

# Derek Stewart

## Head of Enhancing Crop Productivity and Utilisation

Crops for Human Health benefits



The James  
**Hutton**  
**Institute**





# Enhancing Crop Productivity and Utilisation



Genetics



Plant Products and Food Quality



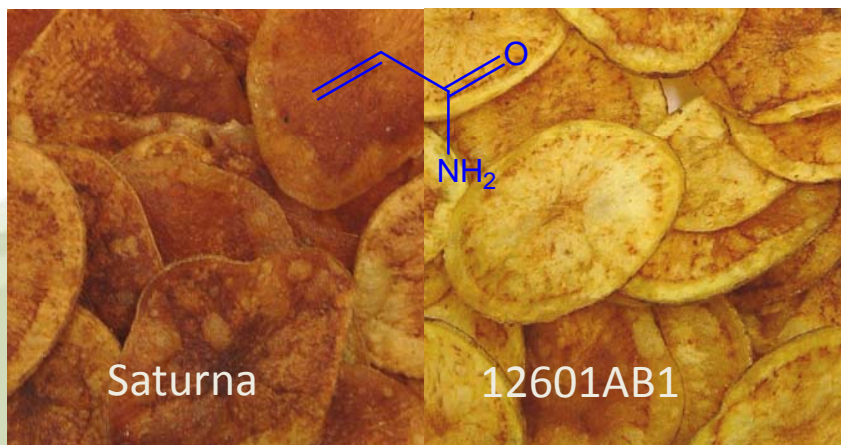


# Food Quality

## Food Quality

Focus: The factors underpinning and driving quality parameters in raw and processed plant foods.

Aim: To employ a systems approach to understand the genetic, biochemical and chemical processes in the developing plant that combine to define the ultimate quality and safety criteria in plant-derived food.





# Food Quality

## Food Safety

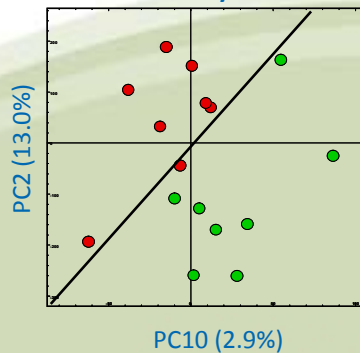
- GM and equivalence
- Impact of GM event with respect to a appropriate biological background and an appropriate environment
- Impact beyond the food level to in vivo testing



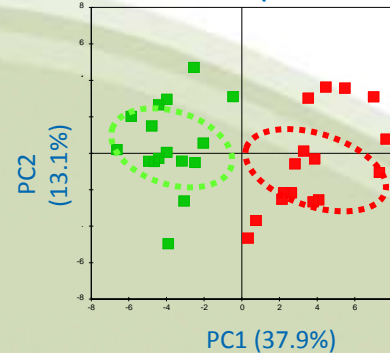
Develonutri  
CROP-BASED NUTRITION



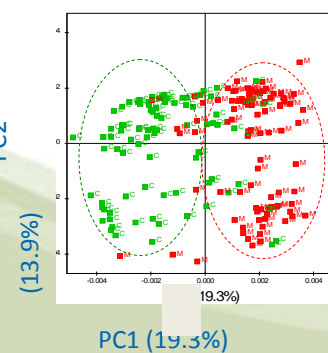
Microarray



Metabolomics (GC-MS Polar)

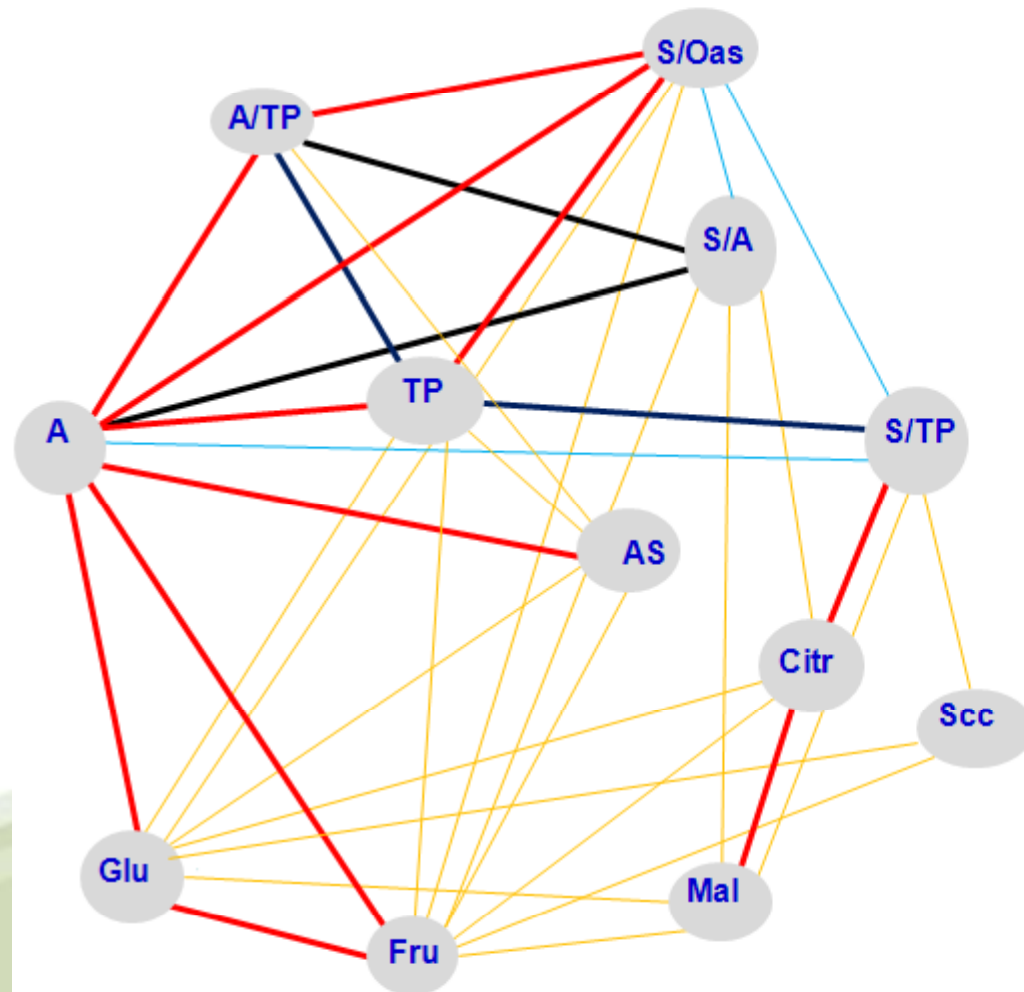


LC-MS





# Metabolite Correlation Network



A and TP  $\xrightarrow{+}$  S/Oas

$\uparrow$  Oas  $\longrightarrow$   $\downarrow$  S/Oas  $\longrightarrow$   $\downarrow$  A and TP

Citr and Mal  $\xrightarrow{+}$  S/TP and A

$\uparrow$  A or TP  $\longrightarrow$   $\downarrow$  S/TP or A  $\longrightarrow$   $\downarrow$  Oas

- $\geq 0.75$
- $0.549 \leq \geq 0.749$
- $-0.749 \leq \leq -0.549$
- $\leq -0.75$



## System for entrainment of potato flavour volatiles on solid phase microextraction (SPME) fibres



- Cooking and sampling conducted in a sealed headspace vial
- Simple, inexpensive, no loss of volatiles
- Small scale – useful for screening
- Comparable to polymer entrainment method (with correct choice of fibre chemistry)



# Correlation of chemical composition (matrix & volatiles) with sensory traits

## Volatiles

- Sulfur compounds
- Hydrocarbons
- Furan and furfural
- Aromatic aldehyde
- Short chain br-aldehydes
- Saturated aldehydes & ketones
- Unsaturated aldehydes & ketones
- Alcohols
- Furan derivatives (sub at position 2)
- Sesquiterpenes
- Esters
- Unknown volatile

