IV CONGRESO IBEROAMERICANO
DE INGENIERÍA DE LOS ALIMENTOS

MODELOS DE NEGOCIO PARA EL DESARROLLO DE INGREDIENTES Y ALIMENTOS PLANT-BASED A TRAVÉS DEL AGREGADO DE VALOR.

PABLO JULIANO/ CSIRO.

4 de Septiembre, 2024

Organiza:

AIALU

Business models for developing plant-based ingredients and foods

Pablo Juliano, Group Leader
Food Processing and Supply Chains

Outline

- CSIRO
- Plant based research at CSIRO
- Trends in plant-based food
- Challenges
- Recent technical innovations
  - Dry vs wet fractionation
  - Precision fermentation
  - Upcycling
- Business models – how to scale up the innovation?

Who we are

Australia’s national science agency

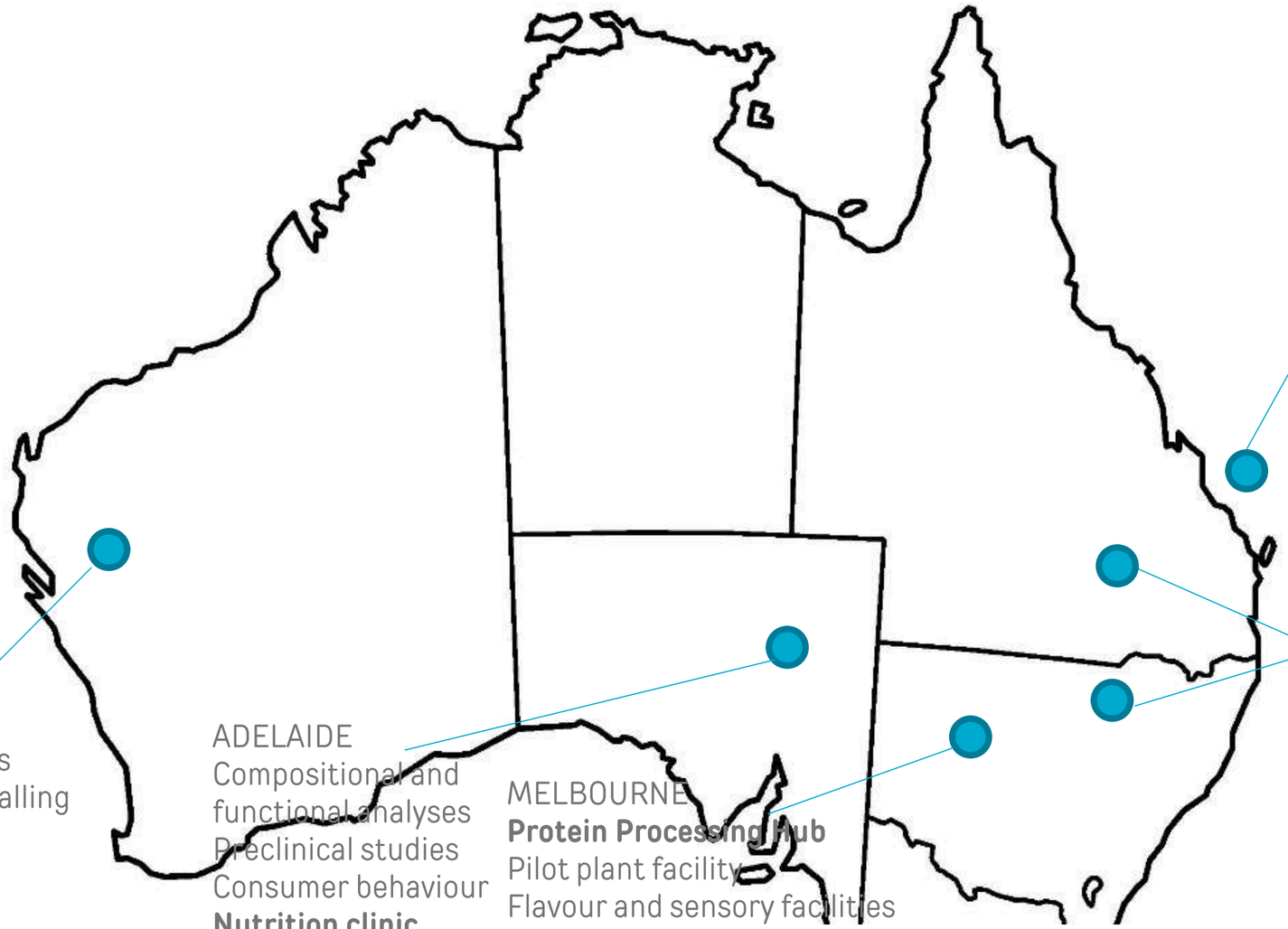
One of the world’s largest multidisciplinary science and technology organisations

5,200+ dedicated people working across 58 sites globally

State-of-the-art national research infrastructure

We delivered $7.6 billion of benefit to the nation in FY21

Plant based industrial research at CSIRO



FLOREAT
Lupin and canola
Livestock systems
LCA and credentialling

ADELAIDE
Compositional and functional analyses
Preclinical studies
Consumer behaviour
Nutrition clinic
Economic and risk analysis

MELBOURNE
Protein Processing Hub
Pilot plant facility
Flavour and sensory facilities
Food safety and stability
Food technology (incl. bioactives)
Precision fermentation
Techno economics and digital techs

BRISBANE
Bioengineering
Pilot plant – meat and meat mimetics
Proteomics
Continuous assurance and compliance for market access
LCA and Credentialling

CANBERRA and MYALL VALE
Soil science
Synthetic Biology
Crop breeding and high value traits
Disease resistance research
Research stations – farming systems
Digital information systems
Lipidomics

Extraction, Separation, Drying and Extrusion Capability

DECANTERS Physical separation of solids such as fibre from extracts

CLARIFICATION Secondary separation and clarification of fat

MEMBRANES Filtration and separation based on size to achieve protein isolate

CHROMATOGRAPHY Pilot scale system for continuous separation

DRYING Pilot scale drying platforms for spray dried and freeze dried powders

EXTRUSION Extrusion & drying of protein into TVP at pilot scale






Extraction Capability

Food grade pilot systems for process scale up and production of ingredients – concentrates & isolates

GEA Multi-purpose Model RO Plant

Ceramic Microfiltration Plant

Reactors

Decanters

Separators

Drying Systems

Chromatography

Extrusion

Membrane based filtration

Dry Fractionation Plant Equipment

DESTONER

PULSE HULLING MACHINE

DEHULLER MHSA

HAMMER MILL

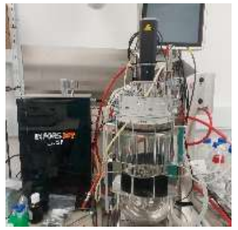
Classifier Mill

Air Classifier

Precision Fermentation Capability

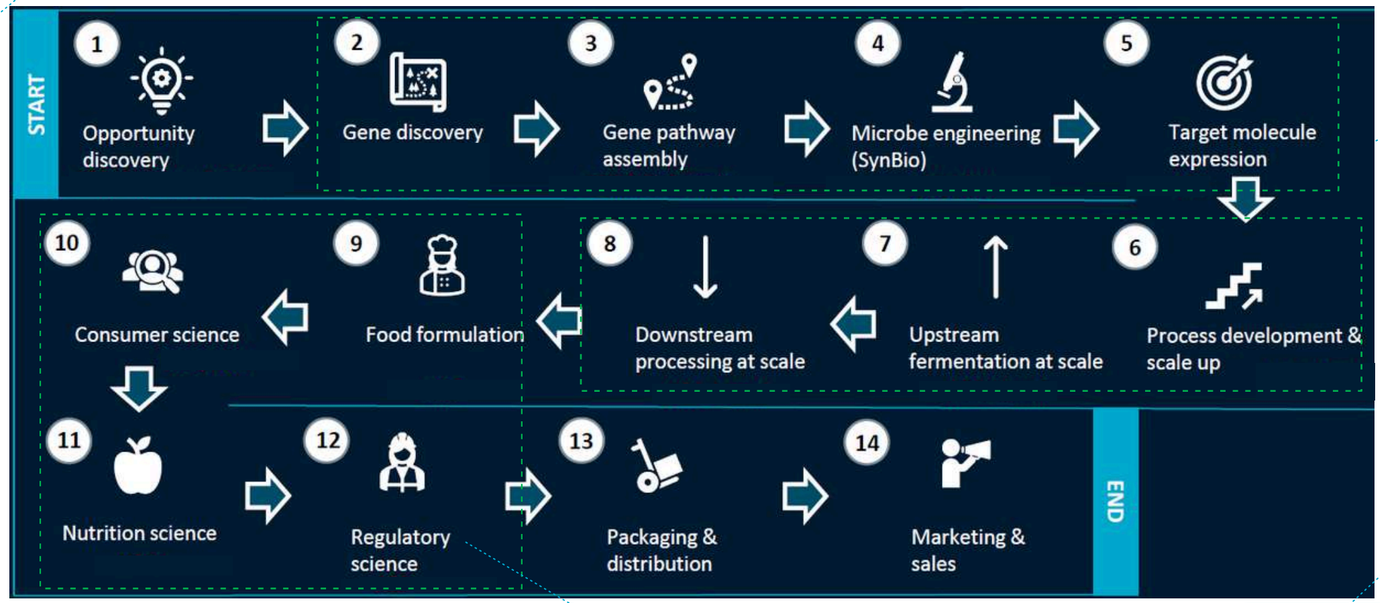
BESTeam | BD&G
Business Engagement and Solutions Team

Market Analysis to Identify Commercial Opportunities



Strain Engineering & Lab-scale Process Development

- *Strain Engineering;*
- *Feedstock optimisation;*
- *High through-put screening;*
- *Flask to 10 L fermentation process;*



Value-adding process and food formulation:

- *Extrusion process;*
- *Nutrition, digestibility, sensory expertise;*
- *Hybrid food formulation with microbial and/or plant proteins;*

Regulatory Science

- *In vitro, in vivo toxicity study;*
- *Human clinical trial in safety and health substantiation;*
- *Science advisory to regulators;*

Pilot-scale Process Development:

- *400L pilot-scale bioreactor;*
- *DSP with homogeniser, TFF, MF, UF, spray drying, freeze drying ;*

Consumer and flavour science

GC-MS
Volatile characterisation

Sensory panel
QDA, dynamics of perception

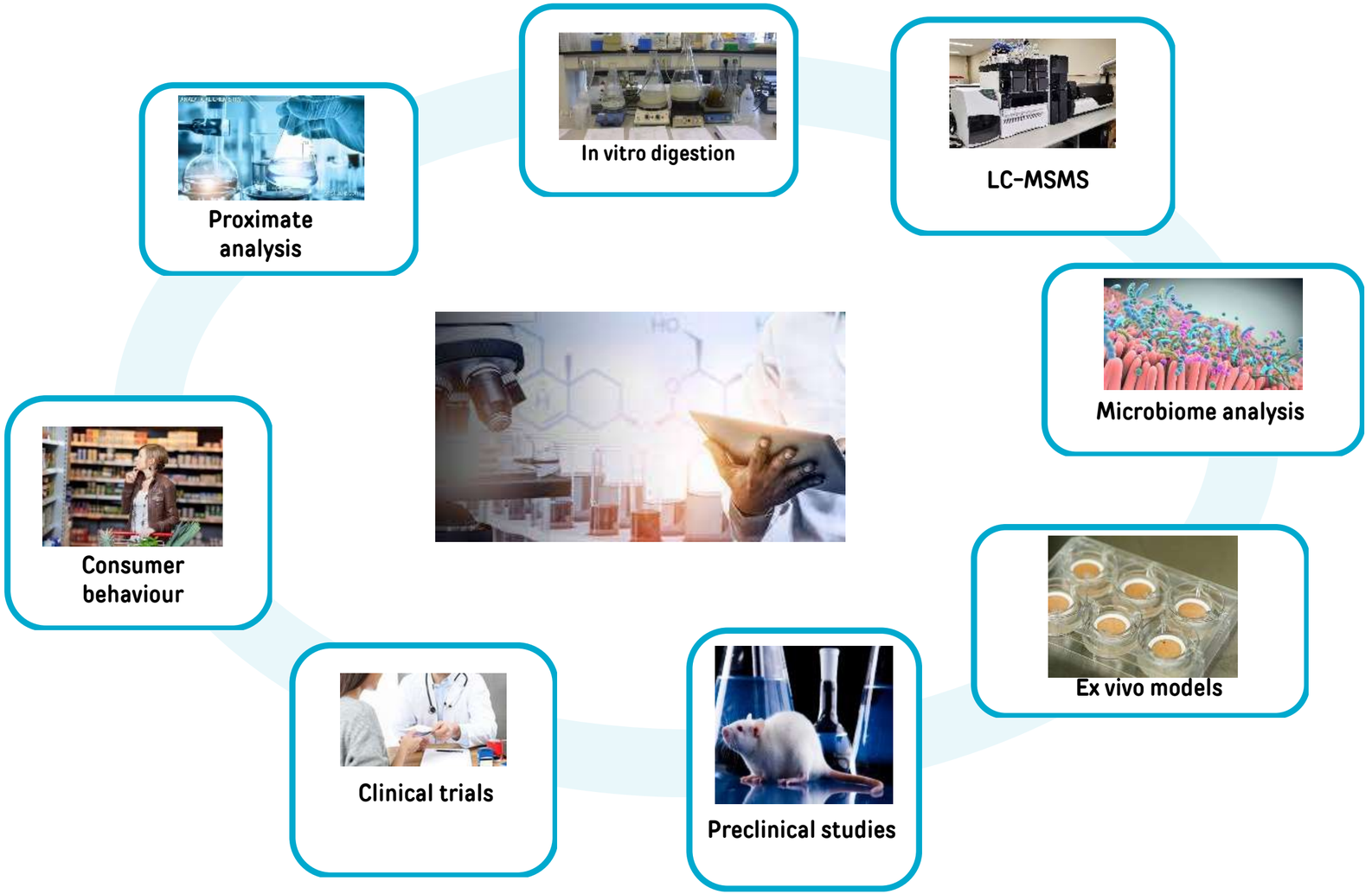
LC-MS
Non-volatile flavour, proteomics

Sussex Ingestion Pattern Monitor
Satiety

GC-olfactometry
Aroma

Adults, children, cross-cultural

Preclinical and clinical trial capability



Plant based market

- Global plant-based food market is expected to reach US$78 billion in 2025 and forecasted to double by 2030.

Category	Invested capital Q1 2024	Invested capital 2023	Total invested capital 2015-Q1 2024
Total alternative protein	**$299 M**	**$1.6 B**	**$15.8 B**
 **Plant-based**	**$58 M**	**$908 M**	**$8.4 B**
 **Fermentation**	**$228 M**	**$515 M**	**$4.3 B**
 **Cultivated**	**$12 M**	**$226 M**	**$3.1 B**

Source: GFI analysis of data from Net Zero Insights. Note: Aggregated data has not been reviewed by Net Zero Insights analysts.

