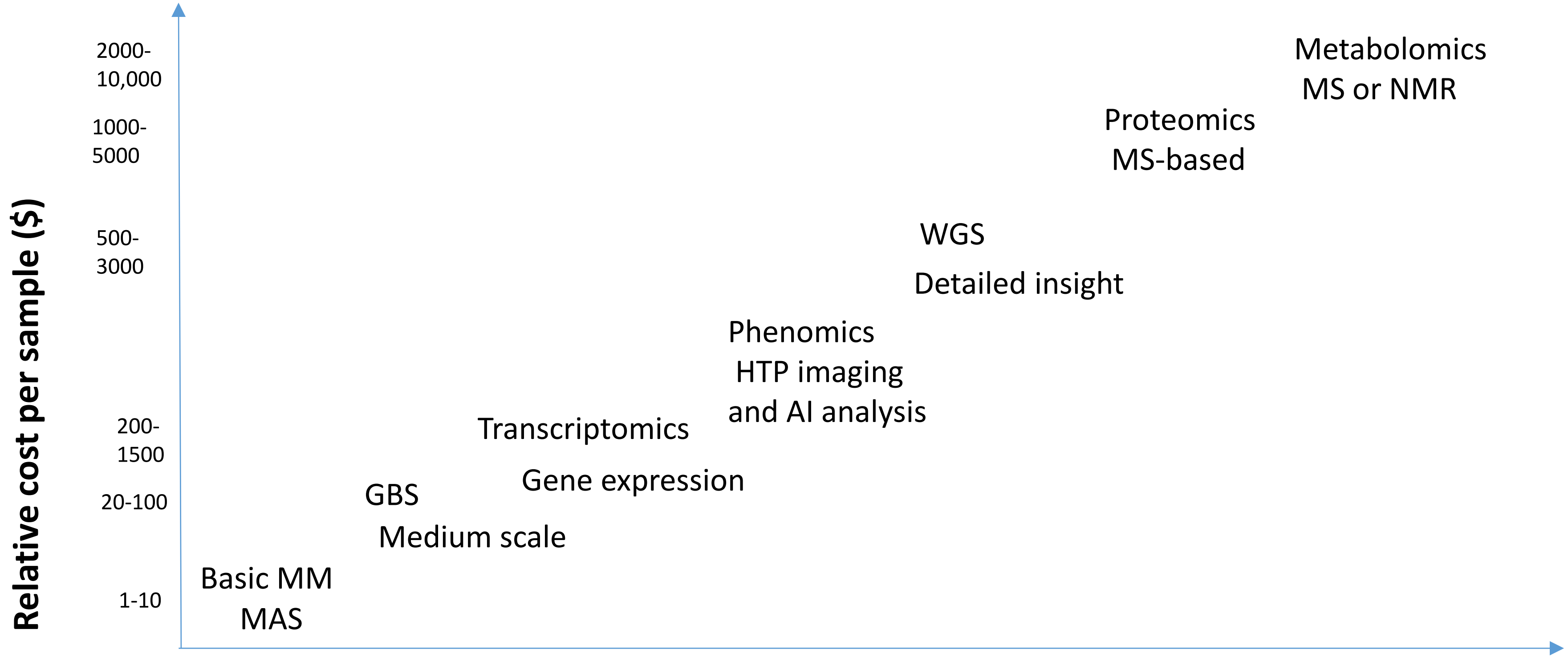
Which omics technologies should genebanks adopt?

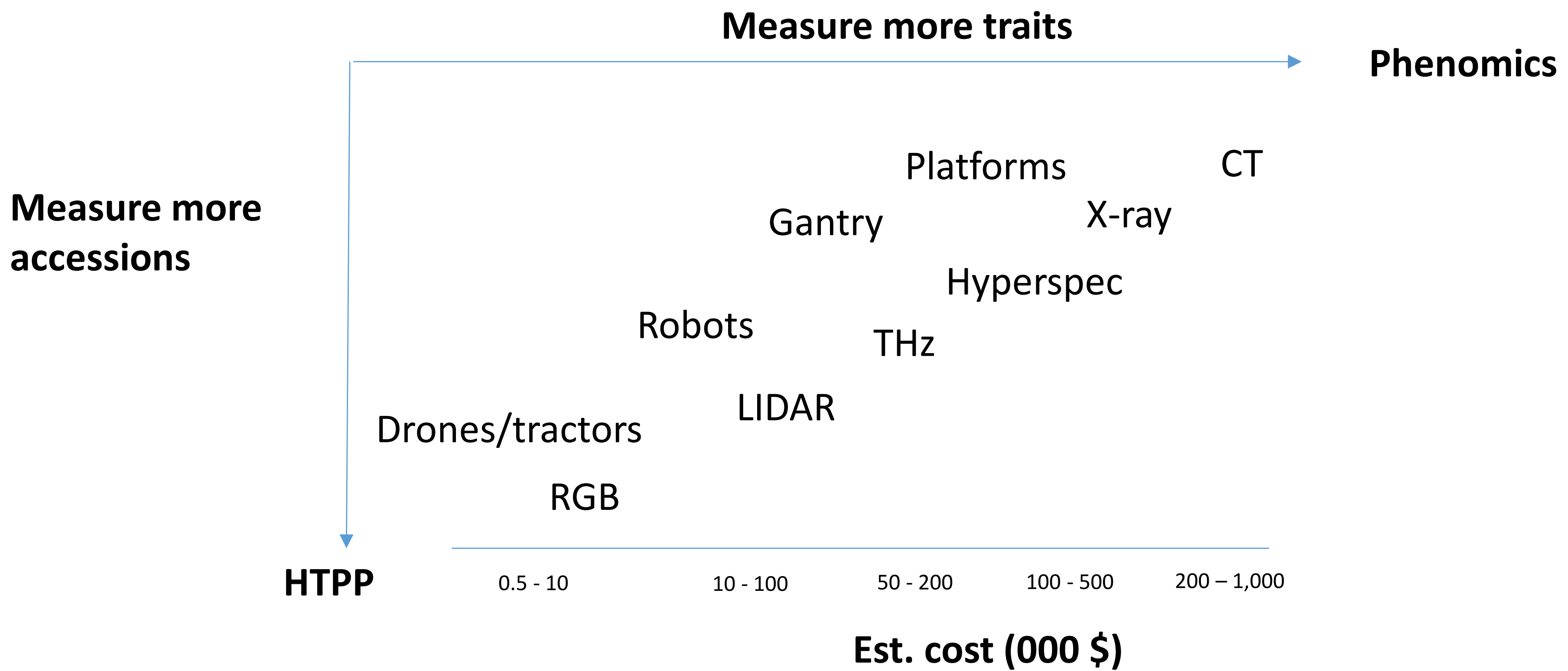
- Omics technologies vary in cost and informativeness
- Investment and adoption depends on your priorities and budget

Cost spectrum of omics technologies



Which phenomics technologies should genebanks adopt?

- Technologies are expensive
- Investment and adoption depends on which dimension you are interested in



Take home message:
Phenomics and genomics together enable genebanks

- Core collection development
- Association mapping for traits of interest – with special focus on climate adaptation
- Trait discovery – e.g. content quality and its transmissibility
- Standardisation
- Consistency and repeatability

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Acknowledgments

ВИР

JGI JOINT GENOME INSTITUTE
A DOE OFFICE OF SCIENCE USER FACILITY

USDA Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE

GRASSLANDS innovation

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agriseeds superior pastures

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Dairy Australia
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