## Matrix compounds

- ◆ Glycoalkaloids
- ▲ Amino acids
- ▲ Sugars
- ◆ Nucleotides

Metabolite	Ar	Int	Sw	Sa	Cr	Of
Methylsalicylate	-0.30	0.95	-0.76	0.86	0.74	-0.39
n-Hexenal	-0.57	0.93	-0.54	0.80	0.89	-0.19
Pentanal	-0.26	0.87	-0.86	0.82	0.58	-0.40
Z-(or E)-2-(2-pentenyl)furan	-0.35	0.82	-0.71	0.67	0.61	-0.05
3-Ethyl-2-methyl-1,3-	-0.64	0.80	-0.87	0.68	0.57	0.04
3-or-2-Methylbutanoic acid	-0.55	0.78	-0.51	0.76	0.67	0.07
AMP g/100g FW	-0.63	0.76	-0.61	0.71	0.63	0.11
GMP g/100g FW	-0.69	0.74	-0.57	0.70	0.65	0.12
1-Pentanol	-0.29	0.73	-0.97	0.72	0.39	-0.34
α-Isopropylidene-2-	-0.14	0.67	-0.85	0.58	0.34	-0.33
EUC	-0.51	0.65	-0.14	0.60	0.72	-0.14
2-Heptenal	-0.40	0.60	-0.59	0.47	0.38	0.21
2-Methylfuran	-0.43	0.60	-0.55	0.60	0.38	0.23
2-Pentenal	-0.69	0.59	-0.30	0.45	0.61	0.31
1-Penten-3-ol	-0.59	0.57	-0.79	0.66	0.29	0.04
2-Propylfuran	-0.49	0.54	-0.43	0.50	0.39	0.33
Octanal	-0.32	0.51	-0.45	0.38	0.30	0.30
2-Ethylfuran	-0.27	0.48	-0.35	0.53	0.25	0.21
Decanal	-0.09	0.38	-0.41	0.30	0.10	0.22
Sucrose mg/g FW	-0.03	0.34	0.27	0.42	0.13	-0.53
5-Methylhexanal	-0.14	0.18	0.01	0.10	0.10	0.41
α-Copaene	-0.16	0.15	0.00	0.13	0.05	0.45
Propanal	-0.45	0.12	-0.01	0.10	0.09	0.63
Nonanal	0.13	0.04	-0.30	-0.02	-0.28	0.44
β-Cubebene or other	0.30	0.00	-0.21	0.03	-0.33	0.14
Glutamate g/100g FW	0.09	-0.02	0.53	-0.05	0.19	-0.22
Dimethylsulfide	-0.15	-0.02	-0.39	-0.12	-0.27	0.70
Fructose mg/g FW	0.03	-0.03	0.54	-0.03	0.30	-0.39
2-Heptanone	-0.03	-0.04	-0.11	0.14	0.00	-0.44
Pentane	-0.18	-0.10	-0.43	0.01	-0.27	0.21
Aspartate g/100g FW	0.31	0.22	0.61	0.23	0.02	-0.43
2-Octenal	-0.49	-0.30	0.41	-0.35	0.06	0.40
2-Butylfuran	-0.21	-0.36	0.51	-0.28	-0.02	0.11
Glucose mg/g FW	-0.36	-0.36	0.40	-0.31	-0.08	0.44
Ethylacetate	0.01	-0.36	-0.16	-0.46	-0.38	0.16
2-Propanone	0.76	-0.39	0.21	-0.37	-0.44	-0.43
dimethyltrisulfide	0.58	-0.43	0.26	-0.43	-0.40	-0.43
2-Hexenal	-0.40	-0.44	0.48	-0.37	-0.22	0.64
Furfural	0.84	0.45	0.37	-0.47	-0.49	-0.27
Benzaldehyde	0.64	-0.51	0.19	-0.36	-0.78	0.11
Heptanal	-0.09	0.52	0.50	-0.45	-0.22	0.12
2-pentylfuran	0.02	-0.55	0.56	-0.47	-0.23	0.05
Dimethyldisulfide	0.59	-0.57	0.49	-0.44	-0.47	-0.44
E-(or Z)-2-(2-pentenyl)furan	0.24	-0.66	0.62	-0.51	-0.42	0.02
Methional	0.46	0.67	0.43	0.60	0.55	-0.21
Benzeneacetaldehyde	0.30	-0.70	0.18	-0.55	-0.76	0.12
E-(or Z)-2-(1-pentenyl)furan	0.10	-0.70	0.64	-0.59	-0.42	0.20
1-Penten-3-one	0.26	-0.72	0.71	-0.69	-0.38	0.15
4-Heptenal	0.19	0.74	0.60	0.64	0.51	0.10
Unknown (RRI 845)	0.59	-0.75	0.31	-0.67	-0.92	0.37
Furan	0.81	0.78	0.57	0.71	0.76	-0.09
Unknown (RRI 1219)	0.13	-0.79	0.81	-0.71	-0.47	0.33
2,4-heptadienal	0.07	-0.80	0.78	-0.73	-0.51	0.48
2-Nonenal	0.03	0.81	0.43	0.79	0.64	0.42
3-Methylbutanal	0.55	0.81	0.44	0.71	0.79	0.00
2-Methylbutanal	0.53	-0.84	0.39	-0.72	-0.85	0.07
2-Methylpropanal	0.56	-0.87	0.49	-0.75	-0.83	0.10
Chaconine mg/100g FW	0.47	0.92	0.61	0.90	0.89	0.64
Solanine mg/100g FW	0.57	-0.95	0.62	-0.92	-0.91	0.48

Ar: Aroma

Int: Intensity

Sw: Sweet

Sa: Savoury

Cr: Creaminess

Of: Off

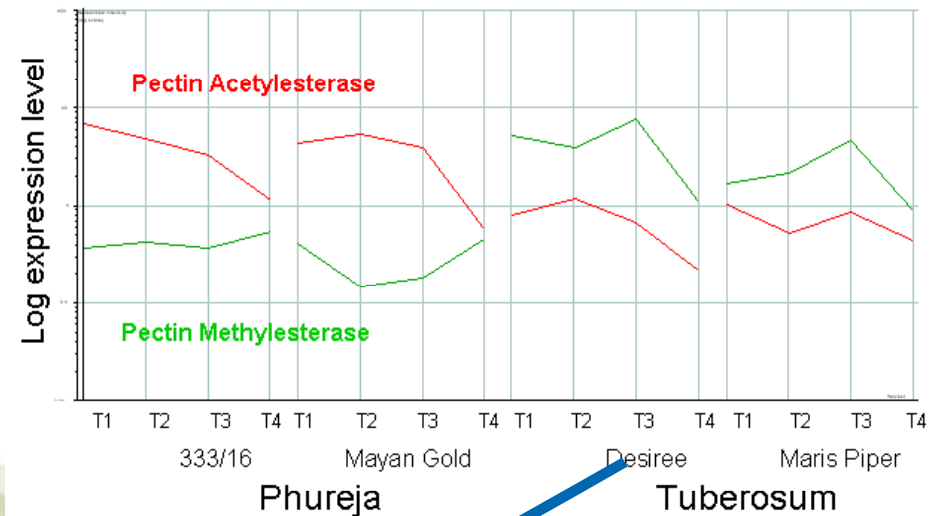
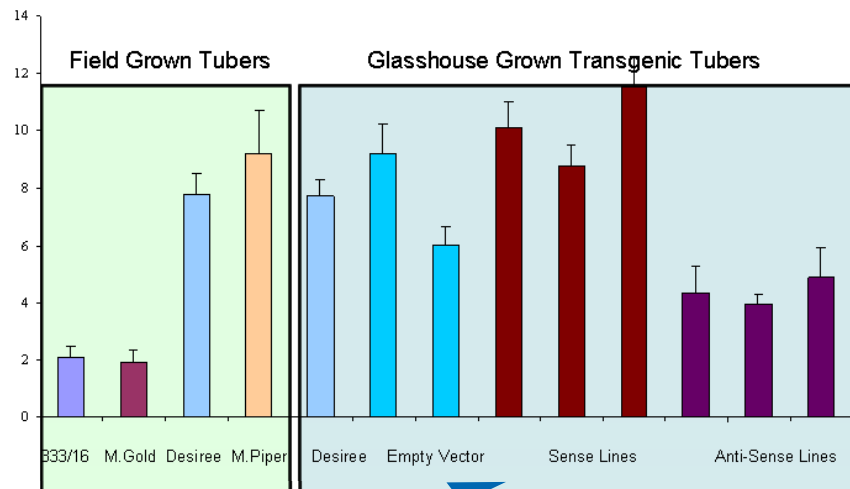
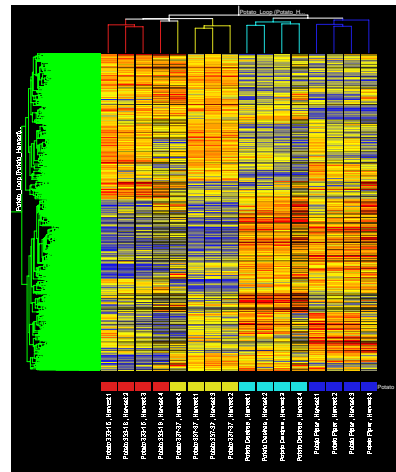
+ve correlation > 0.5

-ve correlation < -0.5

Morris WL, Shepherd T, Verrall SR, McNicoll JW and Taylor MA (2010) Phytochemistry 71, 1765-1773



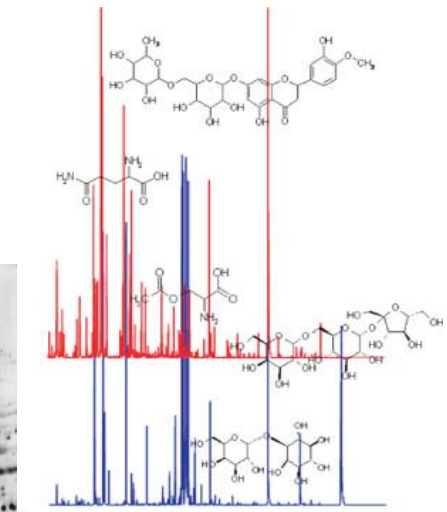
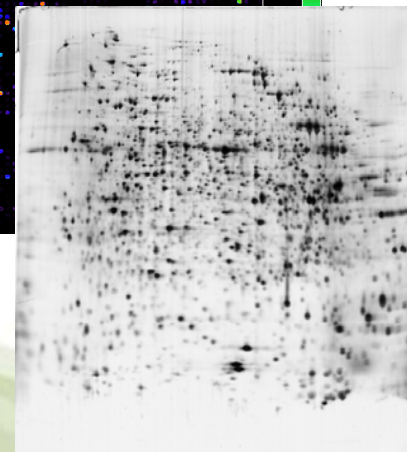
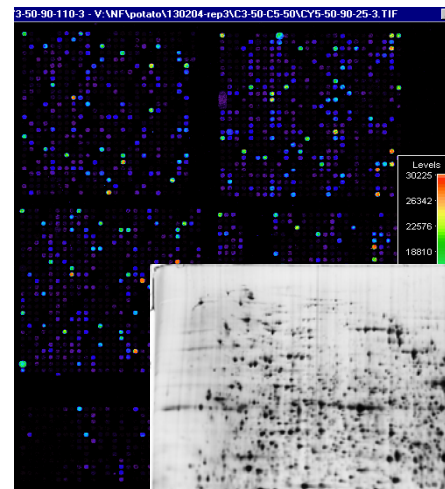
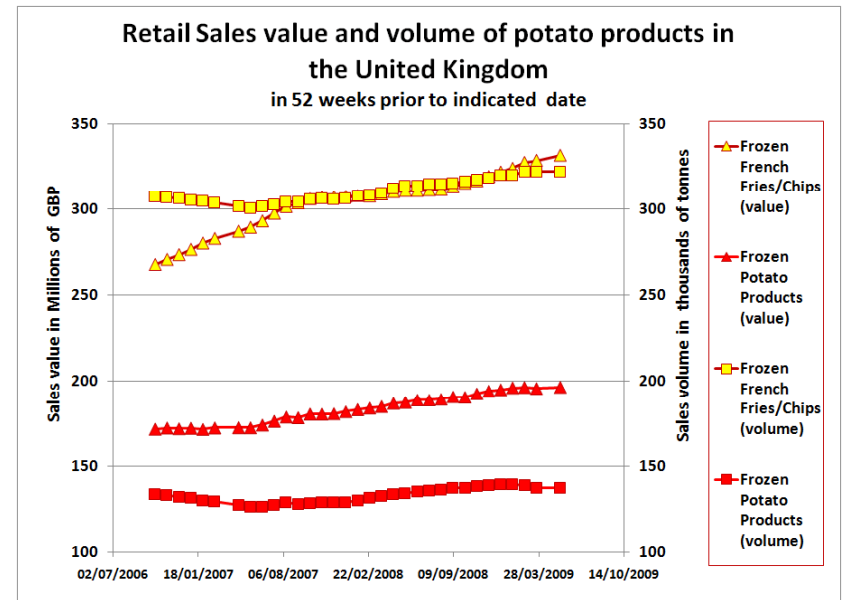
# A paradigm for modern, state-of-the-art food research