Plant-based ingredient and food growth

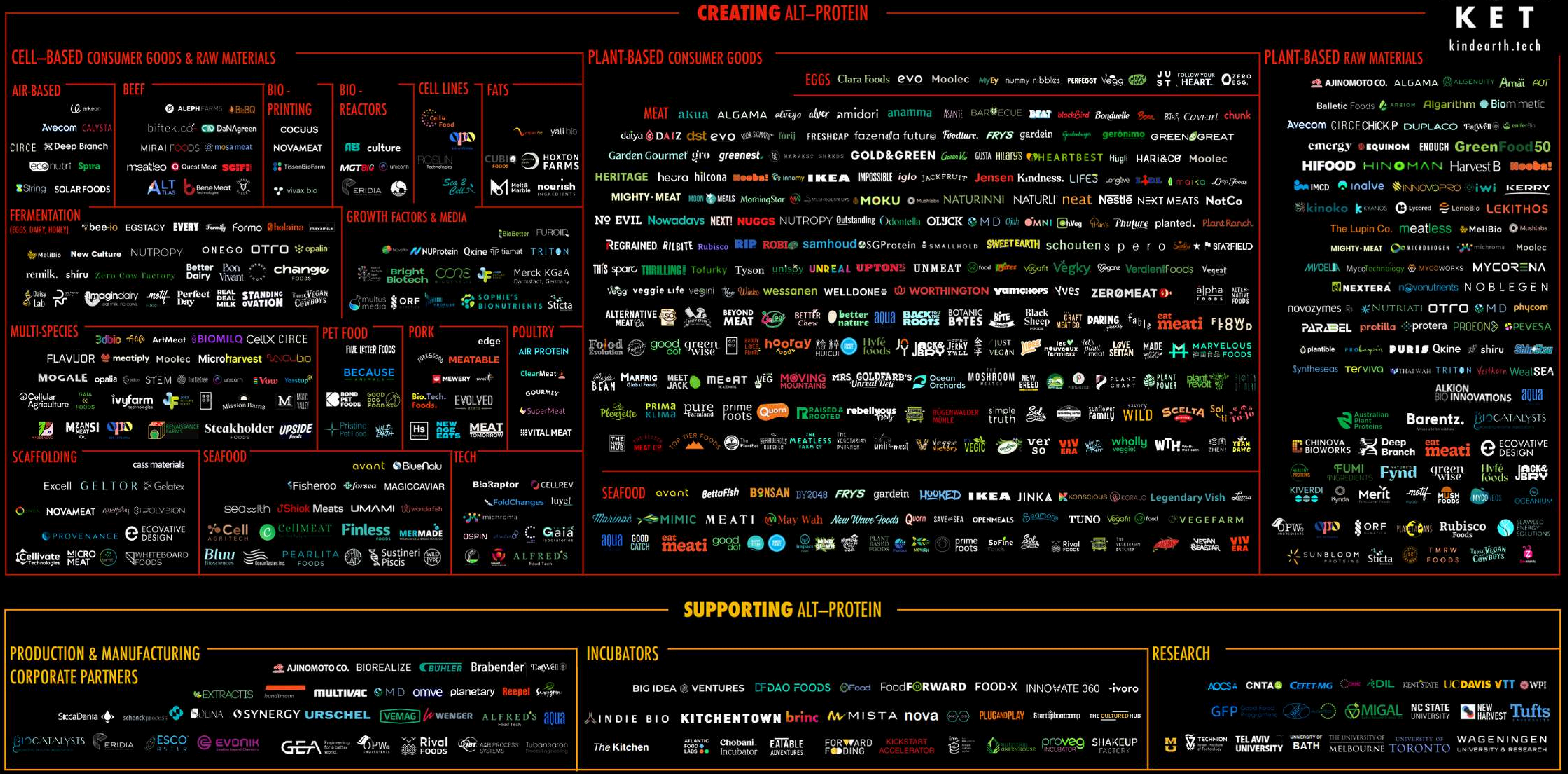
- **Vegans & Vegetarians**: Only make up 12% of plant-based meat buyers
- **Largest Market Opportunity**: 46% of consumers looking to reduce their meat consumption
- **Health:** Consumers #1 reason for buying plant-based meat (followed by animal welfare & sustainability)

Legume	Market size protein products + ingredients (USD Billion)	CAGR (%)
Soybean	7.11 (2019)	7.3 (2026)
Field pea	0.84 (2021)	13.5 (2026)
Chickpea	0.66 (2018)	11.2 (2025)
TOTAL	11.6 (2020)	8.8 (2025)

https://www.csiro.au/en/research/production/food/plant-protein-hub-north-qld

The 2023 Alternative Protein Industry Landscape

KIND EARTH TECH
KET
kindearth.tech



To appear on the map, register at newprotein.org

© 2023 Olivia Fox Cabane | newproteinmap.com

Australian demand for plant-based ingredients

- Several plant-based start-ups launched
- 5-fold increase consumption in Australian supermarkets
- 42% of Australian are flexitarians, meat reducers, vegans

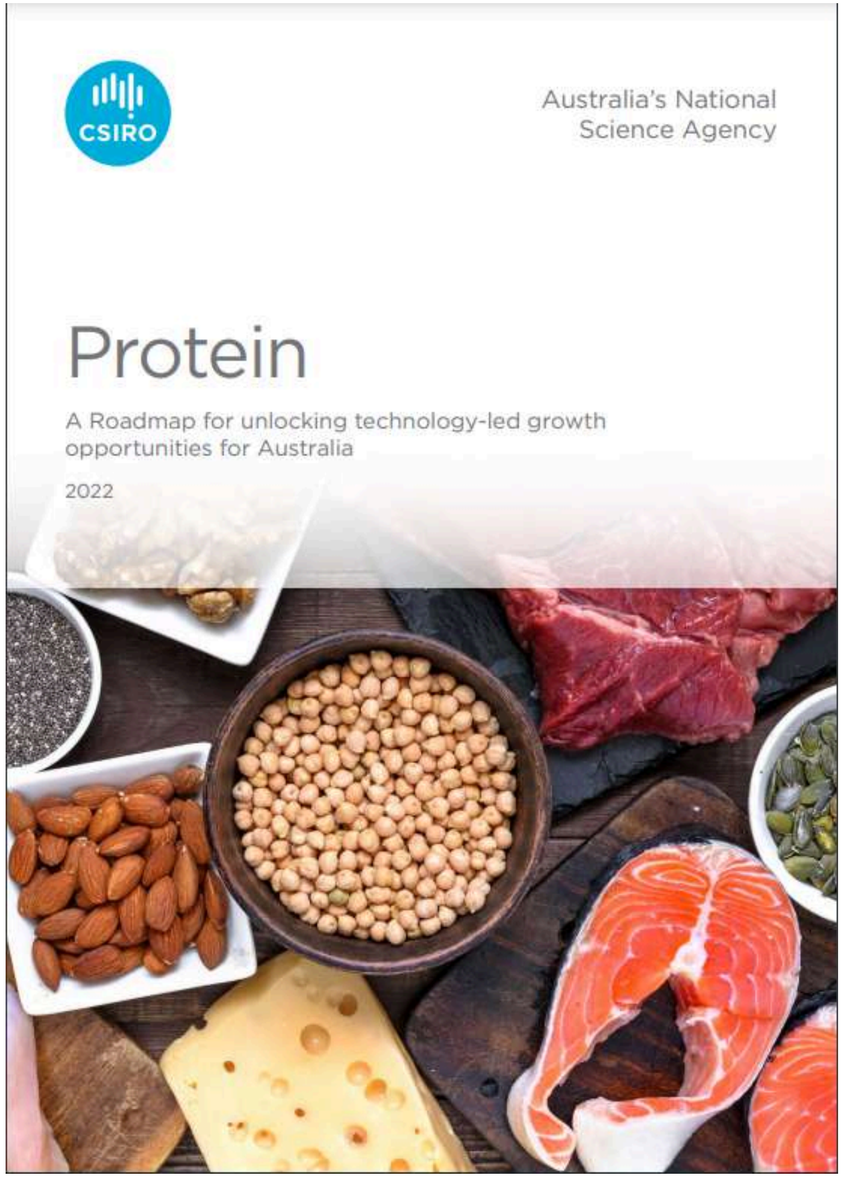
Australia's plant based meat
AUD 133M (2020) WRITE TO US AUD 3B 2030

169,000 tonne plant-based product potential by 2030

https://www.csiro.au/en/research/production/food/plant-protein-hub-north-qld

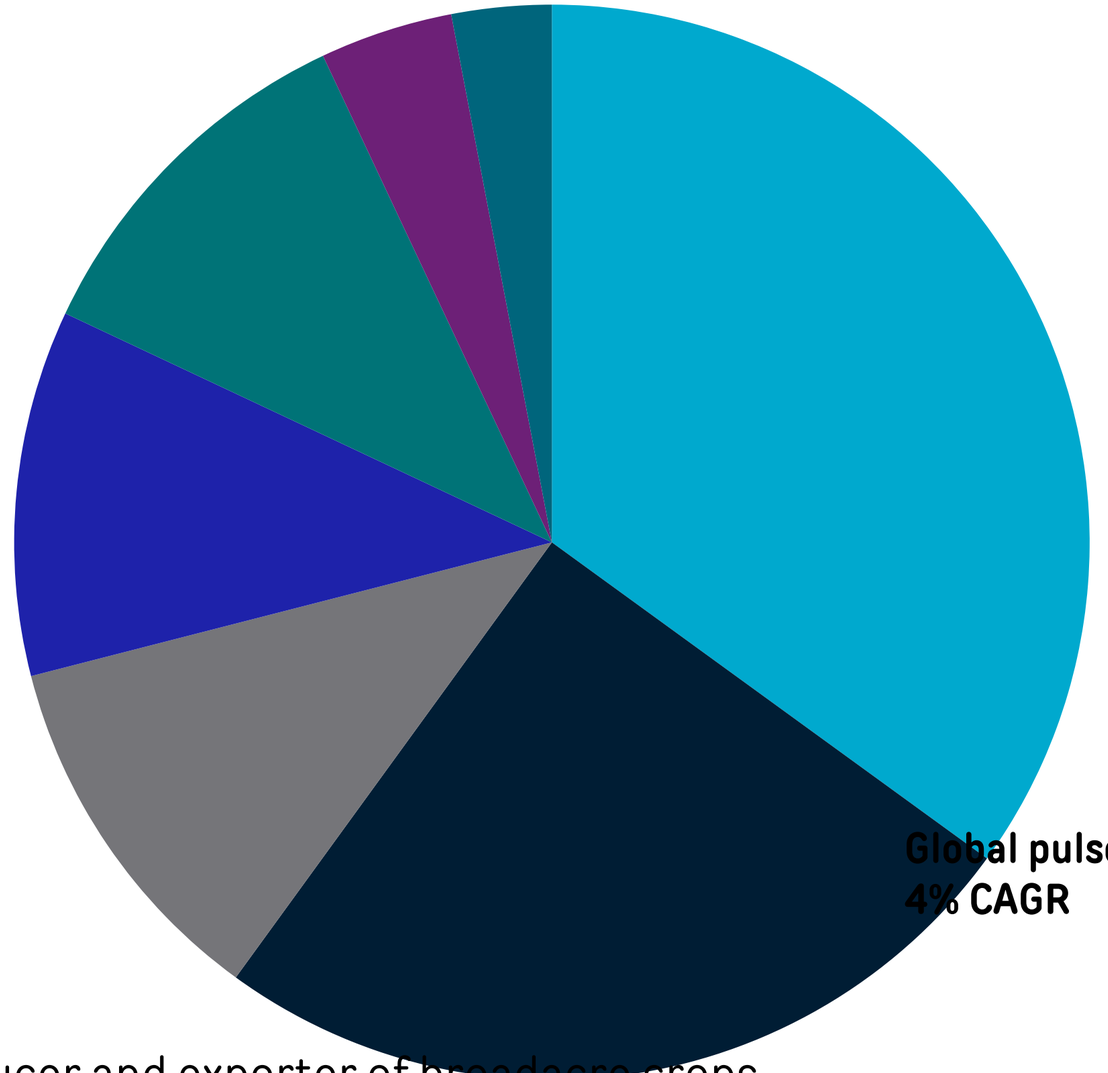
Grain based ingredients and food

Australia's national protein roadmap



https://www.csiro.au/en/news/news-releases/2022/roadmap-to-put-uniquely-australian-protein-on-the-global-menu

Australian legumes



Global pulse market
4% CAGR

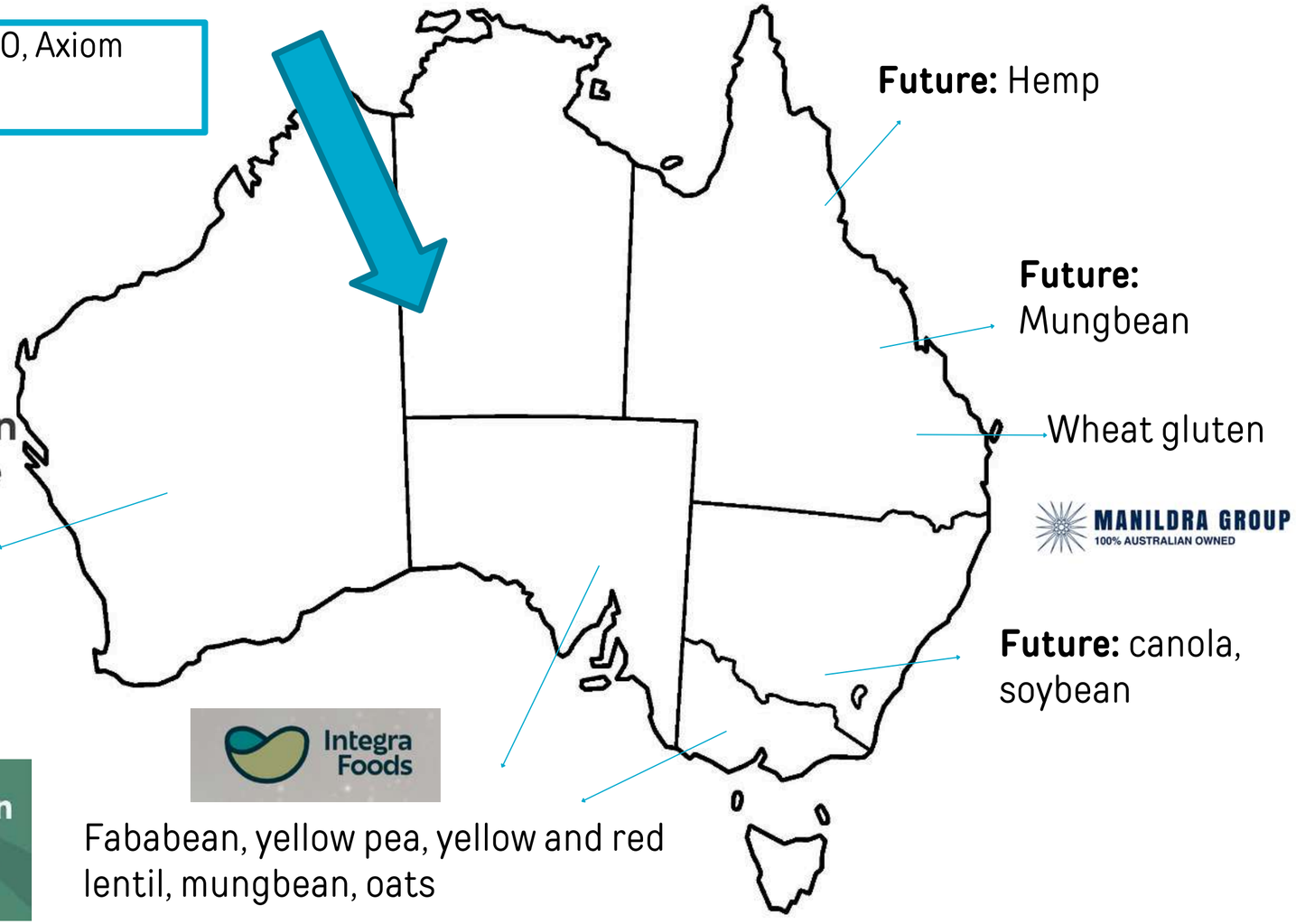
Australia is a key producer and exporter of broadacre crops