## Food Safety

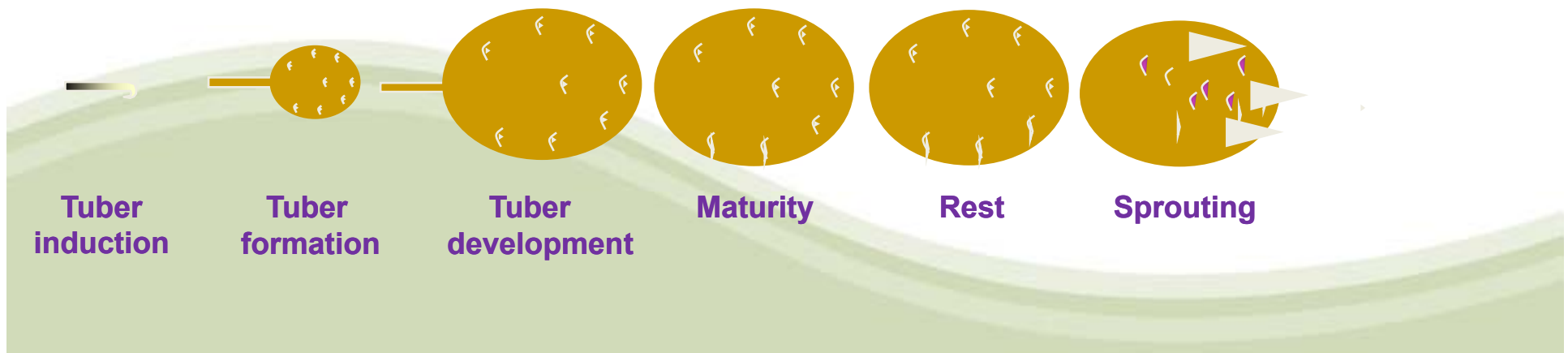
- Acrylamide in processed potato.
- Acrylamide has been added to EU's candidate list of substances of very high concern).
- Application of “omics” approaches in risk assessment.





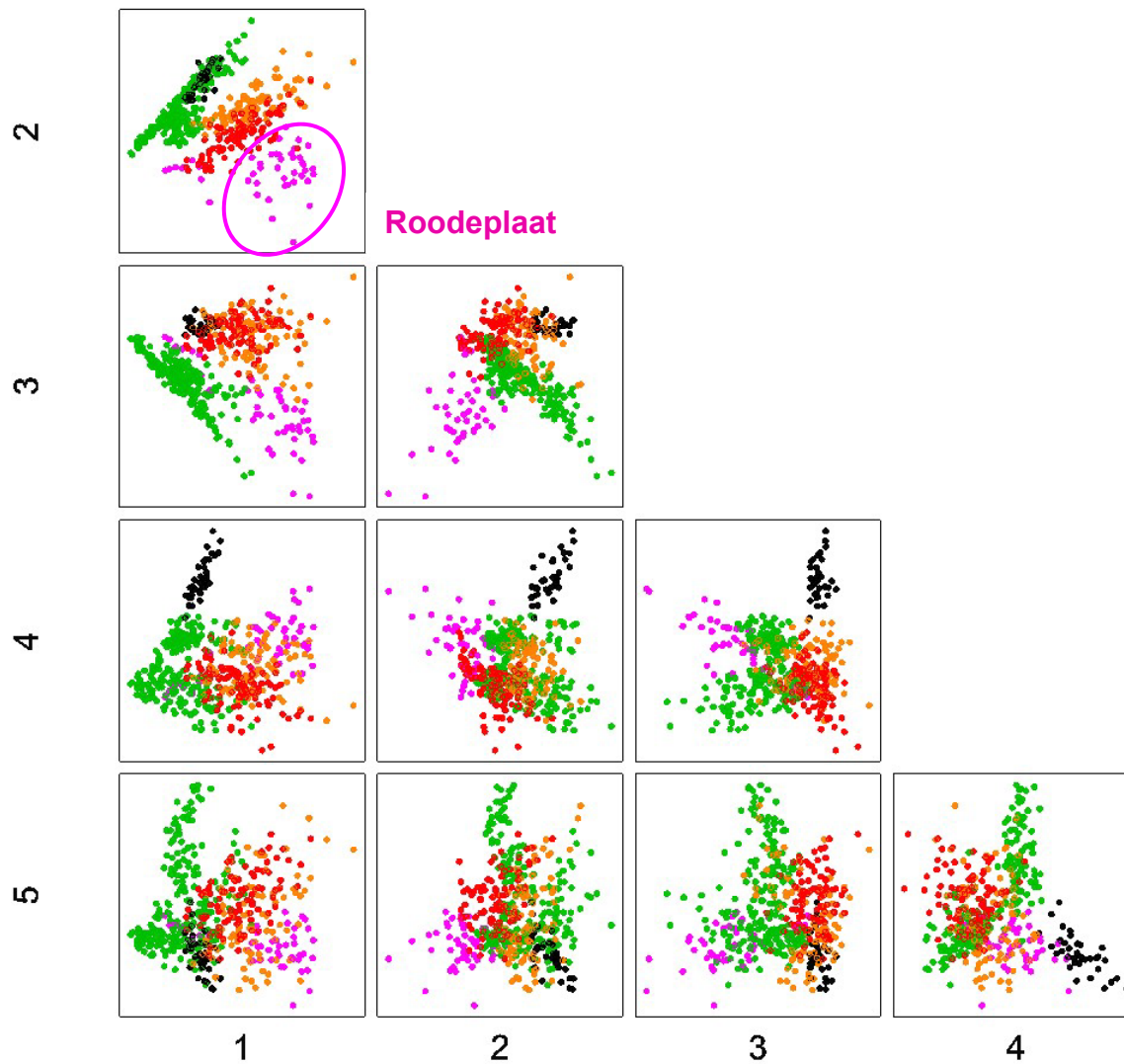
# Approach

- Phenotypic diversity – germplasm collections.
- Temporal changes in phenotypes- tuber development.
- Linking metabolites & phenotypes with genes.
- Hypothesis testing - system perturbations, GM, mapping.
- Contemporary & multidisciplinary approaches.





# G x E



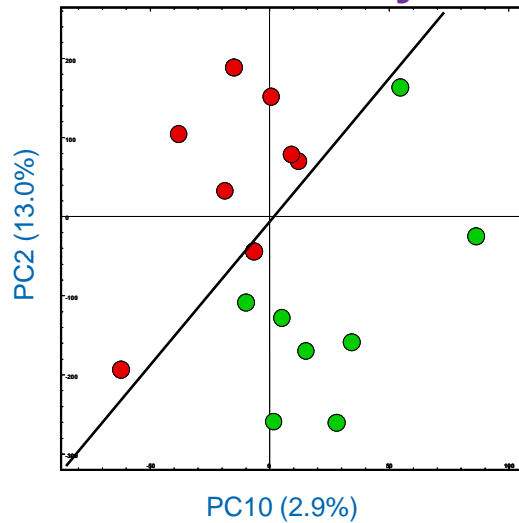
■ Poland  
 ■ ■ ■ South Africa  
 ■ UK

GM  
 Non-GM  
 Organic  
 Conventional

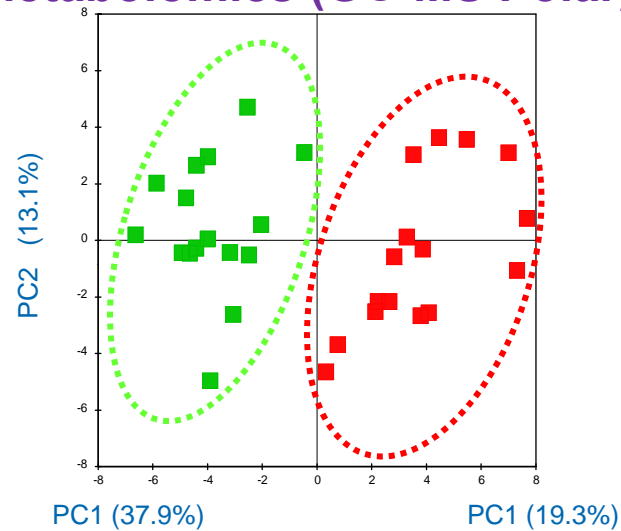


# Crop Management

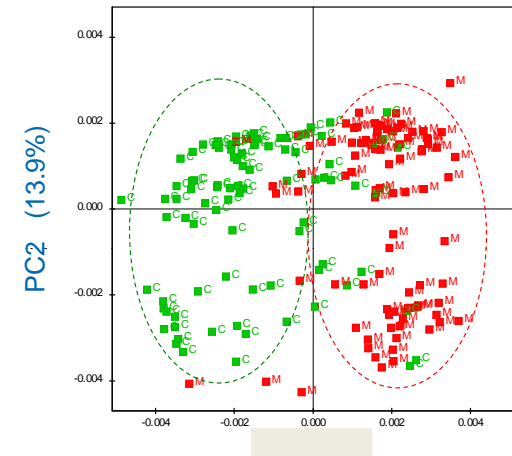
Microarray



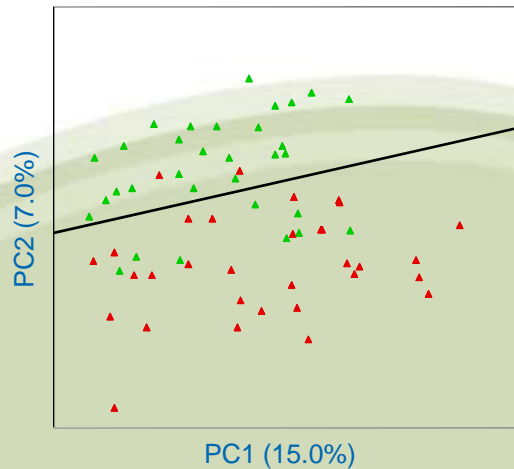
Metabolomics (GC-MS Polar)



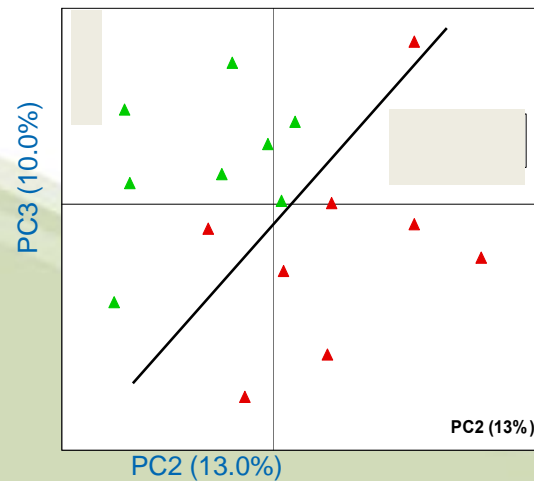
LC-MS



Proteomics



NMR



- conventional
- organic

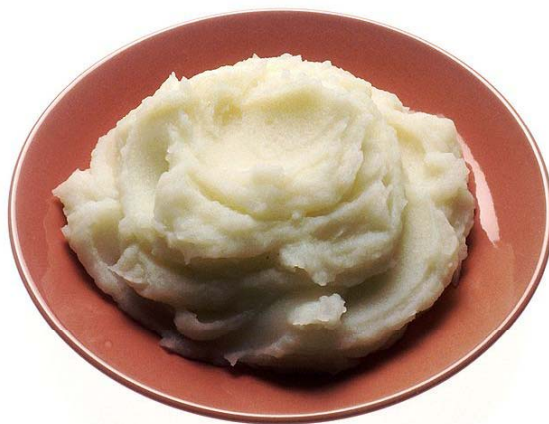
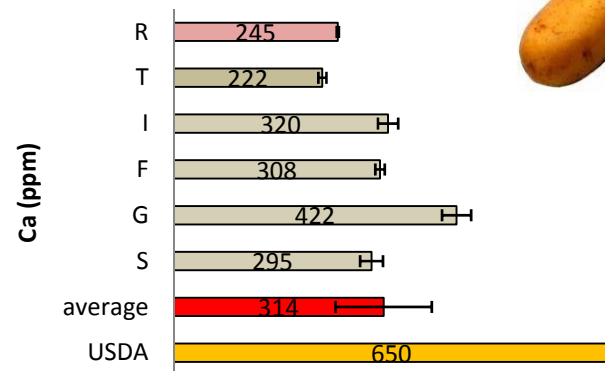


# Food Quality

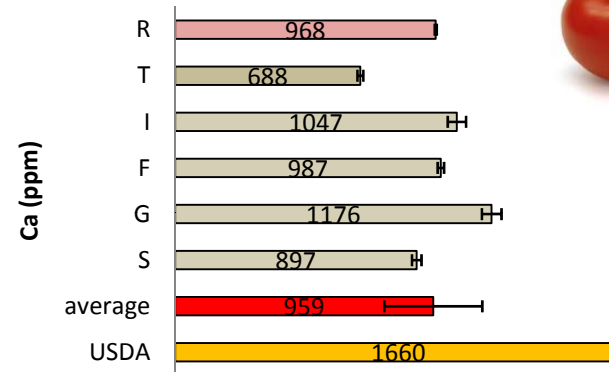


**Develonutri**  
CROP-BASED NUTRITION

## potato



## tomato

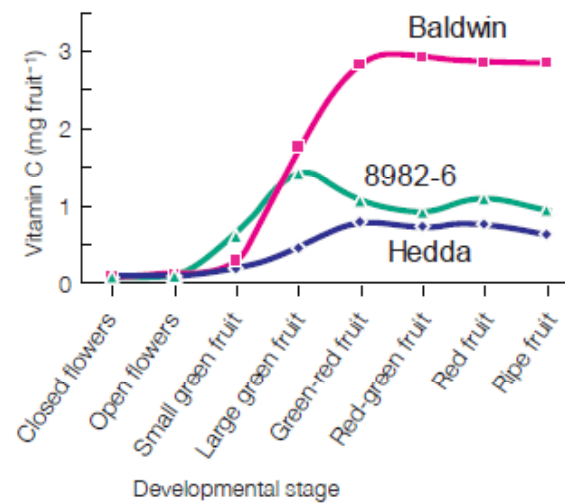
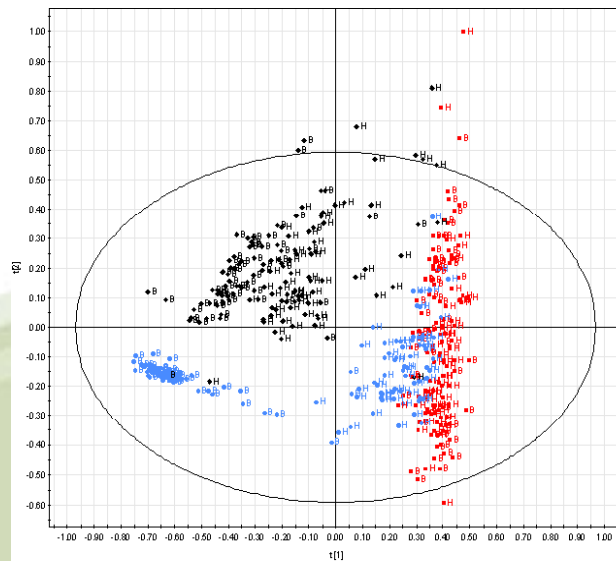




# Plant Products

Focus: The diversification of the food, drink and non-food crop sectors via plant product bioactivity and functionality research.

Aim: Determine the causal components behind plant food, drink and non-food crop functionality and bioactivity and exploit this sustainably via biodiverse resources.



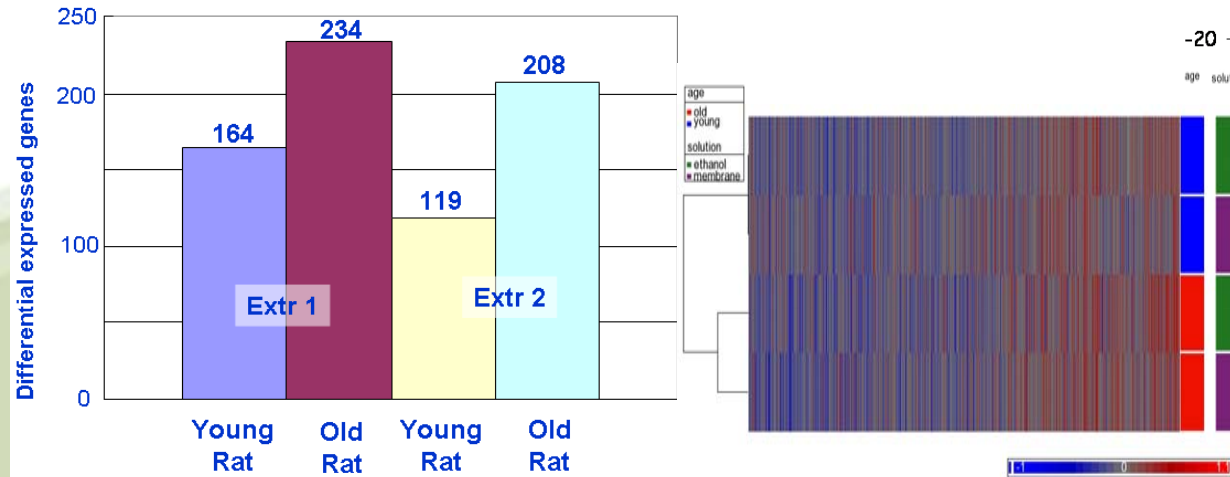


# Plant Products

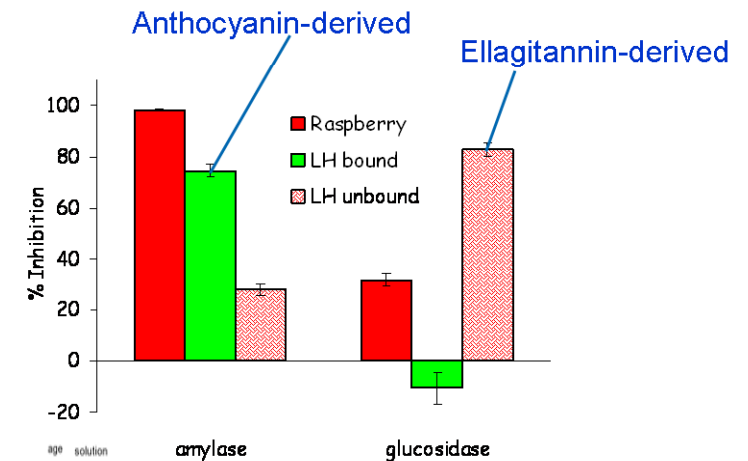
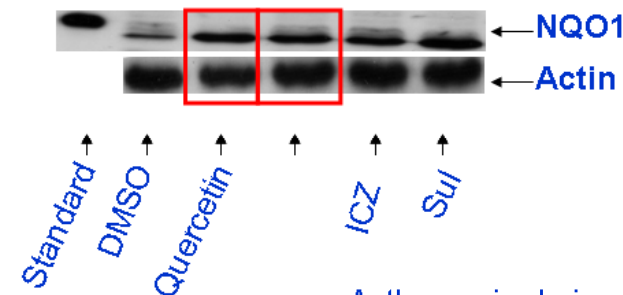
## Bioactivity