Plant-based protein ingredients in Australia

China, Europe, USA

Soybean

E.g. Corbion, ADM, AMCO, Axiom Foods, Cargill, Dupont



Future: Hemp

Future: Mungbean

Wheat gluten

MANILDRA GROUP
100% AUSTRALIAN OWNED

Future: canola, soybean

Fababean, yellow pea, yellow and red lentil, mungbean, oats

Future: hemp

Lupin

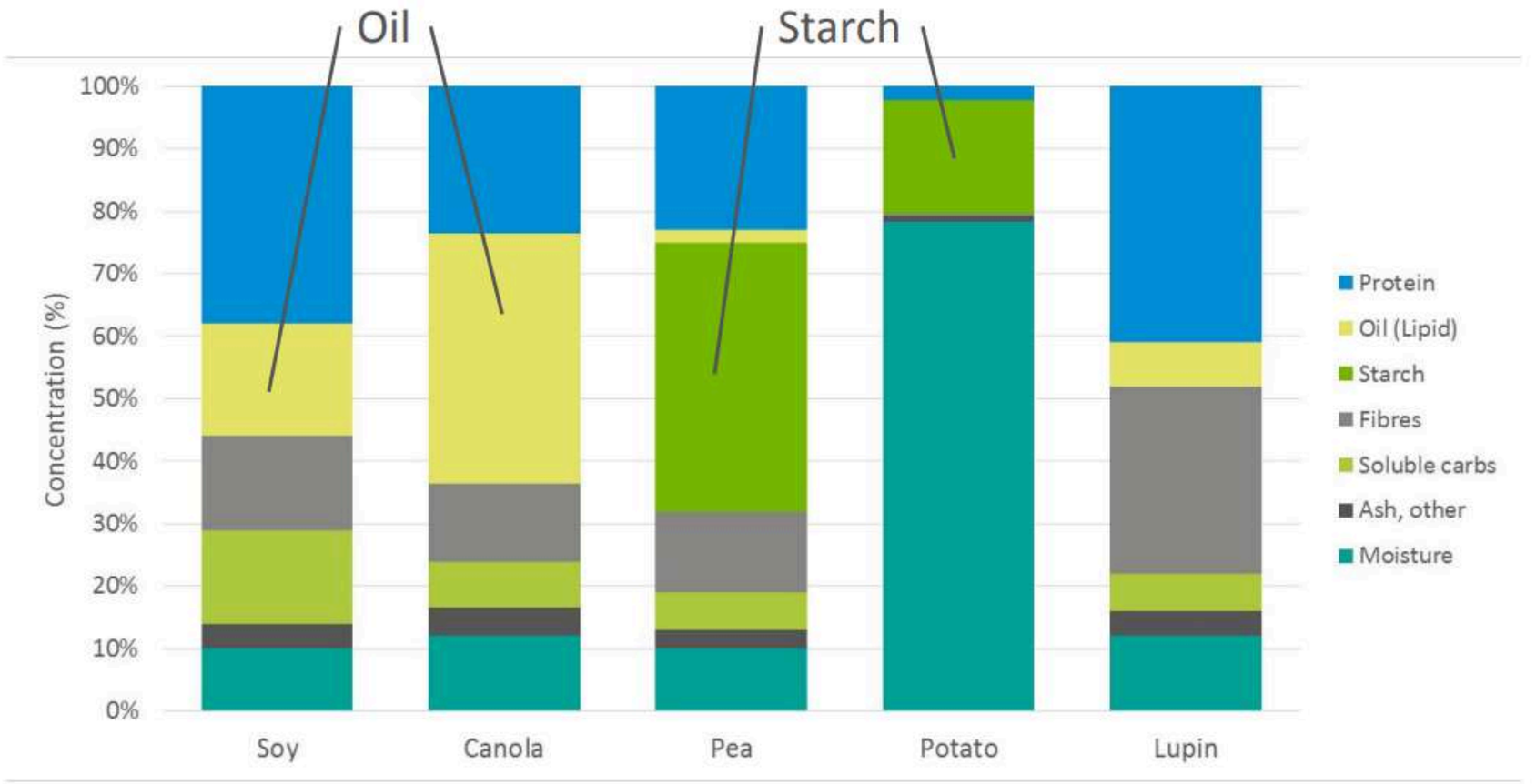
Wide Open Agriculture

Unigrain

Integra Foods

Australian Plant Proteins
www.approteins.com.au

Protein sources



Oil and starch are important for the economic feasibility

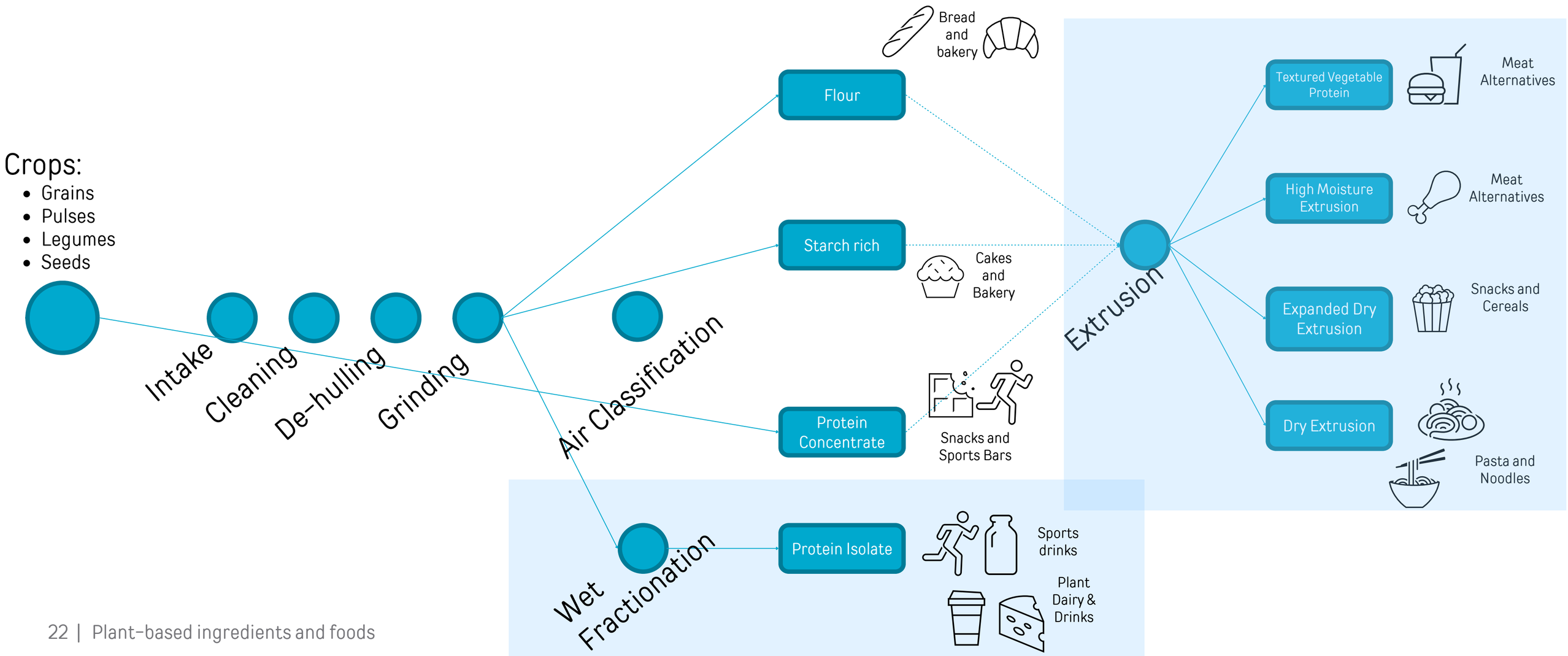
Source: NiZO, 2023

Protein content in commercially available ingredients

	Protein variations	Protein USD/kg (bulk estimates)
Flour	11-39%	1 – 6
Concentrate	>50-85%	3 – 14
Isolate	85-90%	4 – 15

https://www.csiro.au/en/research/production/food/plant-protein-hub-north-qld

Wet and dry fractionation



Challenges in plant-based products

1. Texture and taste
2. Developing cost-effective products
3. Clean label: long list of ingredients
4. Nutritional value and nutrient bioavailability




Source: Maaike Nieuwland, Wageningen University & Research

Ingredient requirements

Local

Need
Locally-produced sources for nutrition and texture in plant-based foods

Solution
Pulses are already widely cultivated but have not been bred for protein

Functional

Need
Functional proteins to replace egg and dairy proteins

Solution
Agricultural and industrial **side streams** can contain high functional specialty proteins

Low-cost

Need
Currently no new protein source can compete with soy on cost

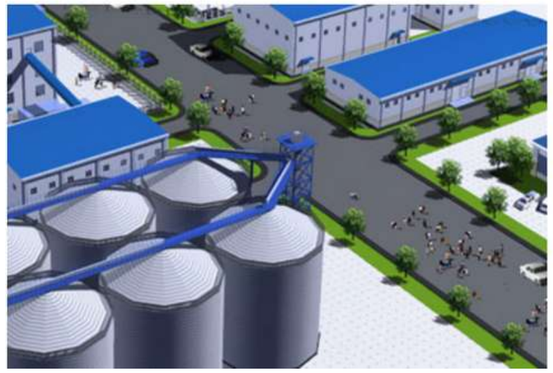
Solution
Fermentative biomass can be produced inexpensively from side streams / organic residues

Source: Maaike Nieuwland, Wageningen University & Research

Maximising regional benefits from plant protein

Protein processing hub

Scoping study
Full Harvest Solutions, Townsville



- 19,200 tonnes of seed annually
- 100% yield
- Capital infrastructure $6-22M
- Net Present Value – $15-$710M
- Payback 1-5 years
- **30-50 specialised jobs**

20-30% protein

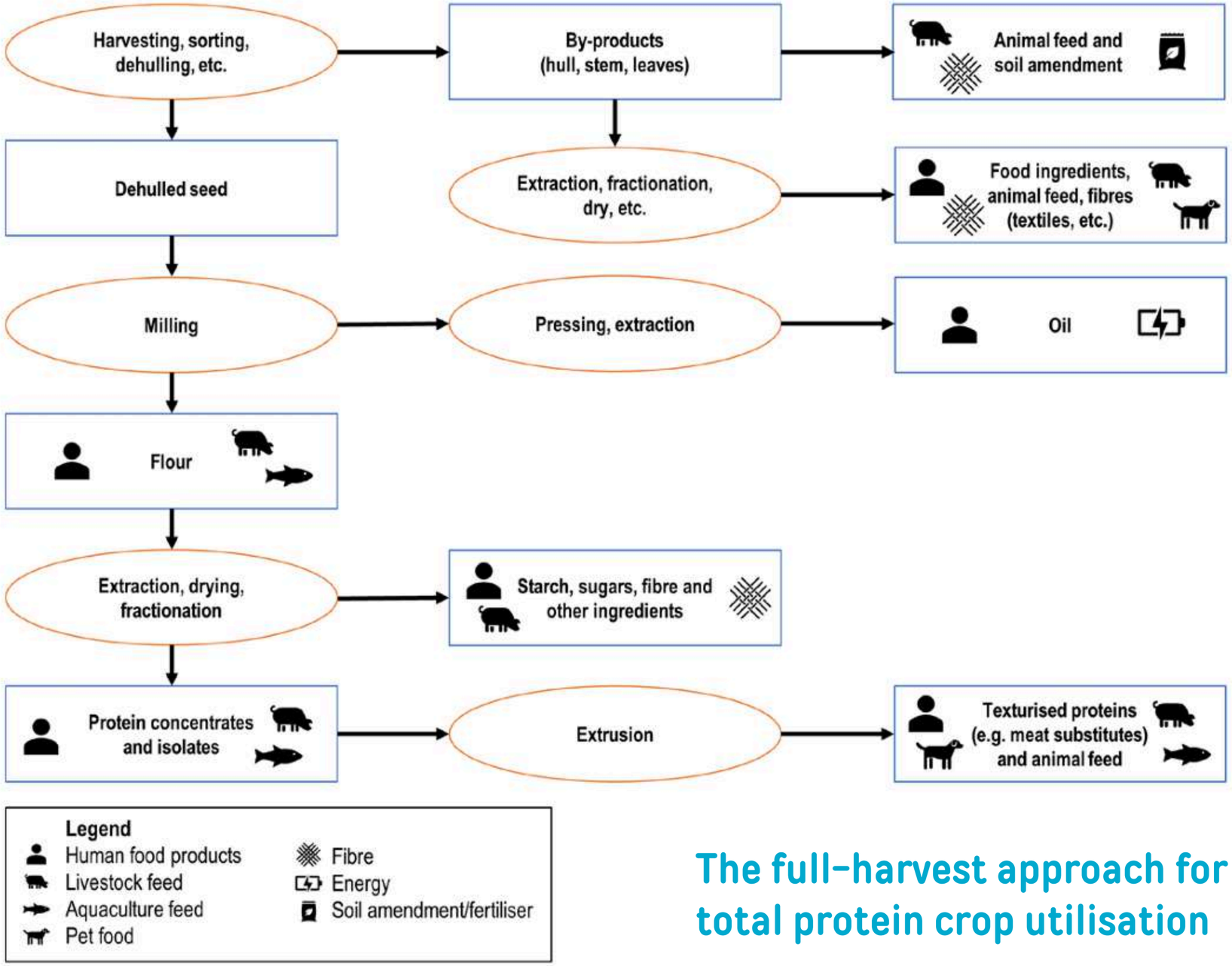
Food, petfood, aquafeed products

By-products:
Starches, fibre

Key environmental indicators
GHG; Water use; Eutrophication
Packaging ; Land water use

Other food ingredients, animal feed, composites, textiles, soil amendment

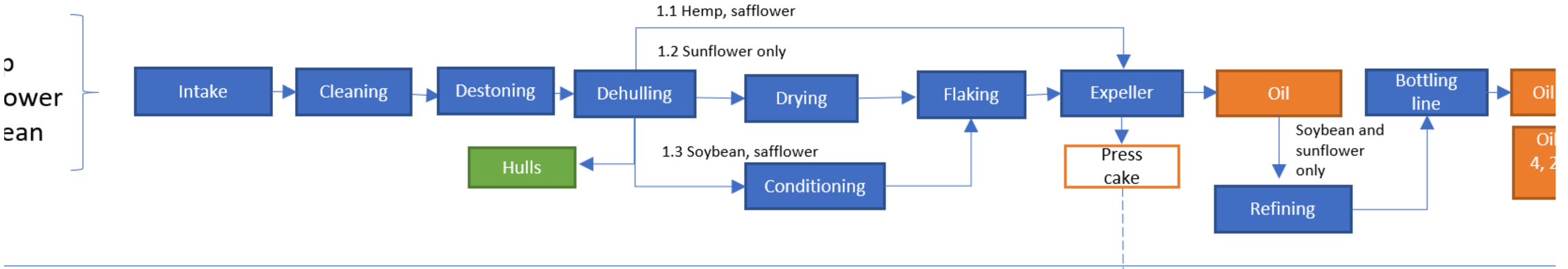
https://www.csiro.au/en/research/production/food/plant-protein-hub-north-qld