- Impact of plant products on degenerative diseases (cancer, CVD, neurodegeneration etc).
- Interaction of plant products with digestive processes.
- Interaction of plant products on gut microflora

## Age-related Rat Liver Gene Expression Following Blackcurrant Consumption



## Stimulation of liver NQO1 by fruit flavonols





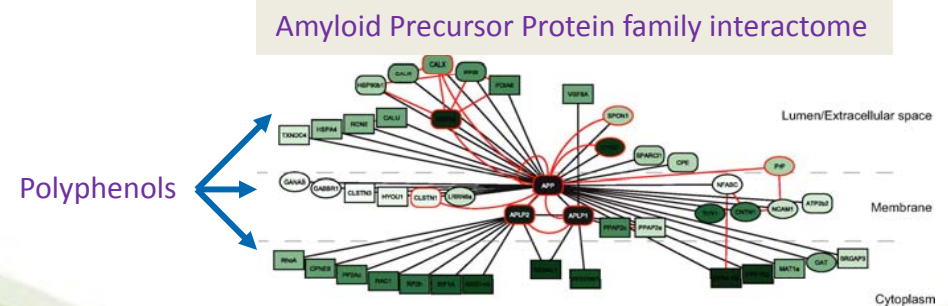
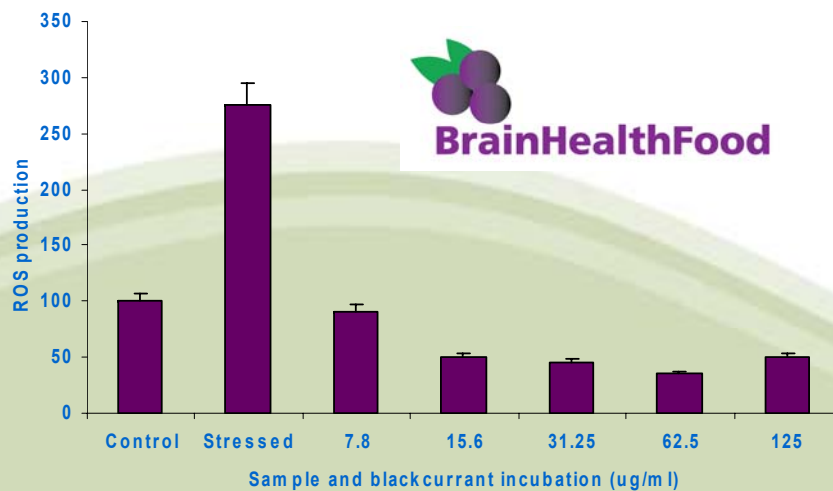
# Plant Products

## Functionality

- Development of a bioactive bread – Barleybread
- Development of fruit waste as a function aid for neuroprotection
- Anti-obesity functionality from developed plant products and historical folk medicine.



## Neuroprotection via blackcurrant polyphenol pre-incubation





# Plant Products & Human Health

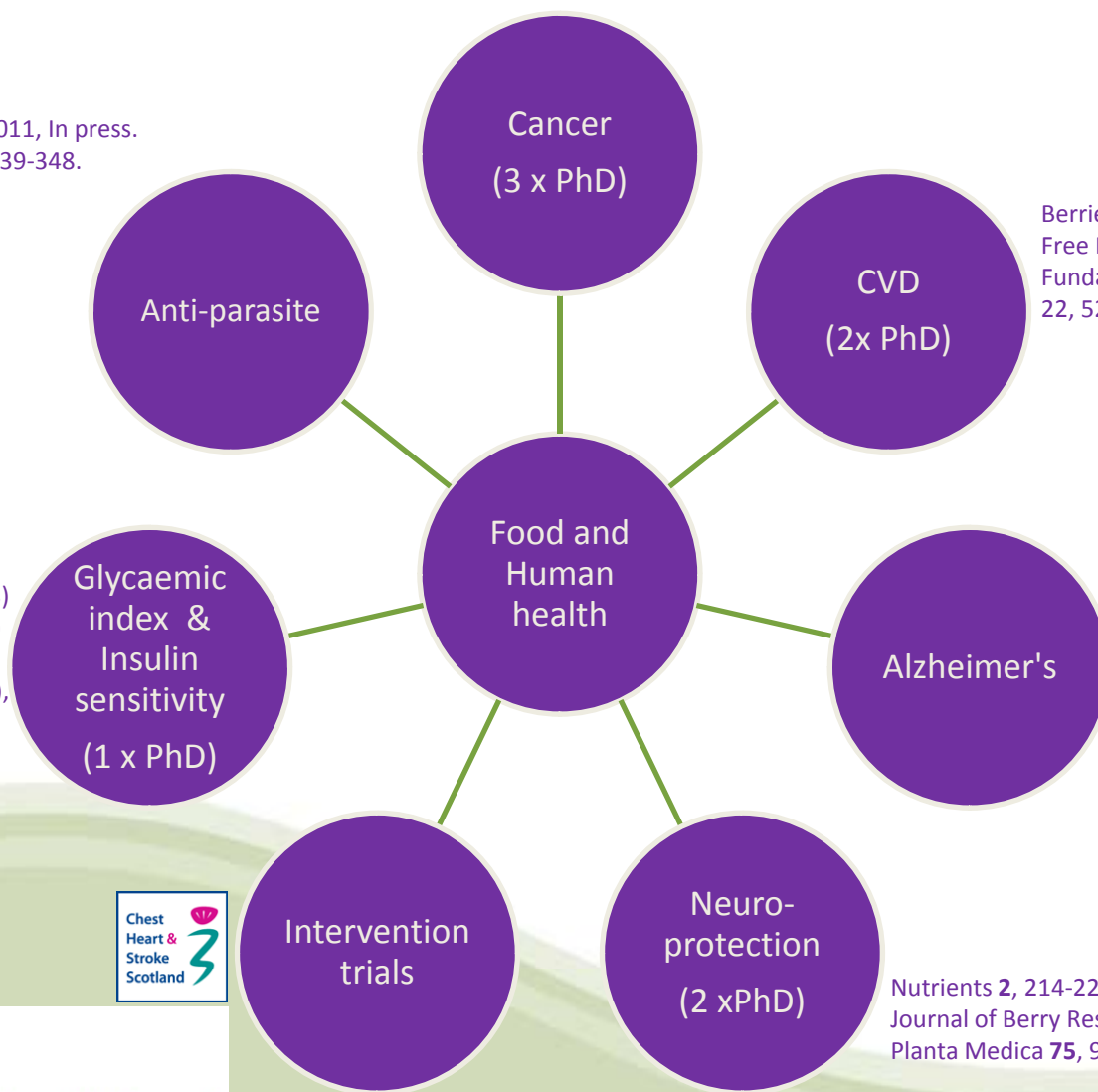


Curr Pharm Biotechnol. 2011, In press.  
Int J Oncol. 2009, 34, 777-86.  
J Agric Food Chem. 2008, 56, 3016-23.  
J Carcinog. 2007, 6, 4-11.  
Phytochemistry. 2007 68, 218-28.

Parasitology 2011, In press.  
Methods 42, 339-348.

Berries and Human Health 2009  
Free Radicals, Health and Lifestyle 2009  
Fundamental and Clinical Pharmacology  
22, 52-52, 2010.

Aging Cell 7, 69-77 (2008)  
Diabetes 57, 699-700 (2009)  
Diabetes (2011, in Press)  
Food Chemistry, 126(3),  
1006-1012 (2011).



Nutrients 2, 214-229.  
Journal of Berry Research 1, 3-12.  
Planta Medica 75, 923



# Commercialisation and Outreach





# Commercialisation and Outreach

## Blackcurrant 'is top superfruit'



**DUNDEE** Blackcurrants have been hailed as the ultimate "superfruit" that can help to fight cancer, heart disease and Alzheimer's, according to a review of published research.

The British berry was judged to be more nutritious than many other fruits, including blueberries and goji berries. The analysis by the Scottish Crop Research Institute (SCRI) concluded that the blackcurrant contained more vitamins, minerals and antioxidants than 20 other fruits tested. Researchers said that compounds in the berry called anthocyanins can help

**THE TIMES**

## Daily Mail



**Squeezing ahead: Blackcurrants**

IT must compete for space on supermarket shelves with exotic 'superfruits' from across the globe. But the home-grown blackcurrant is the healthiest of them all, say scientists.