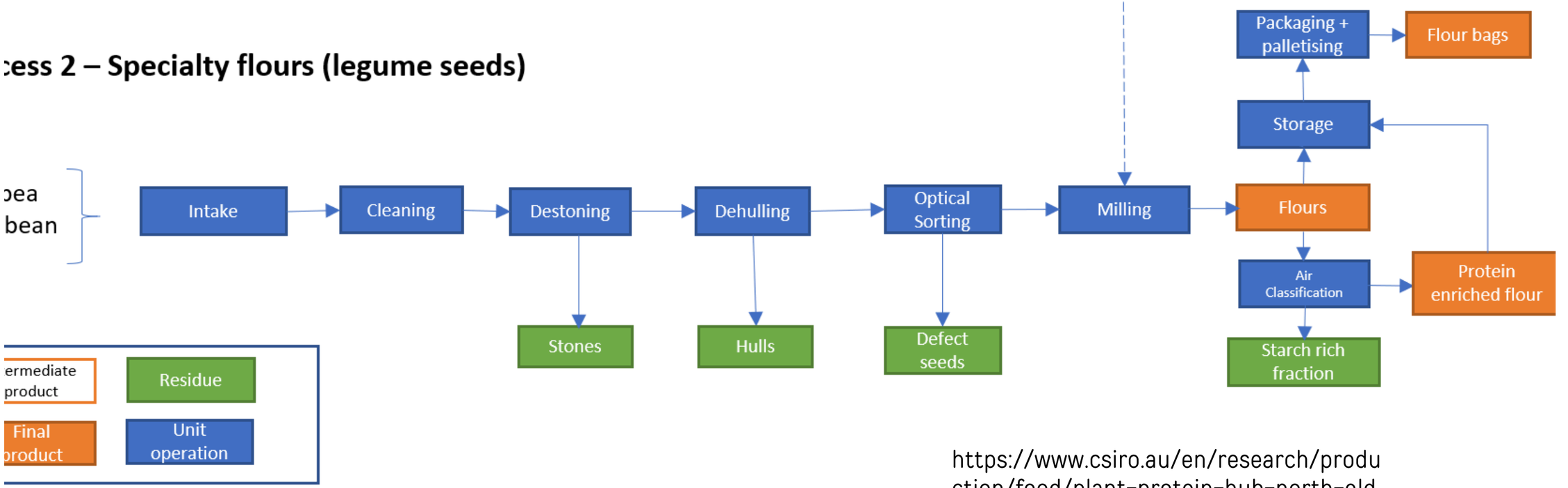
The full-harvest approach for total protein crop utilisation

Hetherington et al. 2022 – Farm Policy

ess 1 – Crude and refined oil (oilseeds)

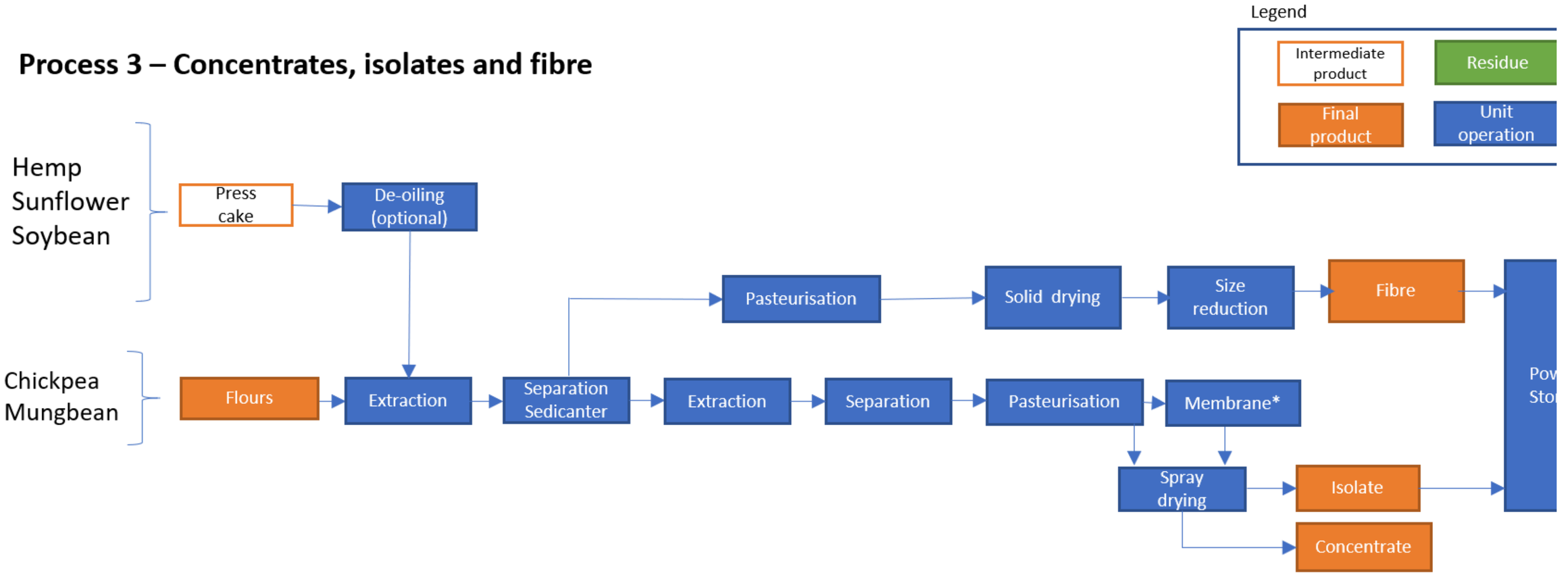


cess 2 – Specialty flours (legume seeds)

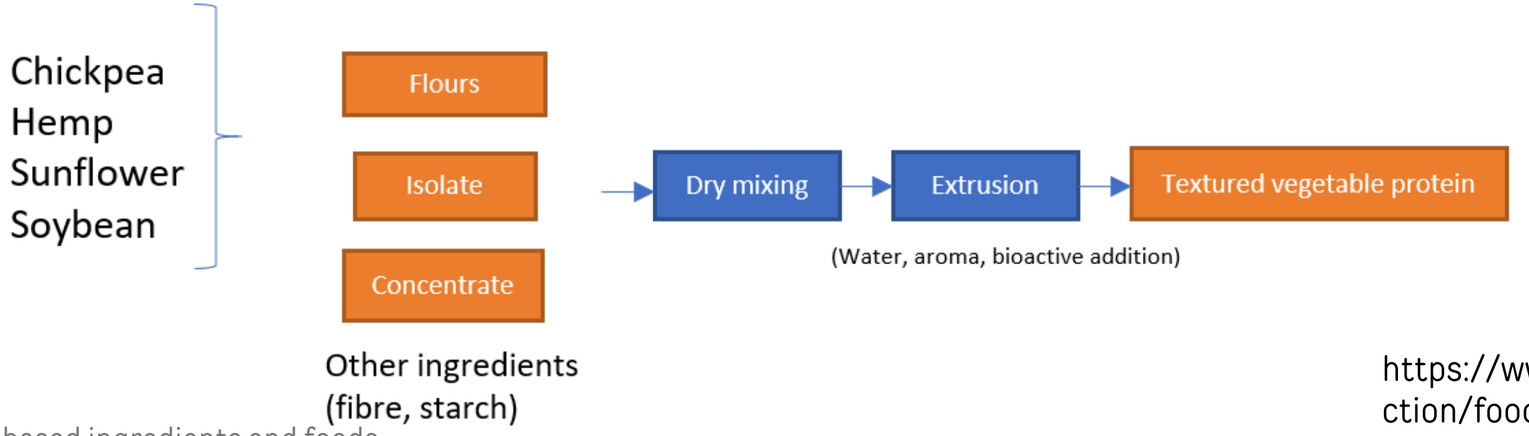


https://www.csiro.au/en/research/production/food/plant-protein-hub-north-qld

Process 3 – Concentrates, isolates and fibre



Process 4 – Textured vegetable protein

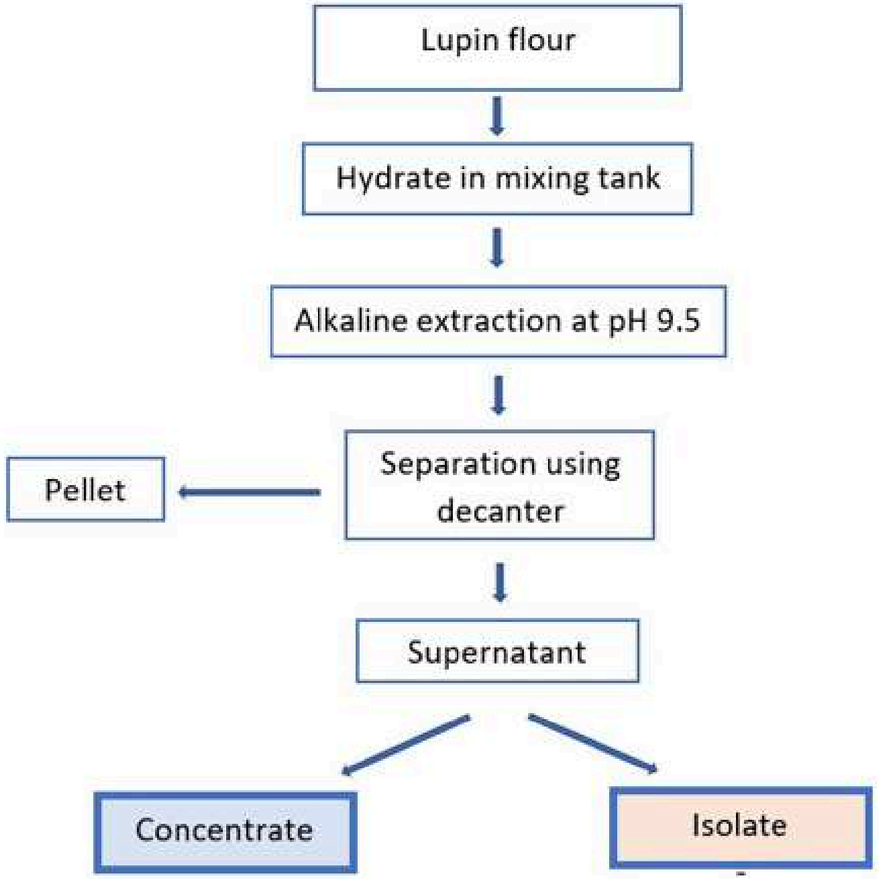


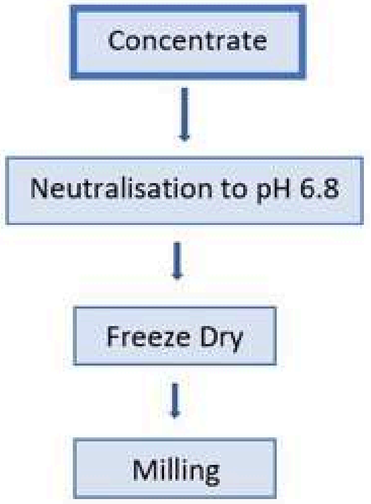
Other ingredients (fibre, starch)

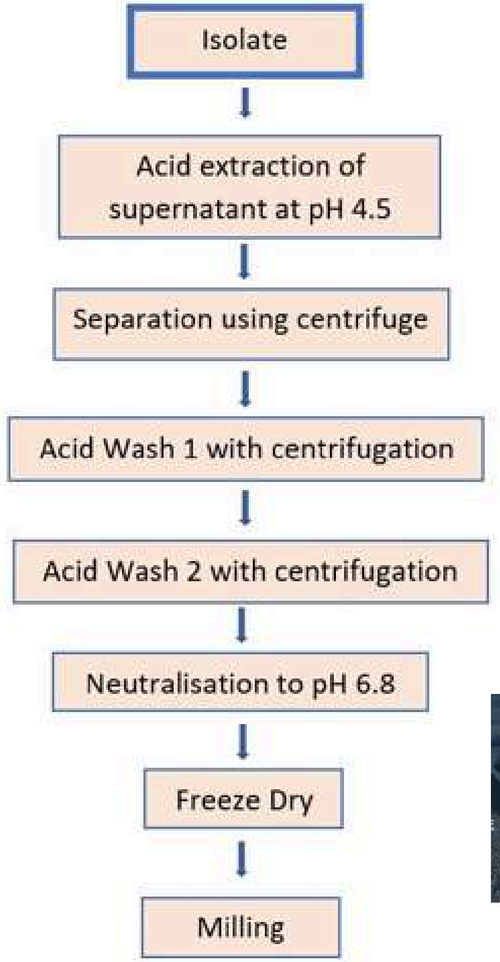
https://www.csiro.au/en/research/production/food/plant-protein-hub-north-qld

Wet fractionation example

FPC Flow chart for lupin

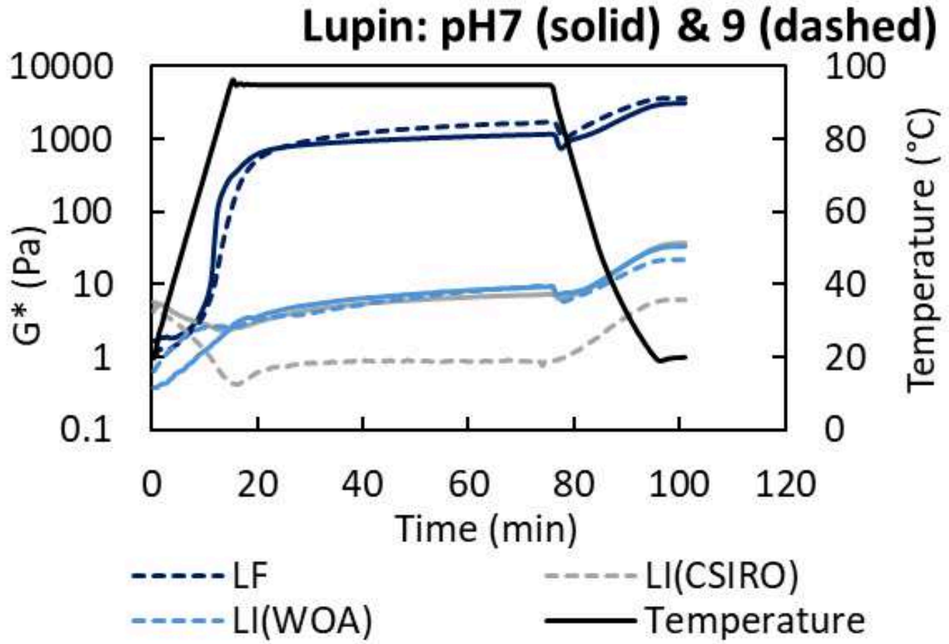






Regine Stockmann

Ingredient Functionality & Food Structure

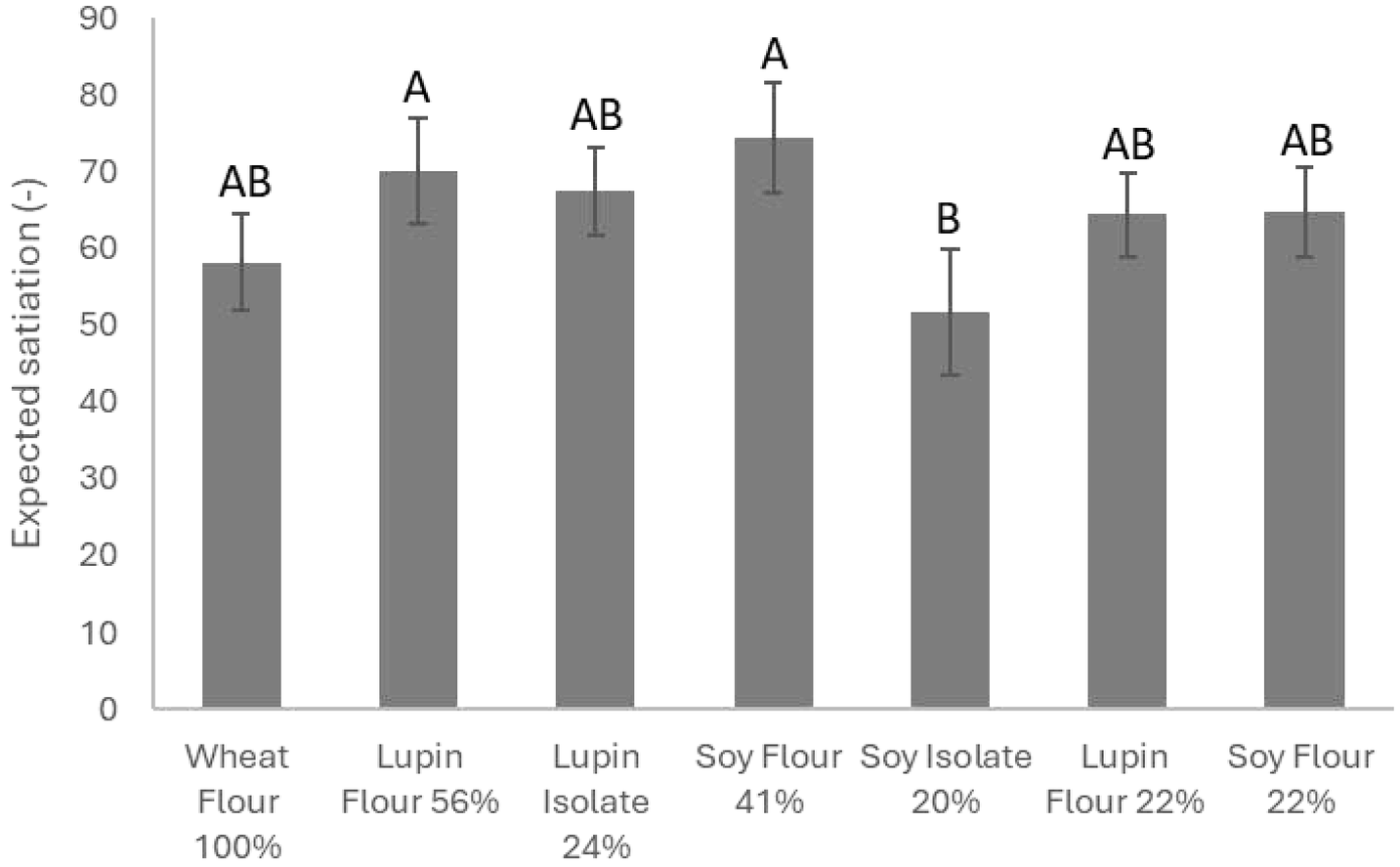


Lupin flour gels strongly on heating: crust formation early in bake, leading to cracking

Lupin isolate gels weakly: minimal crusting and cracking

Simon Loveday

Satiation of lupin flour

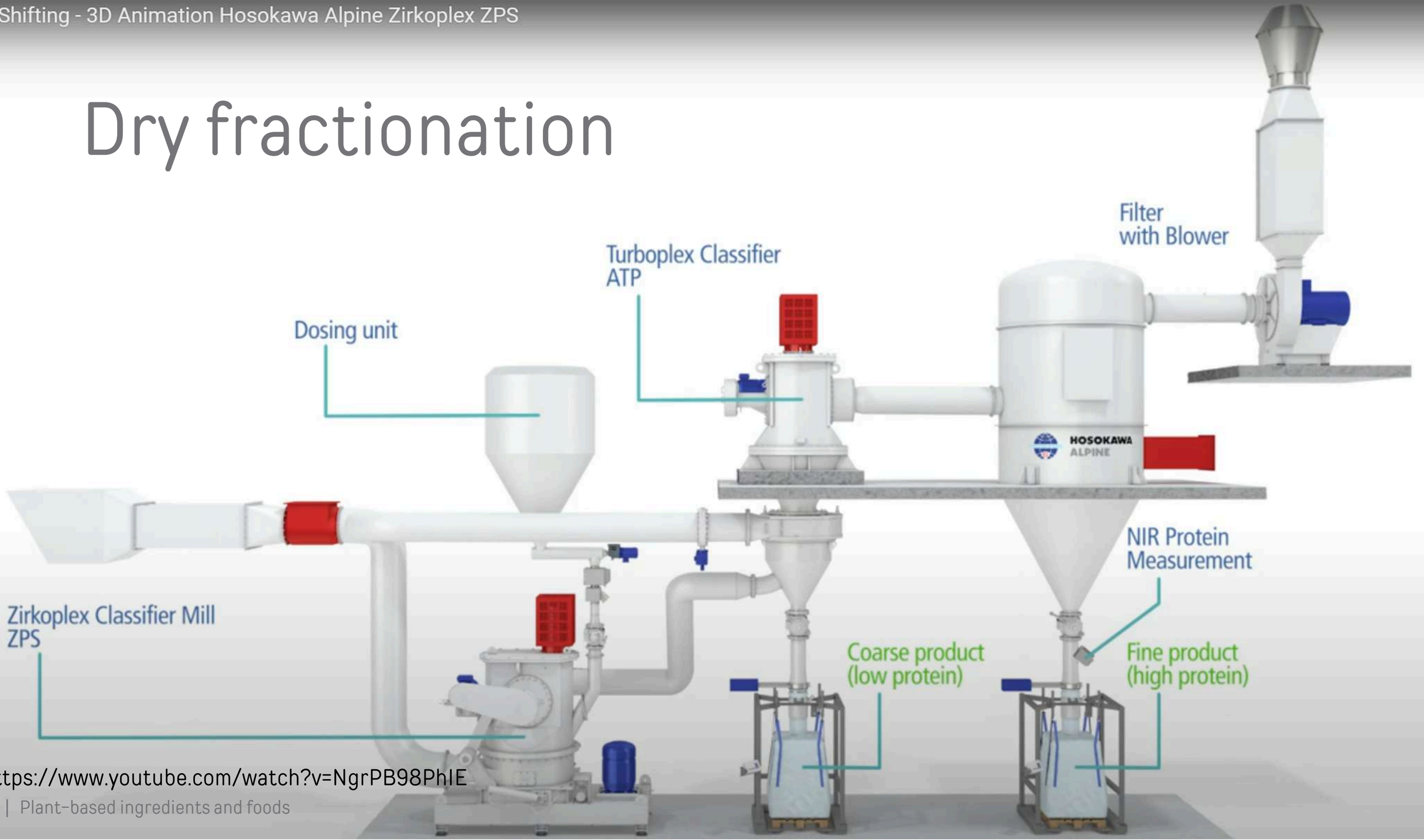


Similar liking as wheat flour and tended to be more satiating than soy isolate

Carol Mosca

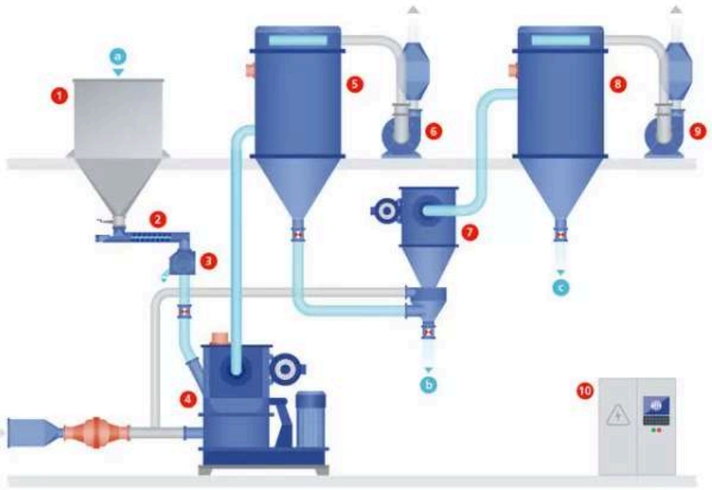
Protein Shifting - 3D Animation Hosokawa Alpine Zirkoplex ZPS

Dry fractionation



https://www.youtube.com/watch?v=NgrPB98PhIE

Combined mill and air classifier units



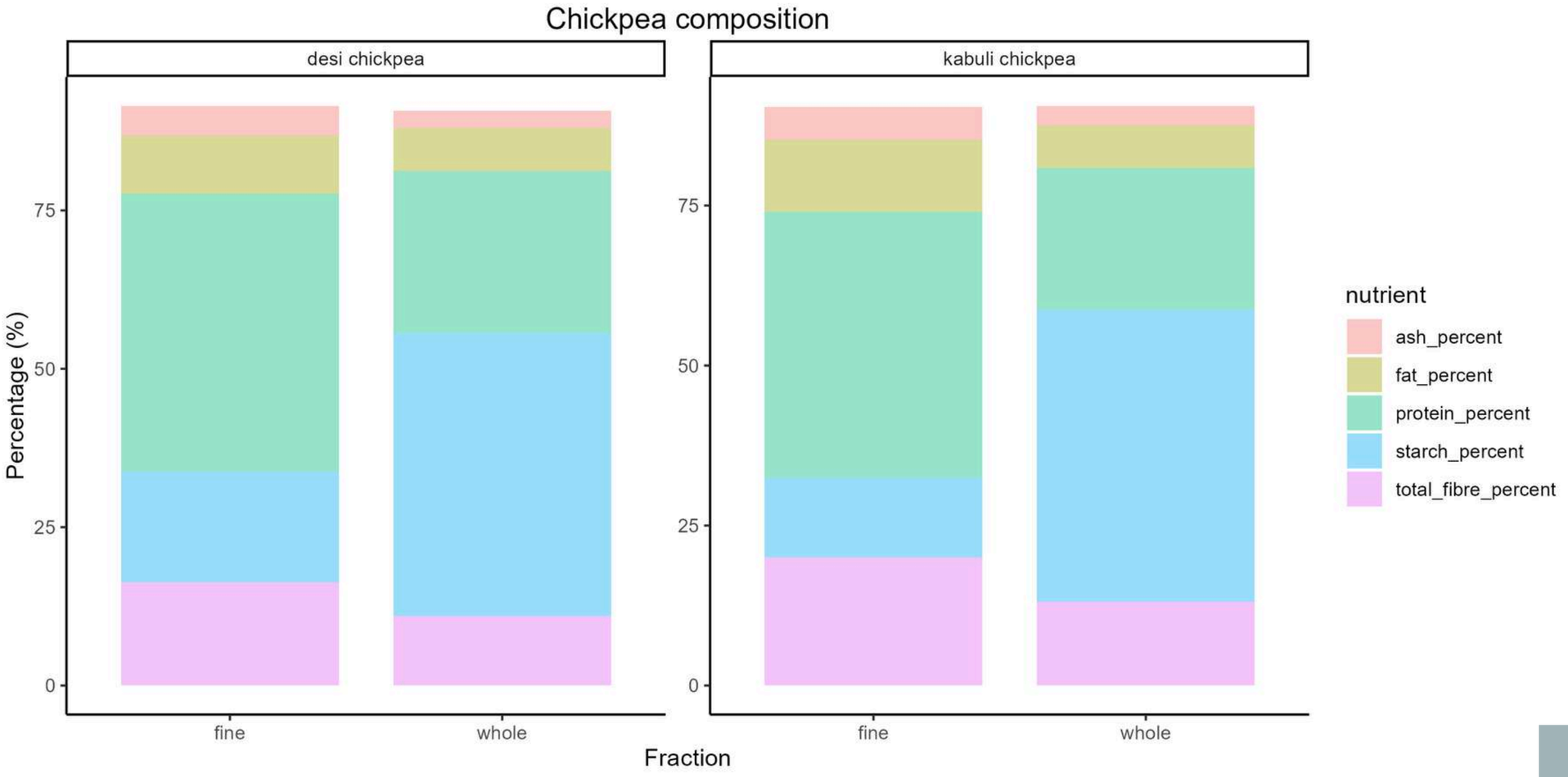
1 Feeding bin 2 Feeding screw 3 Metal separator 4 ZPS classifier mill
5 ZPS automatic filler 6 ZPS blower 7 ATP air classifier
8 ATP automatic filter 9 ATP blower 10 Control cabinet

(a) Feeding product (b) Low-protein fraction (c) High-protein fraction

Regine Stockmann

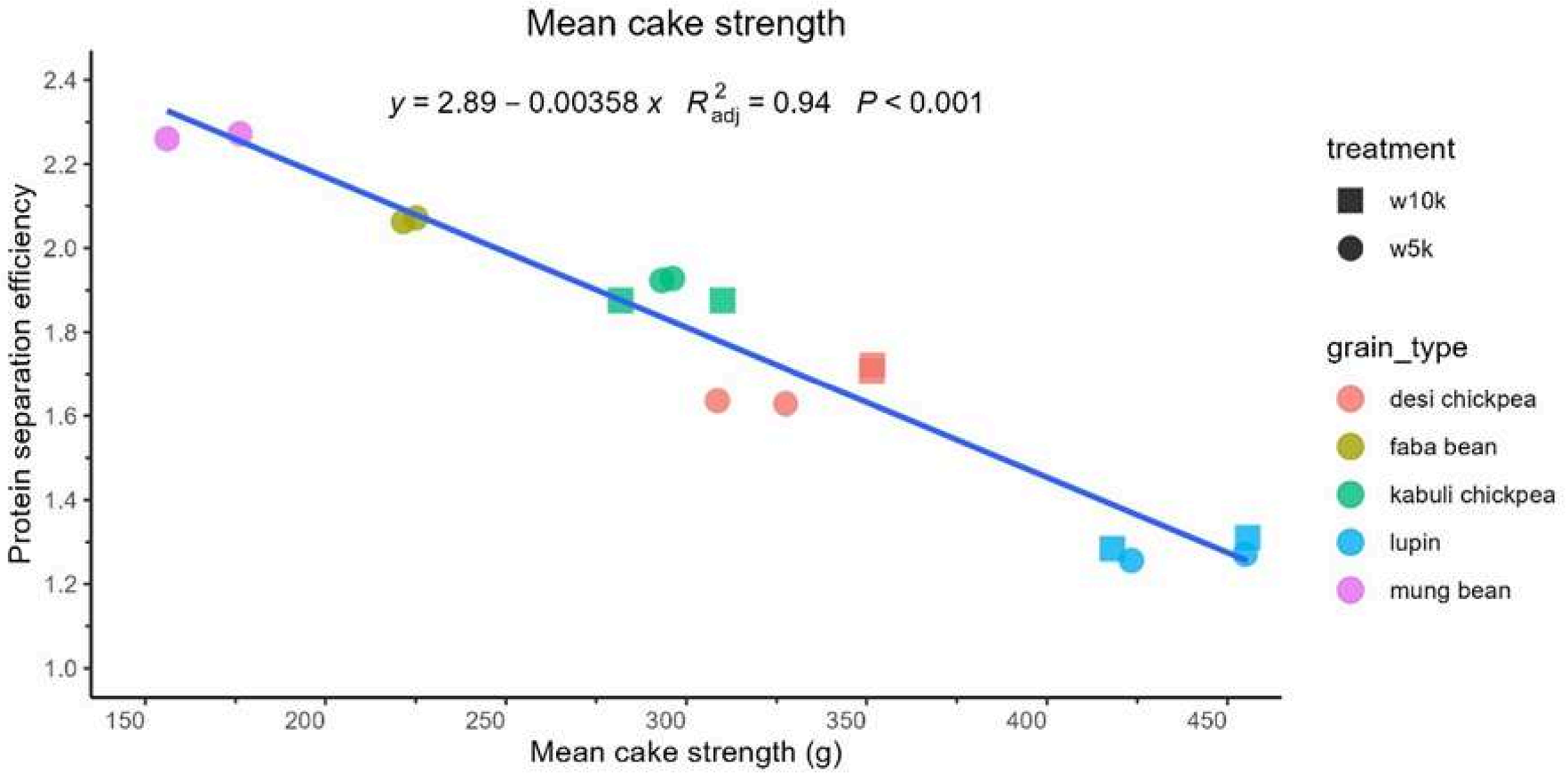
Hosokawa multiprocess unit with an ATP classifier (2–5 kg/h classifier capacity)