A study of 20 fruits found that blackcurrants were the most nutritious. They also contained the highest levels of antioxidants - compounds with the ability to stave off illnesses including heart disease and cancer.

Dr Derek Stewart, of the Scottish Crop Research Institute, who carried out the study, said: 'The combined beneficial composition and impact in health-related studies mean that blackcurrants can claim to be the number one superfruit.'

Besides blackcurrants, Dr Stewart analysed apples, apricots, bananas, blackberries, blueberries, cherries, cranberries, grapefruit, grapes, lemons, mangoes, melons, oranges, passion fruit, peaches, pears, pomegranate, raspberries and strawberries.



**Study claims blackcurrant is the No 1 'superfruit'**

By Emily Thompson Reporter

THE humble blackcurrant is the ultimate "superfruit", according to a new study by scientists at the Scottish Crop Research Institute (SCRI). The berry is more nutritious than many other fruits, including blueberries and goji berries. The analysis by the Scottish Crop Research Institute (SCRI) concluded that the blackcurrant contained more vitamins, minerals and antioxidants than 20 other fruits tested. Researchers said that compounds in the berry called anthocyanins can help

## SCRI takes major role in ClimaFruit group aiming to boost berry industry

Four year award £2.5m budget to cut chemical use and carbon footprint of soft fruit sector

**NEWSPAPER ARTICLE**

Scientists at the Scottish Crop Research Institute (SCRI) have been awarded a four-year, £2.5m grant to lead a major project aimed at reducing the chemical use and carbon footprint of the soft fruit sector.

The project, known as ClimaFruit, is a joint venture between SCRI and a group of commercial growers. It aims to develop new varieties of soft fruits that are more resistant to pests and diseases, thereby reducing the need for chemical pesticides.

Dr Derek Stewart, SCRI's director of research, said: "This grant will enable us to carry out world-leading research into the genetic diversity of soft fruit crops. We will be looking for new sources of resistance to pests and diseases, and developing new varieties that are more resilient to environmental stresses."

## They're berry good for you

The superfruits that boost health and help ward off diseases from cancer to Alzheimer's

**A** study of 20 fruits found that blackcurrants were the most nutritious. They also contained the highest levels of antioxidants - compounds with the ability to stave off illnesses including heart disease and cancer.

Dr Derek Stewart, of the Scottish Crop Research Institute, who carried out the study, said: 'The combined beneficial composition and impact in health-related studies mean that blackcurrants can claim to be the number one superfruit.'



## Oats are so good!

ONCE THE foundation crop of Scottish agriculture, but now regarded as something of a marginal interest, oats could be set to make a comeback, courtesy of the Scottish government's funding.

SCRI, in take part in a major study to develop new varieties of oats that will provide significant economic and environmental benefits for growers.

and environmental sustainability," he added.

Rural Affairs Cabinet Secretary, Richard Lochhead, said: "The Scottish Government is part-funding this five-year project through a £480,000 investment, as part of our commitment to supporting our world-renowned science base and farming industry.

"This should benefit not only the scientific community but also boost Scottish agriculture and stimulate



# Research Aspirations for Food and Drink



- Research at the fundamental level in crops and animals is being addressed for selected issues in the UK and Europe. Targets are still yield & disease resistance. The areas of quality, efficacy, as well as sustainability, are open for exploitation and development.
- At the other end of the scale this is addressed by companies in-house” or e.g. Camden BRI. However depth of analysis and translation back through the chain is lacking
- A major research gap exists at the between these two: taking the crop and plant chemistries and translating these into food and drink scenarios. This is a research space that attracts significant funding: EU, RCUK initiative, PPPs. [Food Security].
- Position the Department as the place to do this. (SFC food and Drink initiative: Scotland Food and Drink Ltd Innovation Centre; Food and Drink Industry Division, Scottish Government; RCUK - Food Security etc).



# Research Aspirations for Food and Drink

## Sustainability.

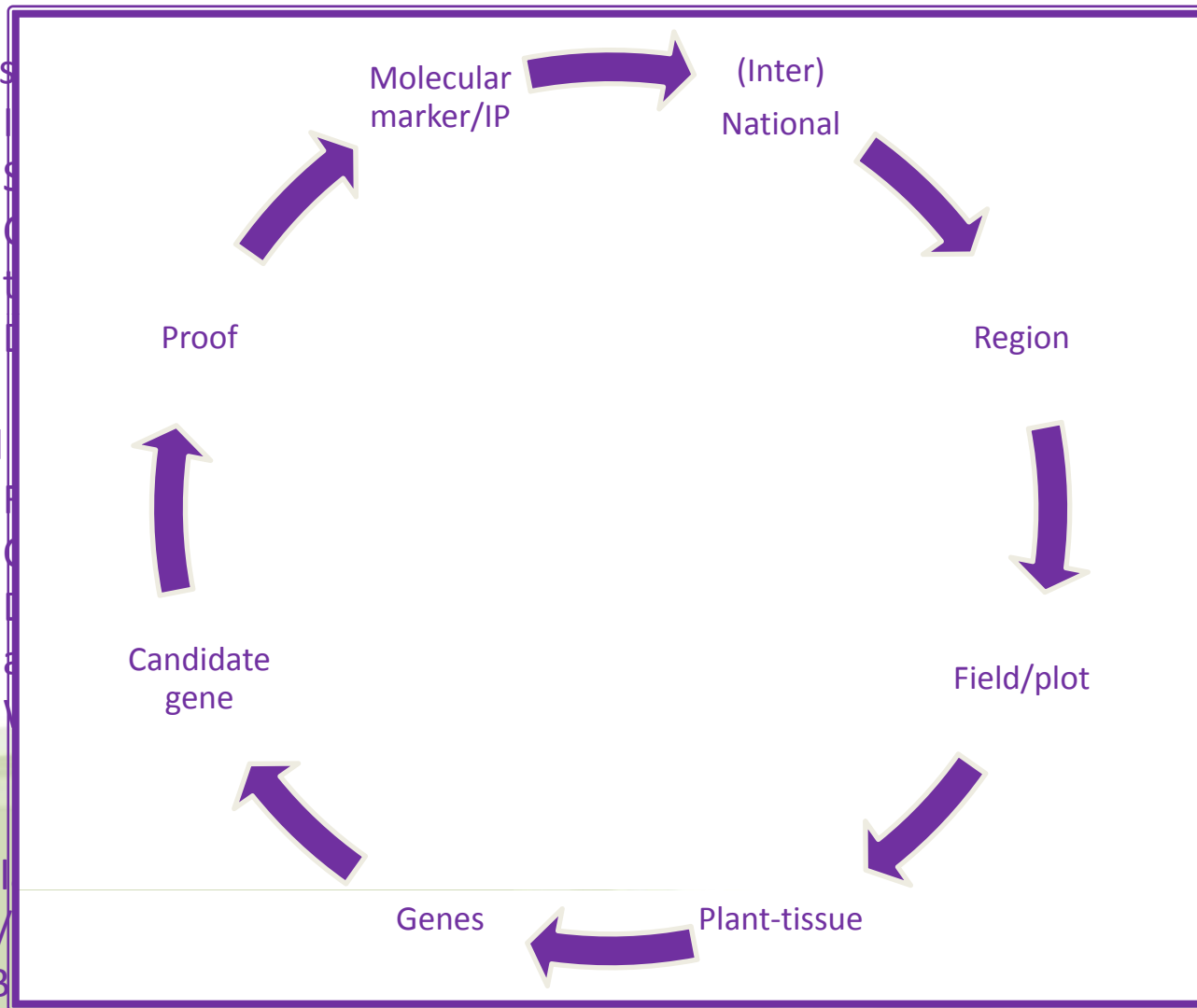
- Crops

- Crop yield
- Crop quality
- Crop resilience
- Crop sustainability

- Food

- Food security
- Food quality
- Food safety
- Food sustainability

Exemplar  
BBSRC/  
EU - KB



Centre for

International

al  
harides.



# Research Aspirations for Food and Drink



## Plant derived food and drink bioactivity and functionality

- Polyphenols from soft fruit – CVD/Cancer/Obesity/Diabetes/Neurodegeneration/Antibacterials.
- Polysaccharides – prebiotic/colon cancer/satiety/obesity.
- Avenamthramides (oats), alkylresorcinols- antiinflammatory.
- Carotenoids – reduced cellular oxidative stress.

Biomedical and clinical network are in place.

*In vitro* and selected *in vivo* research on going.

Needs translation into real food and drinks.

Food functionality requires research: stability, matrix interaction, encapsulation, bioavailability, true efficacy etc.

Functionality testing as part of an HWU consortium would be viable

- Evidence that fruit polyphenols impact beneficially on cognitive function and visual acuity. If proven in a valid trial this would be highly attractive to the soft drinks and the results would feed back to fruit breeding programmes (JHI).
- The impact of fruit polyphenols on oxidative stress cascades is accruing evidence. Real scenario testing, e.g. With a high end sports team, would be a viable test bed to prove efficacy, viability. This could work in combination with the ongoing  $\beta$ -glucan research

## Exemplar Calls

KBBE.2012.2.2-01: Beneficial effects of bioactive compounds in humans.

KBBE.2012.2.3-01: Feed production from food waste.

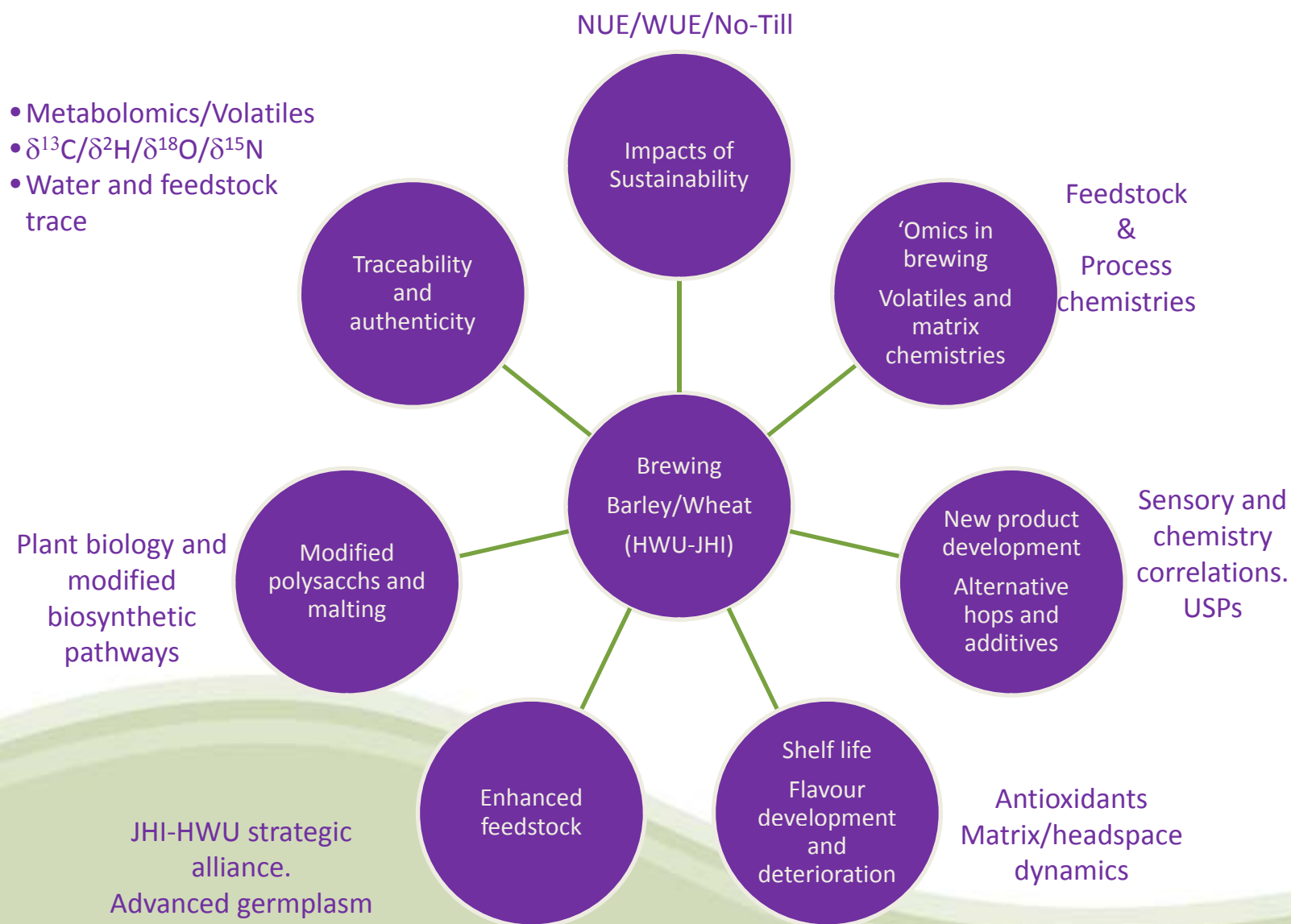
BBSRC - Industrial partnership awards; Bioprocessing Research Industry Club (BRIC); Diet and Health Research Industry Club (DRINC);

Integrated Biorefining Research and Technology Club (IBTI Club)

EPSRC - Technology Strategy Board Collaborative Research and Development and Innovation Platform Competitions.

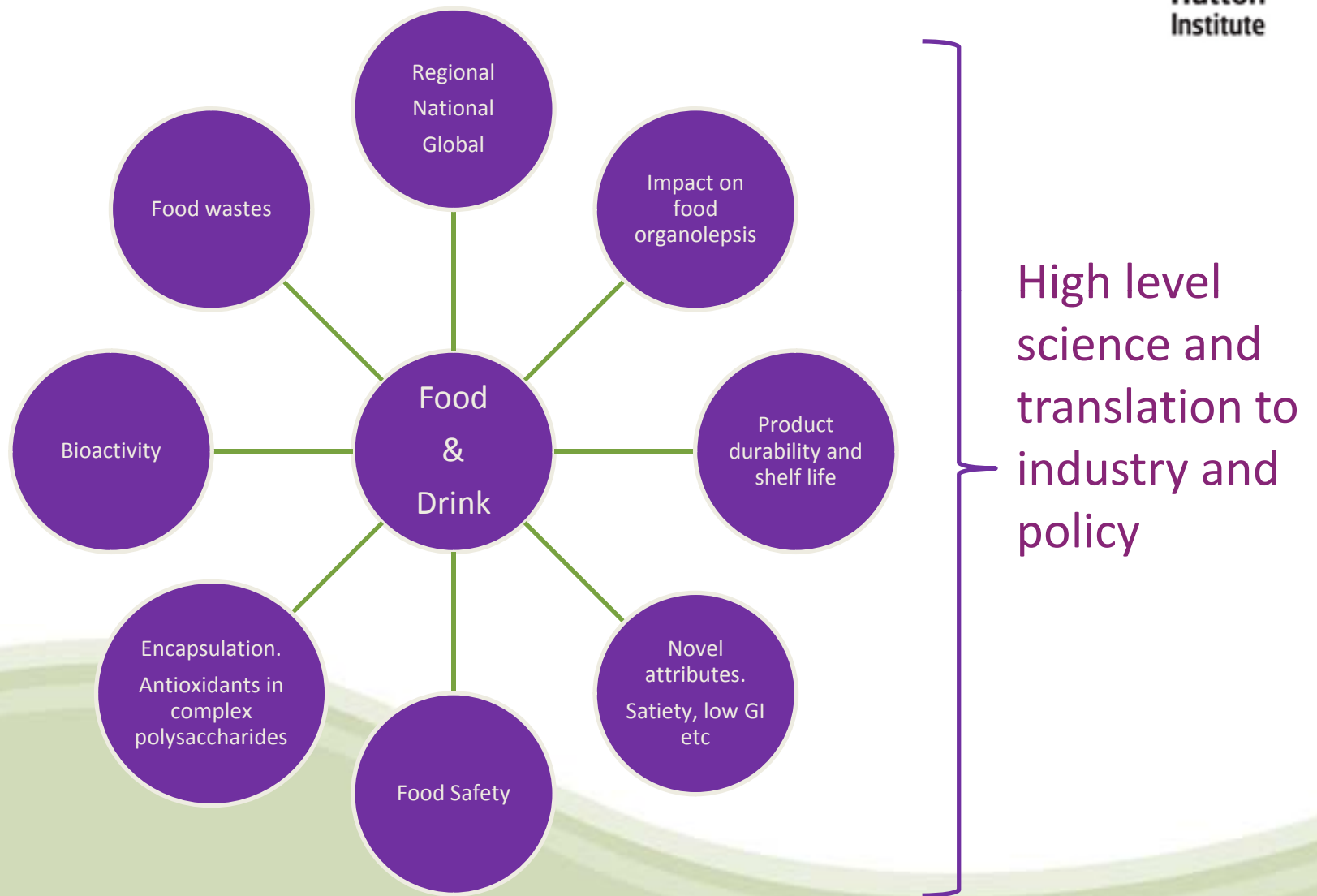


# Research Aspirations for Food and Drink





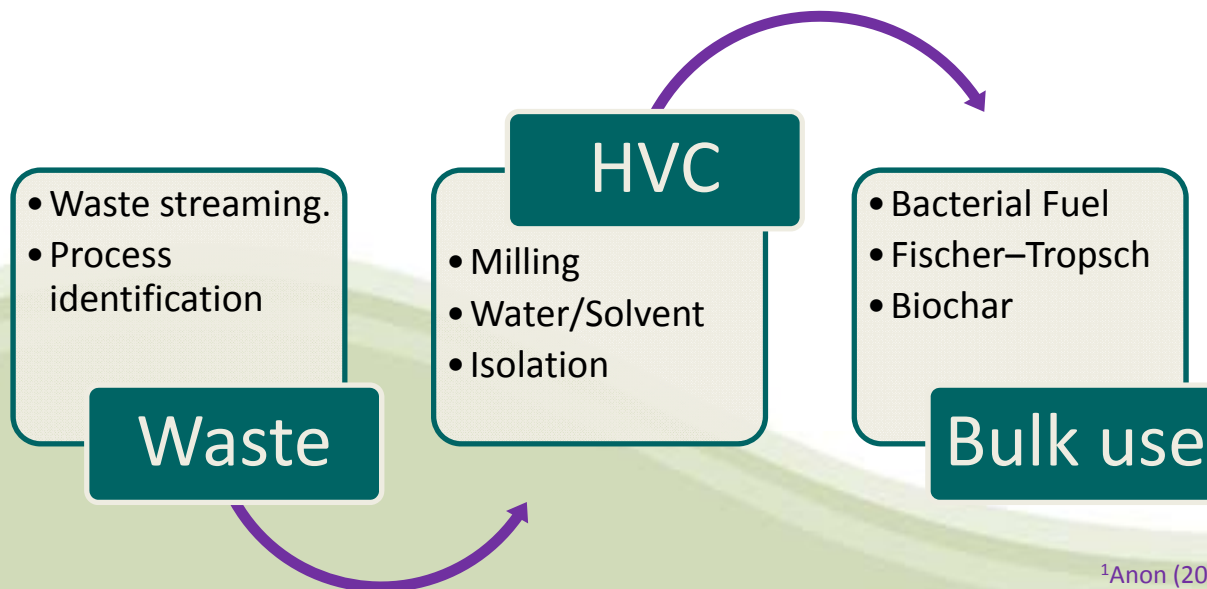
# Research Aspirations for Food and Drink





# Food wastes - Revalorisation

- It is estimated<sup>1</sup> that 8.3 ( $\pm 0.3$ ) MT per year of food and drink waste is generated by households in the UK.
- At the agricultural level often 20% of the crop (potato, turnip, carrot etc) is classed as spoiled or waste
- Selected food wastes can represent significant sources of high value chemicals or carbon skeletons;
  - Potato – protein/peptides, glycoalkaloids
  - Carrot - carotenoids
  - Fruit – polyphenol (anthocyanins, flavonols etc).
- Bulk biomass is complex polysaccharides. This lends itself to a biorefinery approach to utilisation.
- TSB for Nov '11: High Value Chemicals/Biorefinery/ Wastes as a source of bioactive molecules for the consumer goods industry



<sup>1</sup>Anon (2009) Household Food and Drink Waste in the UK; Final Report. WRAP



# Food wastes - Revalorisation

Optimised Bacterial Fermentation As A Viable Source For Bioethanol Production.