Dry fractionation example



Vishal Ratanpaul

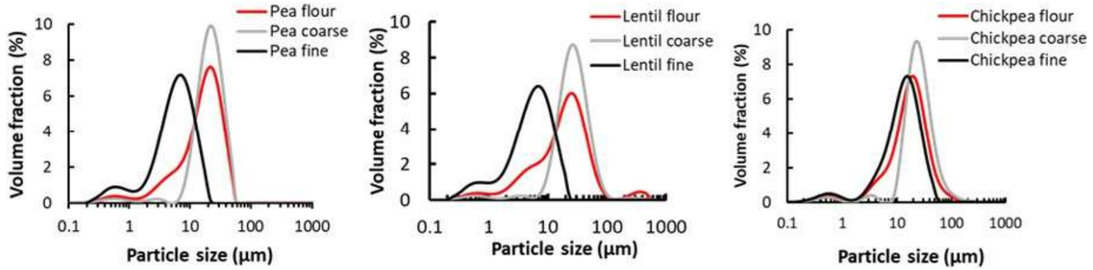
Dry fractionation example



Vishal Ratanpaul

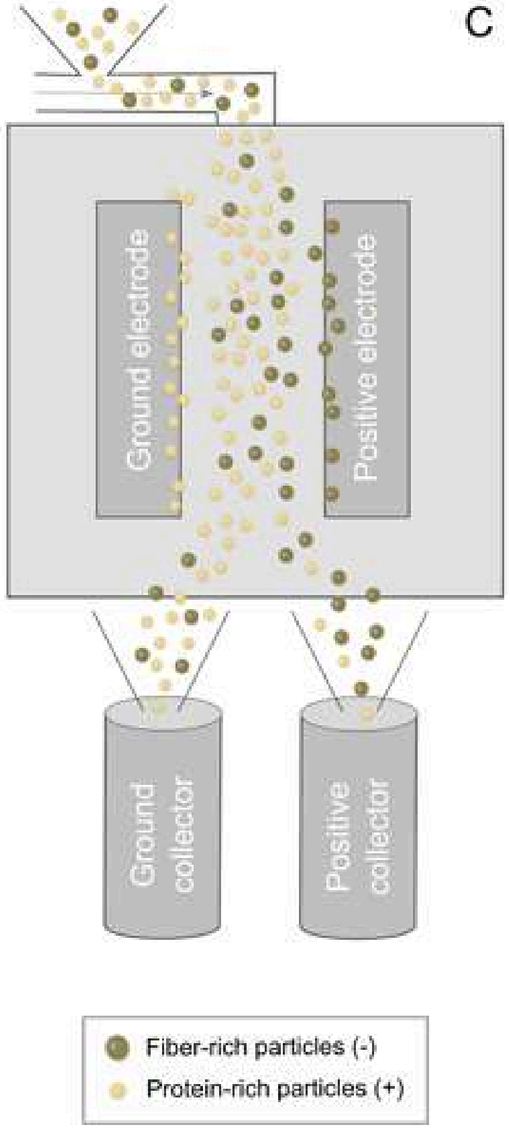
Electrostatic separation

ST Equipment and technology



Xing et al 2020

Alpiger et al 2024



Commercial process under development

Extrusion Texturised Plant Protein

- Low moisture extrusion – T

- High moisture extrusion -

Danyang Ying

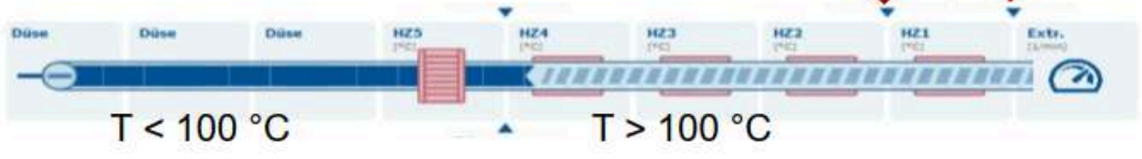
Source: Anton Paar

High Moisture extrusion

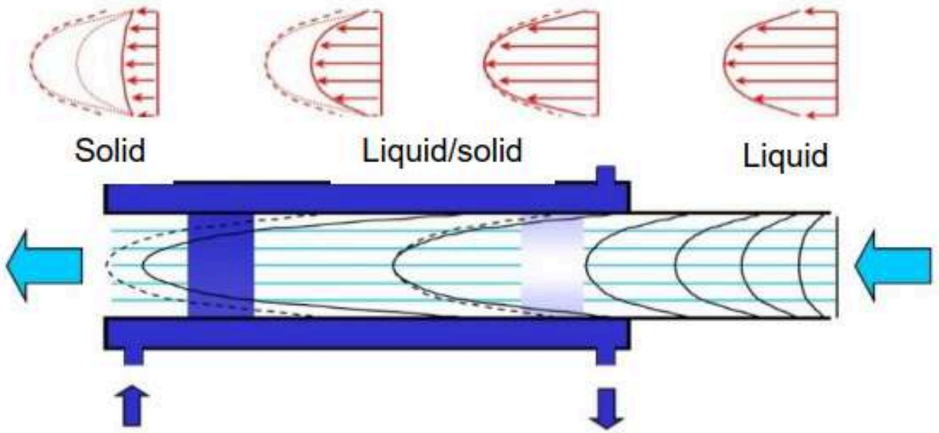
meat analogue – extrusion process & modular cooling die

80 – 40 % Water

20 – 60 % Protein



lamination



Source: Anton Paar

Chemistry during extrusion linking to food and feed nutrition and texture

Foundation research: physicochemical, nutritional, and sensory properties of food and feed extruded products

Computational modelling of food and feed extrusion

Over-Arching Project

Intelligent food and feed extrusion

Jordan Pennells

AI Case Studies for Food Manufacturing

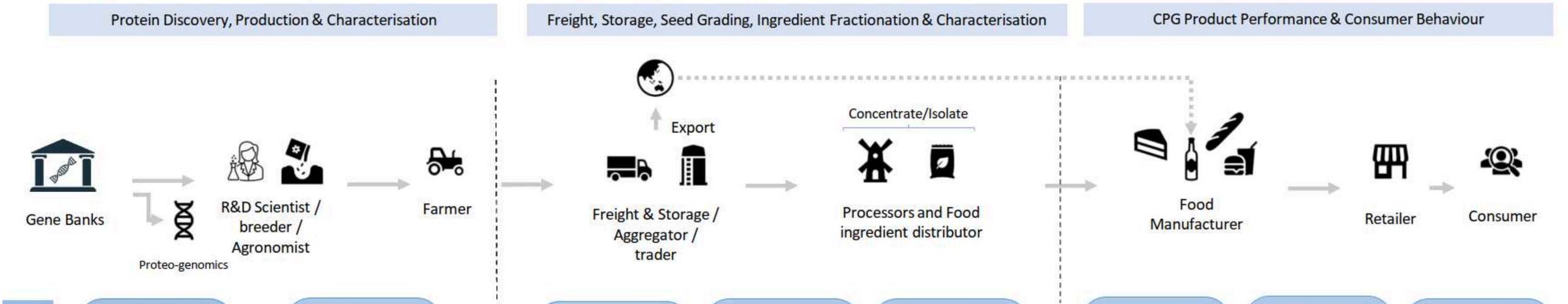
Process Optimisation

GreenProtein AI (est. 2023, Israel) is an initiative supported by Food System Innovations, leveraging AI machine learning technology to optimize the extrusion process for plant-based meat production.

Companies in the plant-based meat sector are facing challenges related to fibrous texture optimization, mainly due to the high costs associated with extrusion R&D. These texture issues have hindered the mainstream adoption of plant-based meat!

© FoodPlant

Strategic investment in plant protein mapping and gap analysis summary



CSIRO DOMAIN EXPERTISE & CAPABILITY REQUIRED

CROPS / TRAITS / ML-AI FSP
- Germplasm Populations
- Speed breeding
- Genome sequencing and analysis (e.g. pangenomics)
- Gene editing
- Gene discovery
- Trait targets
- Phenotyping & ML
- Proteo-genomics / bioinformatics

SYSTEMS / CROPS / AQUACULTURE / H&B / L&W / AI4M
- Identify and develop new cropping areas
- Agronomy
- Modelling (APSIM)
- Pest & Pest control
- Biological control of diseases
- Soil Carbon, N cycle and Soil health
- Field Trials

FOOD / H&B / DATA61
- Safety and Quality
- Pest & Pest Control (e.g. rodent, insects)
- Quality control and monitoring (IoTs)

TRUSTED EXPORT MISSION / L&W
- Life Cycle Assessment
- Safety and Quality
- Provenance

FOOD / MANUFACTURING / AI4Design / AI4M
- Milling
- Protein / Starch fractionation
- Extrusion
- Protein techno-functionality characterisation
- Protein modification
- Flavour profiling
- Fermentation
- Process Optimisation

FOOD/AQUACULTURE / MANUFACTURING / H&B
- Product development & testing
- Feed formulation
- Feeding trials
- Micro-encapsulation
- Nutrition/ Digestibility

TRUSTED EXPORT MISSION / MANUFACTURING
- New packaging materials
- Safety and Quality
- Provenance

FOOD / H&B
- Consumer behaviour
- Sensory science

Chickpea – Mel – IWY
Gene editing

Lupin – Haihua – PhD
Seed coat thickness

Lupin – Lingling – SIP23
Genome scale model for protein/metabolite production

Chickpea - Sally – Winanga-y
Grain Composition

Lupin- Virginia – IWY
Bioinformatics – seed size development

Lupin- Arineh – IWY
Gene discovery - Allergen profile, Digestibility and techno-functional properties

Chickpea – Utpal – IWY
Impact of environment on protein profiles

Chickpea – Fernanda – SIP23
Impact of heat Stress on protein composition

Chickpea – Utpal – SIP23
Proteomics – method development

Chickpea and Lupin – Regina – SIP23
Techno-functional properties of flours

Chickpea and Lupin – Tanoj – SIP23
Flavour profiles of flours

Chickpea and Lupin – Vishal – IWY
Impact milling and fractionation on techno functional properties

Crop Agnostic – Jordan – Winanga-y
Intelligent Extrusion platform

Canola – Ronald – ECR RS – **CSIRO - CAS**
Enhancing nutritional profile through fermentation

Predictive Analytics Next Gen Ingredients – *Xavier – AI4M_P11*
AI recommender system

Capability GAP

Integrated proteo-genomics workflow

GxExM on Protein quality

Seed quality monitoring (during freight & storage)

Techno-functional properties of plant based ingredients – **Small scale characterisation Lab**

Dry-fractionation – Small scale platform

Digestibility & Nutritional profiling

Structure-function relationships of plant protein ingredients in food matrices both plant and animal

Case studies

Plant-based protein ingredients and product innovations

Australian Plant Proteins

- Optimised wet protein fractionation of faba bean concentrat
- Powder with significantly better functional properties (taste an other products on the market
- $35M plant protein facility in Horsham, Victoria
- Hub in South Australia under construction
- **Challenge:** circular use of starch and fibre by-products
- Crops: fababean, yellow pea, yellow and red lentil, mungbean,

https://www.csiro.au/en/work-with-us/funding-programs/SME/CSIRO-Kick-Start/APP

Wide Open Agriculture

- Lupin sourced in regenerative farming systems
- Translated process developed at Curtin university to pilot s
  function (gelling, moisture retention, oil binding, neutral fl
- Produced samples for market testing (protein content 75%

- WoA Buntine Protein

SENSORY	
Colour	Pale yellow/neutral
Texture	Flowing powder
Smell	Neutral, slight grain
Taste	Neutral
TECHNO FUNCTIONAL PROPERTIES	
Solubility - HIGH	Min. 80%
Emulsifying Capacity - HIGH	Min. 60%
Emulsifier Stability - HIGH	Min. 65%
Gel Strength - HIGH	Min 80g
pH value	Neutral

https://ecos.csiro.au/cracking-lupin-wide-open-sausages-to-high-value-protein-ingredient/

FIGHT FOOD WASTE
Cooperative Research Centre
REDUCE - TRANSFORM - ENGAGE

Spent grain valorisation

- Commercialised spent grain flour
- Protein enrichment and fractionation (ongoing)

NutriV

- Brought solution to key grower packer for large superm
- Non-retail and waste products is converted into vegeta
- Supported snack line launch of Goodies offering 2 serve

100% of brassica and other vegetables

k

Bestie Kitchen

- Supported the product and process development era dogs
- Developed suitable carrier formulations and processing a bioactivity of the chew
- Supported translation of extrusion into commercial trials

https://blog.csiro.au/pet-food/

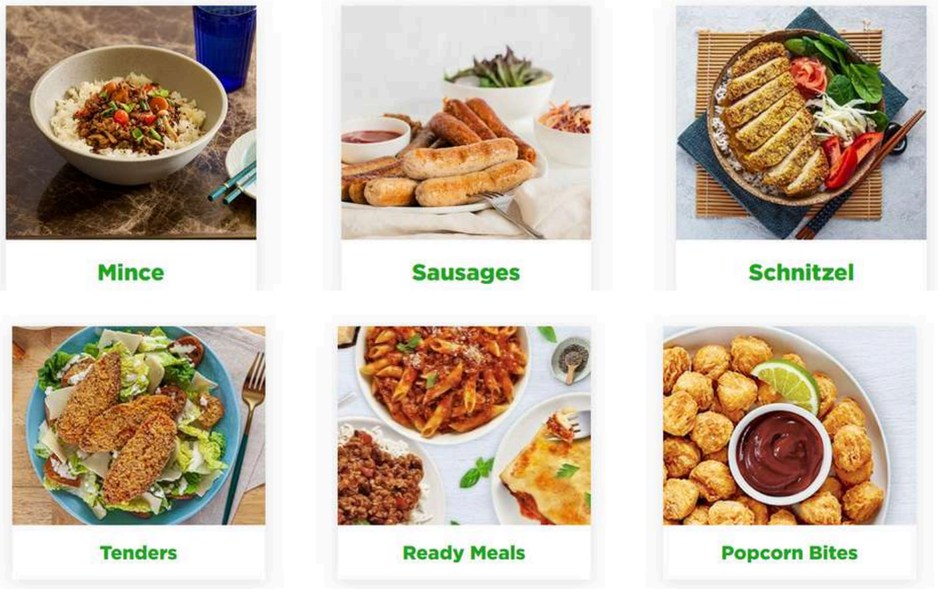
CannPal Therapeutics

- Helped discover natural therapeutic oils and include them into a joint health supplement powder to prevent osteoarthritis
- CSIRO's microencapsulation technology MicroMAX applie annabinoids into powder formulation
- Pilot trials enabled commercial samples that led to manuf international customers

https://www.csiro.au/en/work-with-us/funding-programs/SME/CSIRO-Kick-Start/CannPal-Animal-Therapeutics

v2Food

- Developed new IP to create plant-based meat p… nique sensory and market differentiation
- Process developed at our pilot plants … ths
- Facilities hired for commercial ingredie… gement
- Reverse engineered meat flavours from amin… ors
- Nutrition science support



v2Food – Nutrition Science

- **Overall Objective:** To ensure that product development activities have a nutritional lens applied and look for opportunities for improvement
- Focus on protein quality, nutrient bioavailability and potential health benefits (microbiome, satiety)
- Exploring opportunities to enhance product to deliver benefits in developing countries

v2Food – Nutrition Science to Date

- Characterising the nutritional quality of v2mince
  - Fibre composition
  - Protein content and aa composition

- Understanding functional attributes
  - *in vitro* fermentation, microbiome composition, short-chain fatty acid production
  - Protein digestibility
  - Effects on satiety
  - Iron bioavailability

- Understanding nutrition requirements for different meat varieties
- Understanding nutritional challenges in specific markets

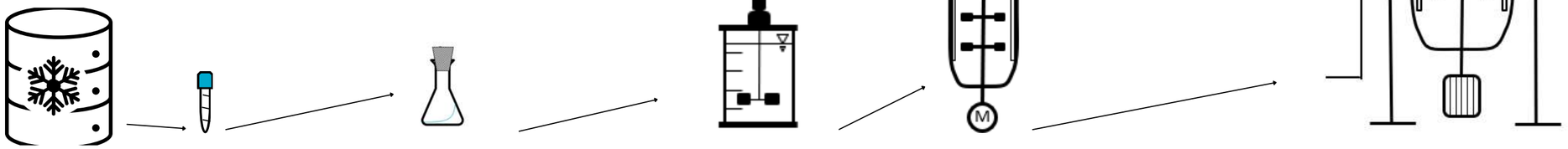
Belograjdic DP *et al* Assessing protein quality, in vitro intestinal iron absorption and human faecal microbiota impacts of plant-based mince. Nutrients (2024) 16, 2339

v2foods commercial pilot testing

Precision fermentation for development of “cowless” protein and fat

Fermentation

Upstream processing (USP)



Working cell bank

Seed train

Pilot plant production

- Cell banking

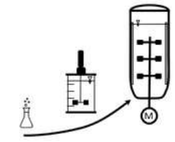
- Shaker incubator for flasks and microtiter plates

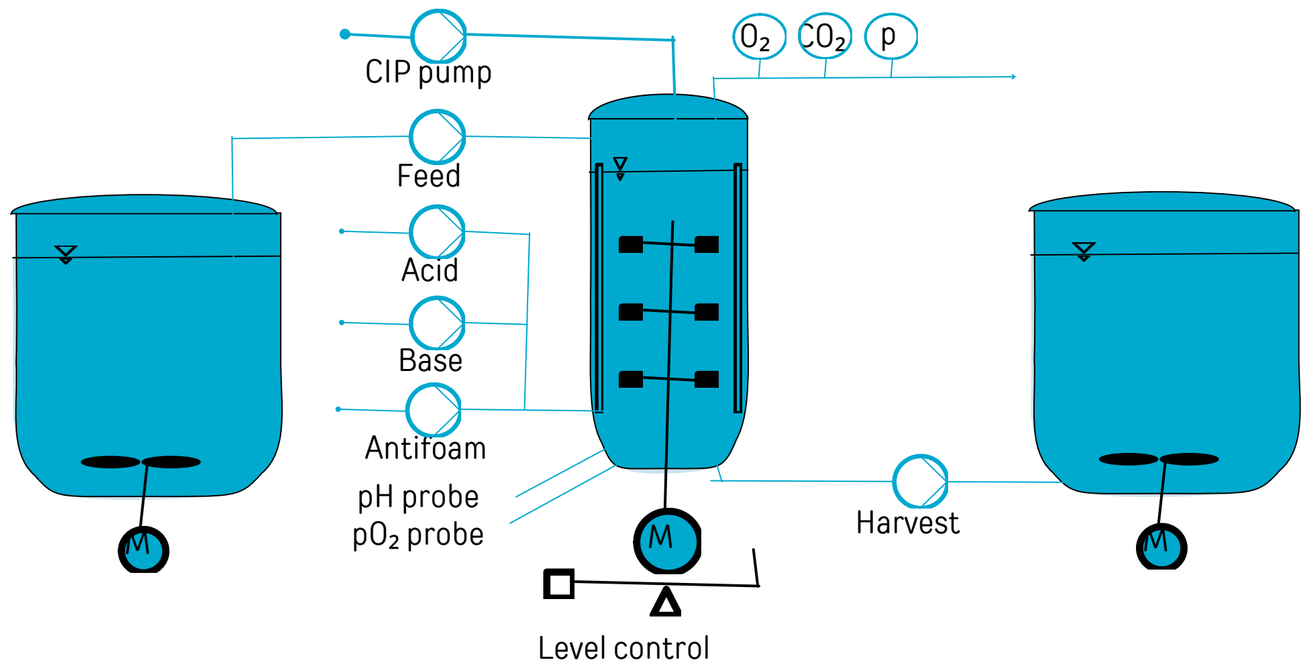
- 2L glass benchtop fermenters

- Stainless steel vessels (10 L, 50 L, 100 L, 400 L)
- **Future vision**: 1000 L

Geoff Dumsday

Bioreactor configuration





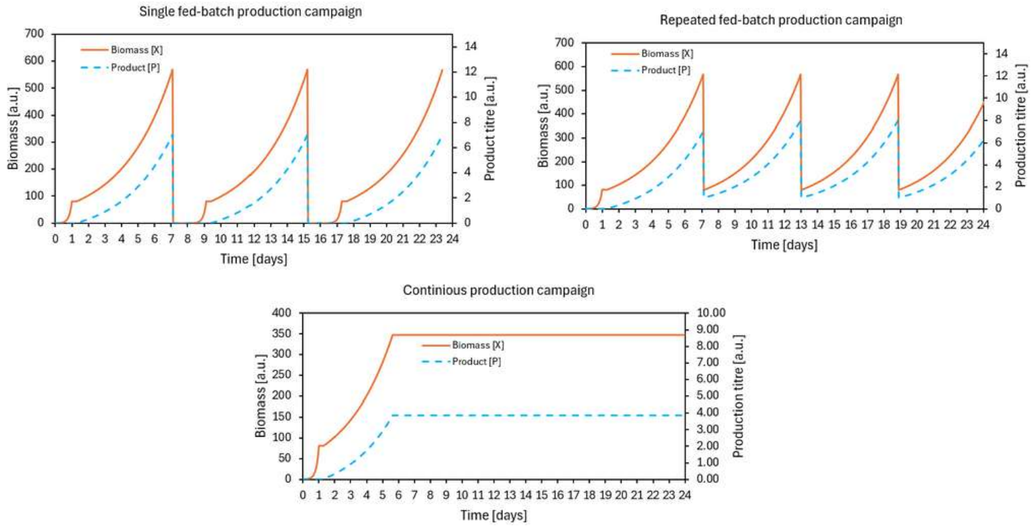
Bioreactor configuration (flexible):

- Batch, fed-batch and continuous operation modes
- Process monitoring: pH, pO_2, temp. and pressure controlled, off-gas analysis (O_2 and CO_2)
- Enables:
  - Real-time kLa determination
  - RQ controlled feeding
  - Precise determination of steady-state
- Monitored SIP and CIP systems (food-grade compliant)

Aim of the design = High degree of **flexibility** for a wide bandwidth of bioprocesses

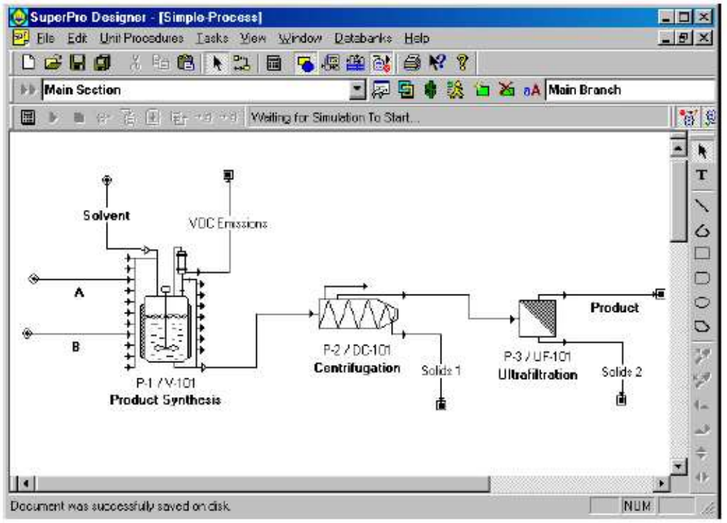
Bioprocess modelling

1. Kinetic modelling



- Individual for every process
- Comparing operation modes
- Predict space-time-yield (STY)
- Predict oxygen demand
- Predict generated heat

2. Techno Economic modelling

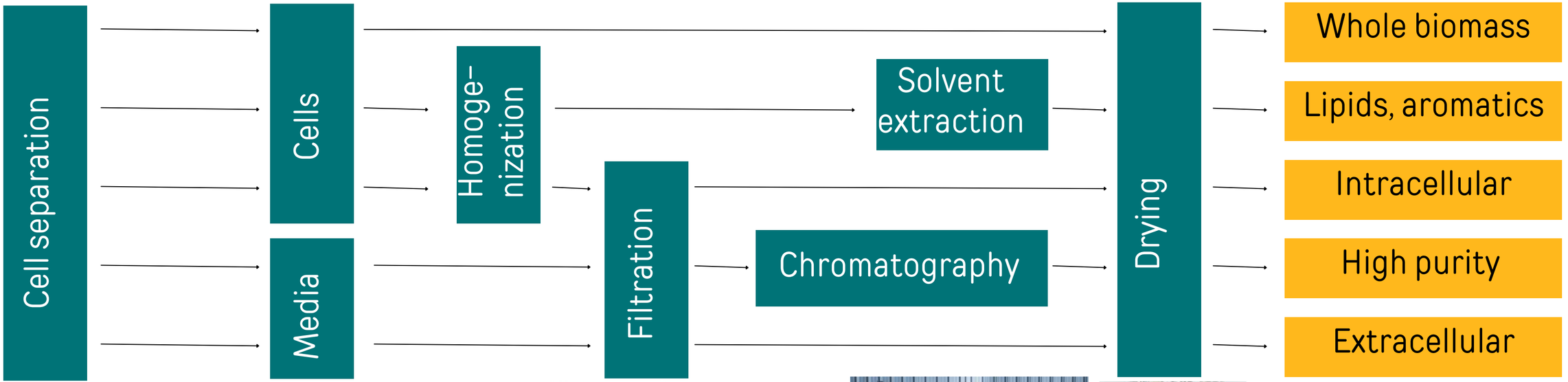


- Number of bioreactors
- Size of USP and DSP equipment
- Mapping mass flows
- Variation in raw material costs

David Wollborn

Product purification

Downstream processing (DSP)



Solids separation
Centrifugation (or filtration)

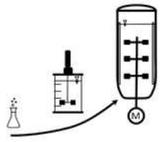
Cell lysis
Homogenisation or chemical

Separation/Extraction
Filtration/Chromatography /extraction

Drying
Spray drying
Freeze drying

Formulation and products
Encapsulation
Food science
Testing

Recap of our One-Stop-Shop capabilitie



START

1. Gene discovery
2. Gene pathway assembly
3. Microbe engineering (Synbio)
4. Target molecule expression
5. Process development & scale up
6. Upstream fermentation at scale
7. Downstream processing at scale
8. Food formulation
9. Consumer science
10. Nutrition science
11. Regulatory science
12. Packaging & distribution
13. Marketing & sales

END

FROM GENES TO PLATES

Potential microbial-based ingredients

- Flavours
- Colours
- Texturised protein (e.g., quorn, Typcal)
- Biomolecules from side streams – carbohydrates can be upcycled as a feedstock to make more protein

Quorn mycoprotein – Fusarium venenatum

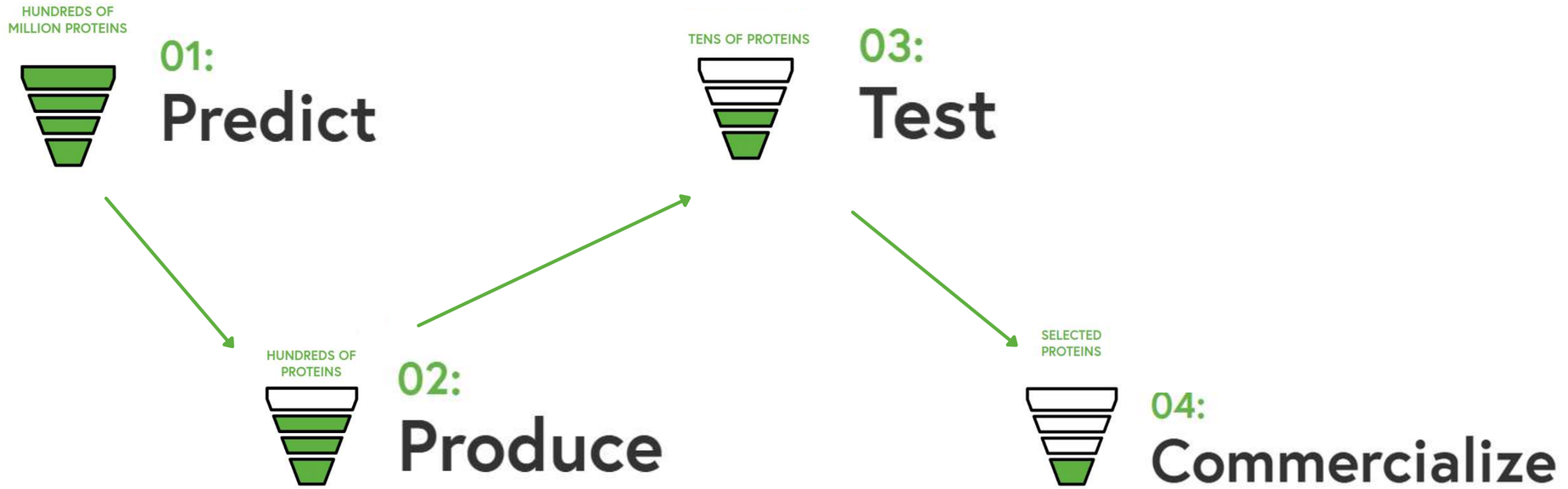
AI Case Studies for Food Manufacturing

Ingredient Identification

shiru

Shiru (est. 2019, USA) uses AI, bioinformatics, and precision biology to discover & produce high-value ingredients from functional **proteins found in nature**