Screen the Pectobacteria isolates for activity

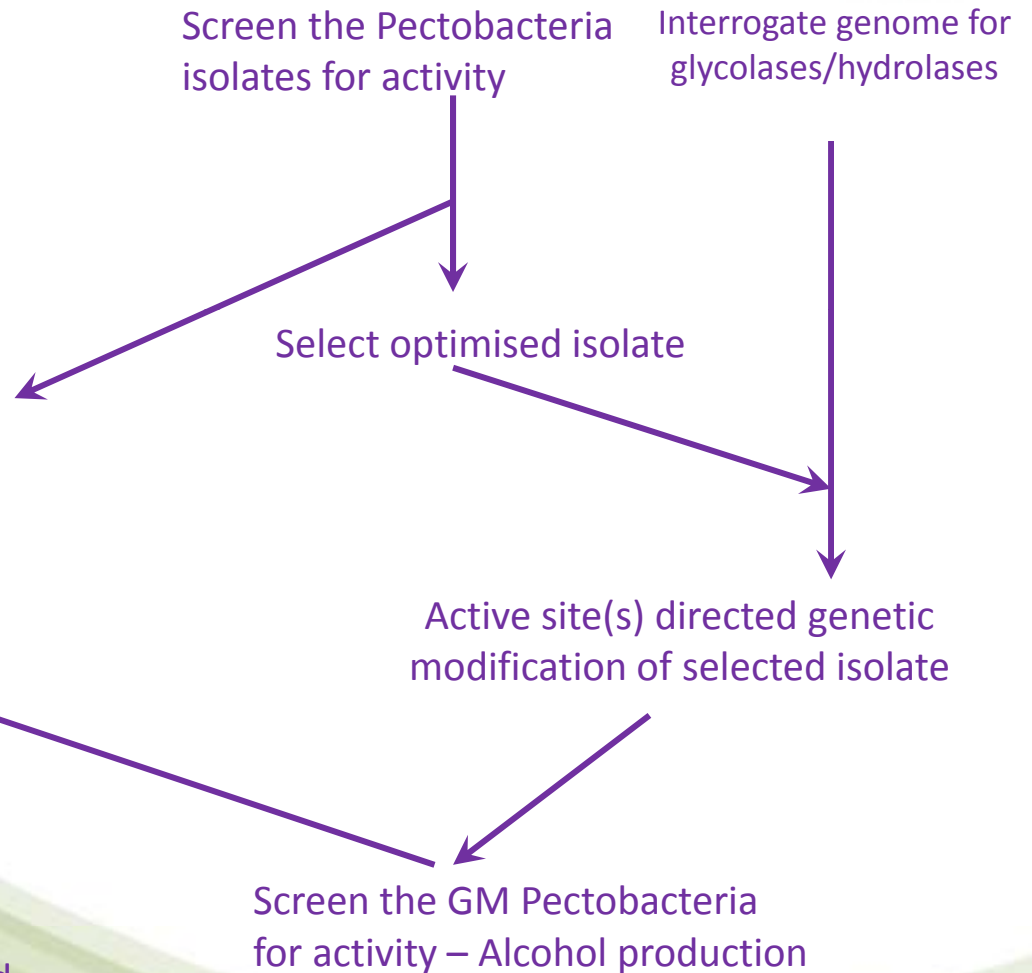
Interrogate genome for glycolases/hydrolases

Select optimised isolate

Active site(s) directed genetic modification of selected isolate

Screen the GM Pectobacteria for activity – Alcohol production

Pectobacteria and feedstocks: Model crop and waste polysaccharides





# Research Aspirations for Food and Drink



## HWU Collaborations

- Development of new statistical and mathematical approaches to mine 'omics data (food, plant brewing etc) (MACS).
- Changes in nutritive value throughout the food chain. Establish the relative merit (economic and nutritive) of local versus imported food and to identify the sectors within the food chain wherein nutritive (and economic) values is lost. Logistics Research Centre.
- Development of a (International) Centre for Food Safety. LS, TMS, CNG, MSME etc. Combined group addressing issues surrounding food composition, matrix interactions (implications for dosing), transport chain and duration, nano-issues, toxicology, bioactivity, nutrition, modelling etc.



# Research Aspirations for Food and Drink

## Routes to realisation



SFC - Scottish Universities Industry Innovation Network for Food and Drink

EU-RTD: Feedstock based research – climate change, environment, sustainability, fundamental plant biology.

EU-Capacities – Research for SMEs

Completed: Barley bread, BrainHealth food

In preparation:

- Po-taste-o – Agronomic practices to manipulate and optimise potato quality
- PolyphenolRichFood - Polyphenol-rich foods for prevention of functional decline of the elderly.
- Func-i-Bev - Development of Wild Grown Fruits as a Source of Functionality in Beverages (Func-i-Bev)

EU-Interreg IVB: Climafruit (€6.2M, JHI € 1.1M)

- Developing the NWE knowledge-based economy by capitalising on our capacity for innovation.
- Sustainable management of natural resources and of natural and technological risks.
- Promoting strong and prosperous communities at transnational level

EU- Marie-Curie Actions: Single person grants (consumables rich)

EU- Centre of Excellence.

RCUK/DEFRA – Numerous strategic and targeted priorities many food and drink related: Food Security and Living with Environmental Change (LWEC).

Scottish Enterprise

- Proof of concept
- Scotland Food and Drink Innovation network/centre

Public Private Partnerships

- Technology Strategy Board
- Knowledge Transfer Partnership



# Competitive Grants



- EU EUBerry: The sustainable improvement of European berry production, quality and nutritional value in a changing environment: Strawberries, Currants, Blackberries, Blueberries and Raspberries
- EU ClimaFruit - Future proofing the North Sea berry fruit industry in times of climate change
- EU METAPRO - The development of tools and effective strategies for the optimisation of useful secondary metabolite production in plants
- EU *BRAINHEALTHFOOD - Bioactive compounds from blackcurrant processing waste for brain health*
- EU *DEVELONUTRI - Development of high throughput approaches to optimise the nutritional value of crops and crop-based foods*
- EU *EU-Sol - High quality solanaceous crops for consumers, processors and producers by exploration of natural biodiversity*
- EU *BARLEYBREAD - European guidelines for healthy high fibre, low salt baking process based on the use of European barley*
- EU *SAFEFOODS - Promoting food safety through a new integrated risk analysis approach for foods*
- EU *NOFORISK - Quantitative risk assessment strategies for novel foods*
- EU *NORTHERN BERRIES - Natural antioxidants in fruit.*
  
- LINK Development of high profile germplasm for UK production of blueberries
- LINK QUOATS; Harnessing new technologies for sustainable oat production and utilisation
- LINK Reducing energy usage and wastage by improving ethylene control of potato sprouting
- LINK Developing breeding and selection tools to reduce spoilage of soft fruit and wastage in the supply chain
- LINK Producing low acrylamide risk potatoes
- LINK *Integrated pest and disease management for high quality protected raspberry production*
- LINK *Understanding and improving flavour characteristics of potato*
- LINK *Develop physiological, agronomical and genetic tools for the selective increase of L-ascorbic acid content in blackcurrant*
- LINK *Physiological, biochemical and molecular characterisation of bud dormancy in woody perennial species*



# Competitive Grants



FSA	Development of a standard, validated procedure for the isolation of transgene flanking regions in GM crops and detailed analysis of transgene insertion
FSA	Development of unified data models and data pre-processing strategies and the generation of meaningful, standardised statistical analyses of metabolome variability in crop plants
FSA	Transcriptome, proteome and metabolome analysis to detect unintended effects in genetically modified potato RERAD Assessment of plant germplasm for bioactive molecules
KTP	Extending the shelf-life and reducing saturated fat levels of oatcakes
Scot. Ent.	Novel treatments for shelf-life extension of minimally processed foods
Scot. Ent.	Heath pea ( <i>Lathyrus linifolius</i> ): development of a natural appetite suppressant
Charity	Cardiovascular function and intake of soft fruit: effects of qualitative and quantitative variation in berry antioxidants status
Charity	Role of <i>Nrf2</i> in mediating cancer chemoprevention by fruit polyphenols
Industry	A new analytical tool for quality and authenticity control of premium Scottish Whisky.
Industry	Bacterial biofuels
Industry	Compositional analysis of blackcurrant/Manipulation of strawberry texture and nutritional content
Industry	Integrating quality trait development with large scale gene expression analysis in potato
BBSRC	Manipulating lignin to improve biofuel conversion of plant biomass
Res. Cncl.	Plant metabolites for healthy plants and healthy people
Res. Cncl.	Effect of methyl jasmonate on the bioformation of chiral volatile compounds in vegetable foods
Res. Cncl.	Development of metabolomics based methods to benefit assisted breeding in perennial ryegrass
Res. Cncl.	Rubus metabolomics; effect of inheritance and environment on beneficial phytochemicals