Their 1st product (OleoProTM) was launched in 2023: a plant protein-based fat ingredient that is solid at room temperature



AI driven protein flavour prediction database

Proteins
(current number: 773)

Bioactive peptides
(current number: 5014)

Allergenic proteins
with their epitopes
(current number: 136)

Sensory peptides and
amino acids
(current number: 582)

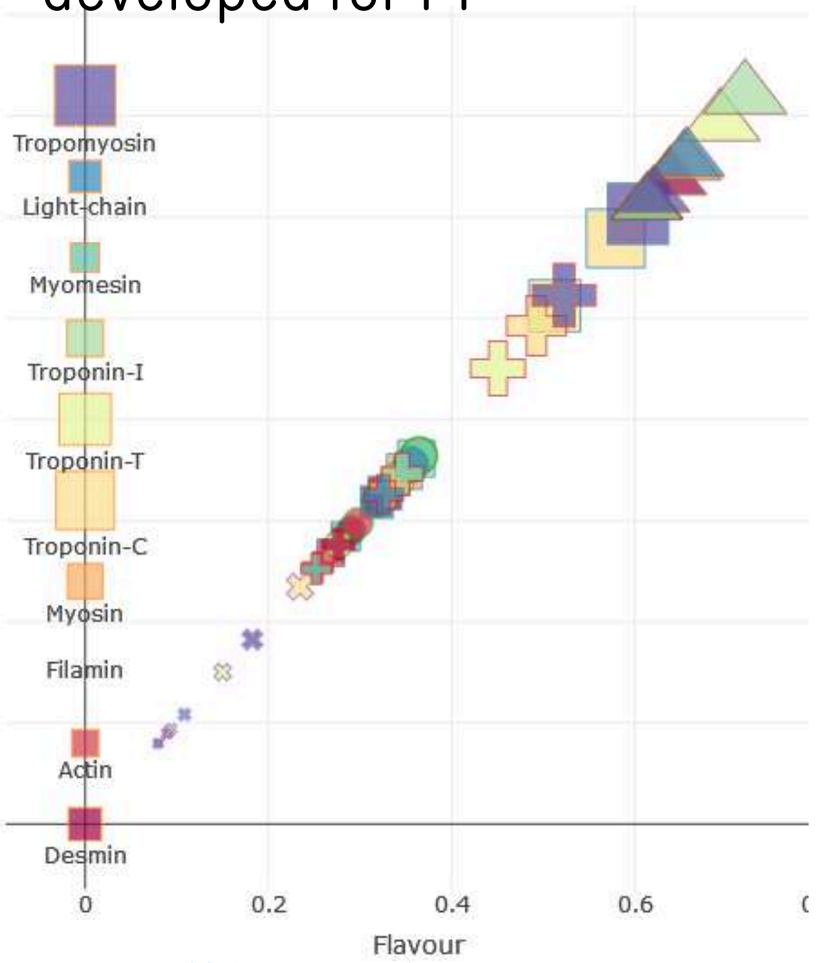
BIOPEP-UWM Virtual
(current number: 312)

BIOPEP-UWM repository of amino
acids and modifications
(current number: 184)

Submit new peptide
sequence

https://biochemia.uwm.edu.pl/biopep-uwm/).

Example for myofibrillar protein developed for PF

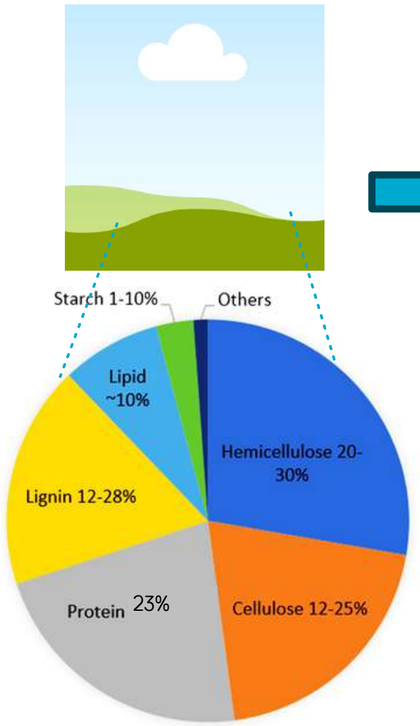


https://github.com/lorenzopallante

Algorithm – virtuous multitaste

Netsanet Shiferaw

Brewer's spent grain (BSG) upcycling



Fibre-rich & protein-rich BSG-derived ingredients

Total Lipid (%)	~12.9
Total Protein (%)	44%
Carbohydrate (%)	58.9
Total amino acid (g/kg DW)	236.1-294
Gross Energy (MJ/Kg)	22.2

>95% conversion of BSG biomass waste into fermentable sugar

High yield (>44%) in *Pichia fermentas*, (other microbial studies, 32-42%)

Myintzu Hlaing

Case studies

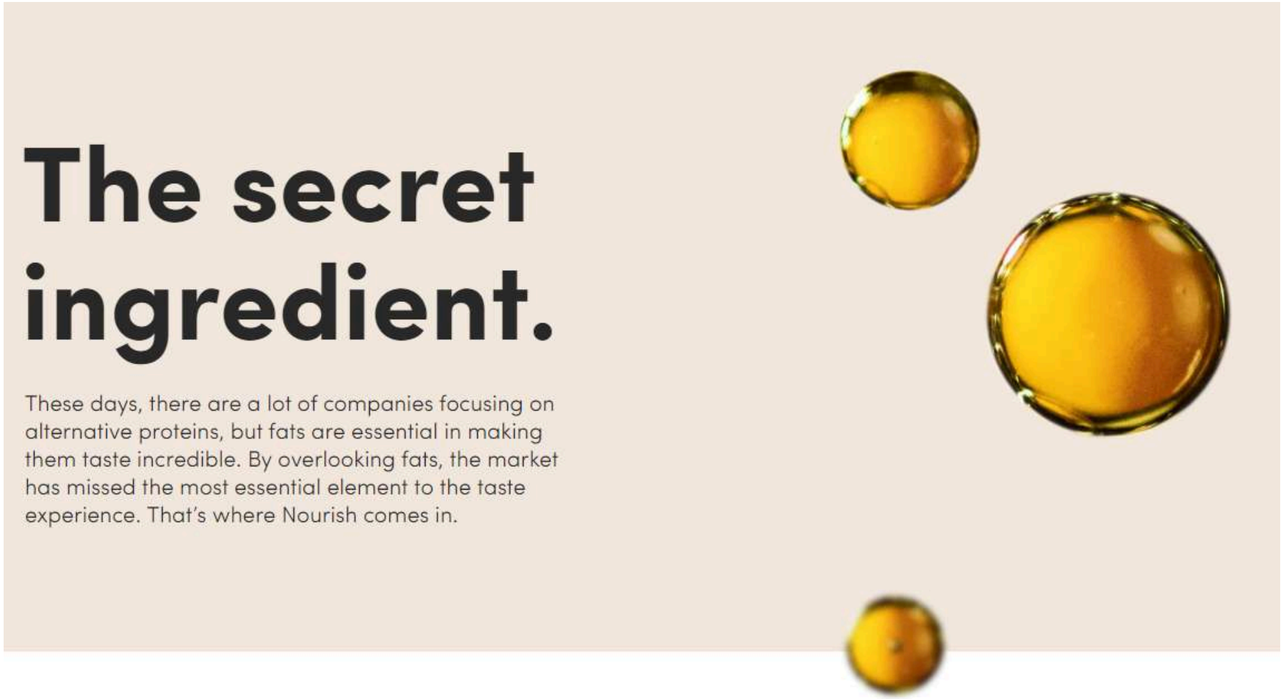
Precision fermentation for development of “cowless” protein and fat

Eden Brew

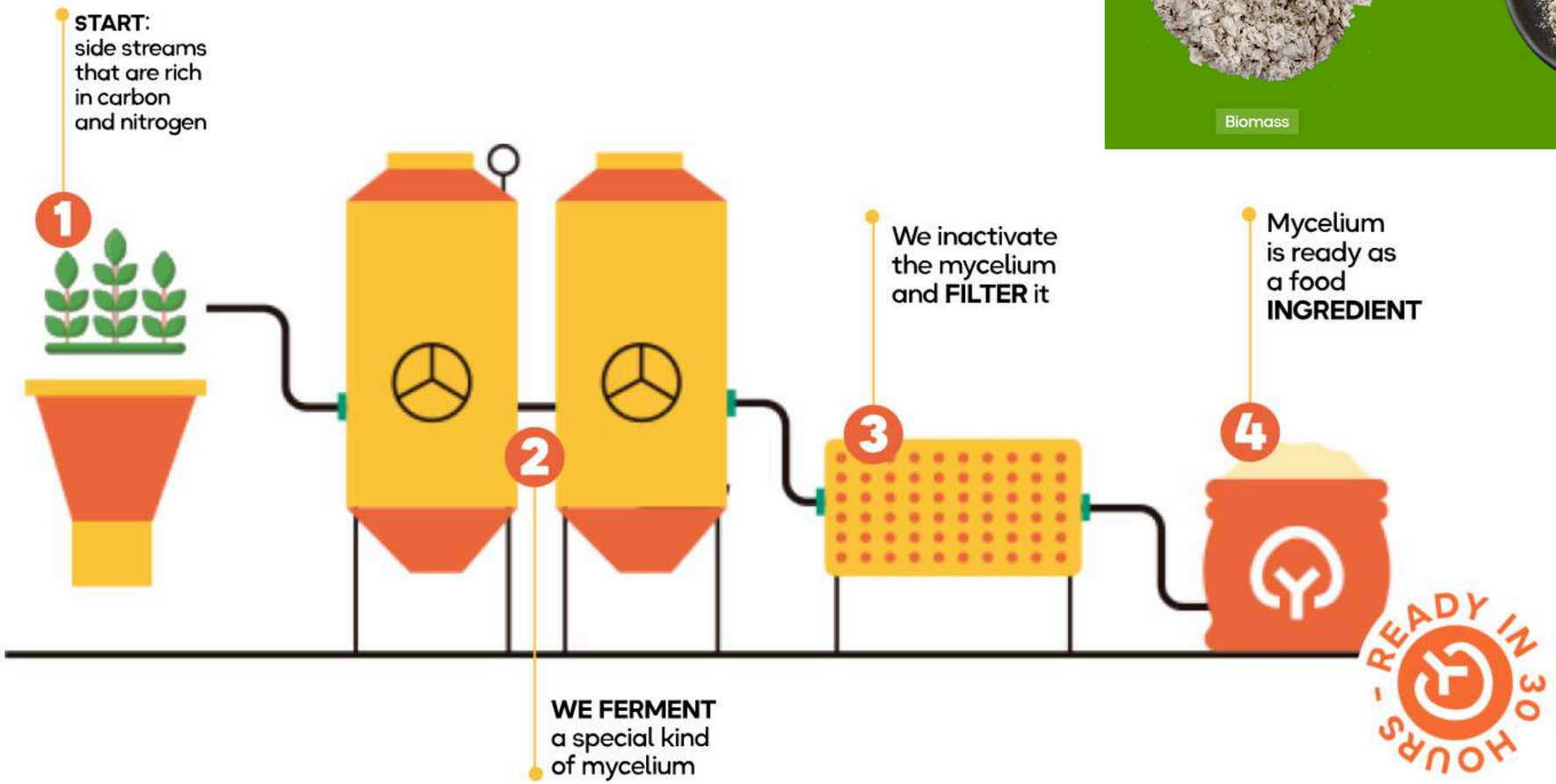
- CSIRO's Synbio technology in yeast to produce milk proteins through precision fermentation
- Precision fermentation processes commercial-scale development
- Collaboration with local dairy giant Norco. Co-operative Limited to launch animal-free dairy products

Nourish Ingredients

- Precision fermentation technology to produce animal fats without using animal products or palm/coconut oil
- Animal-free fermented fat as flavour and functional ingredients supplied to other next-gen foods such as plant-based, alternative non-dairy milk
- "*Cell-cultured meat meets animal-free fermented fat*" – collaboration between cultured meat company Vow and Nourish Ingredients



Typcal



[Typcal – Typcal – O futuro do alimento]

Innovation creates choice for all consumers

Animal-based

Meat-based burger

Blended

Plant & meat-based burger

Fully plant-based

Plant-based burger

Plant-based burger with heme

Hybrid products

Plant-based burger with cultivated fat

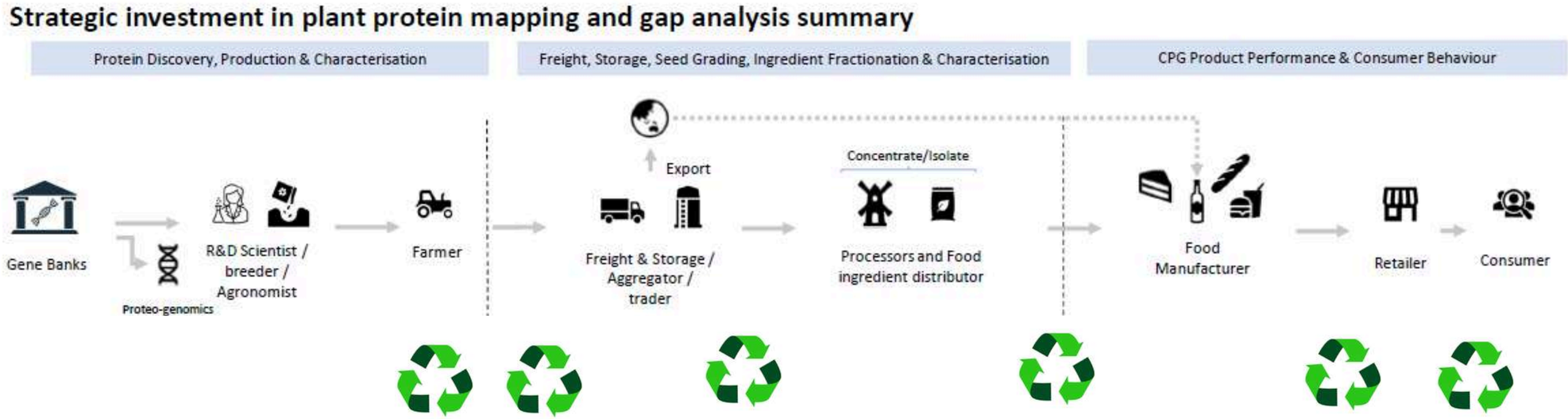
Cultivated meat

Fully cultivated

Synthetic gelatin

Challenges ahead

Upcycling economy



Redesigning future crops **Novel processing for safety, functionality, stability and health**

Environmental sustainability and market access

Acknowledgements

- CSIRO Future Protein Mission team
- CSIRO Crops Program
- CSIRO Food Program team
- CSIRO Kick-Start team
- CSIRO Sustainability Program
- CSIRO Nutrition, Consumer and Health Programs

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