Annual Report 2014

Genes to Energy | Energy to Yield

plant energy biology
ARC CENTRE OF EXCELLENCE

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Plants are the elemental miners of the earth and the atmosphere, that have sustainably provided our food and resources throughout human history.

Understanding how they do this, and how changing climates will impact on their function is a key investment of our generation to safeguard our shared future.

Harvey Millar | Director, ARC Centre of Excellence in Plant Energy Biology

The Centre

Centre Overiew

Plants harvest huge amounts of energy from sunlight. This energy feeds, clothes and fuels our world.

The Australian Research Council Centre of Excellence in Plant Energy Biology (PEB) is focused on better understanding the way in which plants capture, convert and use energy in response to environmental change, with a view towards improved plant energy efficiency.

Mission and Vision

Our mission is to:

- define the complex system that determines overall energy efficiency in plants
- discover the key signals, 'gatekeeper' cells, and (epi)genetic controls that regulate this energy system and
- manipulate these in combination, to optimise energy efficiency across the whole plant in order to enhance yields.

Our vision is to enhance plant energy efficiency by simultaneously optimising energy capture, conversion and use in changing environments, in order to improve the sustainable productivity of plants.

Strategic Priorities

- To elucidate the fundamental mechanisms of energy biology regulation in plants.
- To be a leading Centre for advanced training and education for plant and computational biologists, in Australia.
- To build strategic collaborations for Australia within the international science community.
- To enhance plant biotechnologies in order to build technological innovations and aid Australian agricultural innovation.

Addressing a critical problem in Australia, for the world.

The world faces three interconnected threats to food security. These are:

- Limited agricultural resources (land, water and key nutrients).
- A rising human population and per capita food consumption.
- A yield gap that results from reduced productivity of crops in the face of mismatches between crop genetics and unpredictable environments.

Increasing overall 'plant energy efficiency' – the efficiency not only of energy capture, but also of energy conversion and use by plants in order to produce yield – is key to long-term food security.

Current international research aims at optimising single-input processes in order to increase plant productivity, for example photosynthetic rate or nutrient uptake. Plant function is, however, complex. Changing inputs alone can reduce the efficiency of downstream processes and thus limit their effectiveness.

Adding efficiency gains together, via molecular signalling and controls, can increase crop plant productivity. The Centre aims to increase the efficiency of energy conversion and use by plants by making plants better at allocating resources and more tolerant to environmental challenges.

This approach to improving the sustainable productivity of plants will aid in future-proofing food production for Australia and the world.

An innovative research plan.

PEB proposes a novel approach to improve sustainable plant yield, by optimising the overall efficiency of energy capture, conversion and use by plants. Rather than optimising single nutrient inputs or product outputs, efficiency gains in plant metabolism, transport, and development will be more effective at enhancing overall plant productivity.

Improving multiple parameters simultaneously is a necessary solution to the increasing demand for more crop yield from finite land, water, and nutrient resources. Unpredictable environmental challenges adversely affect plant growth and further perturb plant energy balance, limiting yield.

The epigenetic controls, gene variants and signals discovered will provide a new basis for sustainable productivity of crops and will future-proof plants in changing climates.

Enhancing plant energy efficiency will be approached via three Research Programs, which combine to translate molecular insights into whole plant performance.

These three programs are:

- P1: Energy metabolism and signalling
- P2: Gatekeeper cells and specialisation
- P3: Gene variants and epigenetics

The Centre brings together a collection of the world's best researchers in complementary disciplines, and integrates scientific research across the range of scales required to truly address the different aspects of the energy efficiency challenge in plants .

Collaboration, not competition.

Collaborating across Universities and with Industry Partners avoids the reinvention of approaches and draws on existing expertise. Sharing keeps our research at the cutting edge and builds an international network for its recognition and implementation.

Launch of the Australian Research Council Centre of Excellence in Plant Energy Biology, 2014-2020.

In 2014 the Australian Research Council awarded funding to the Centre of Excellence in Plant Energy Biology, to see research through till the year 2020. The new Centre builds on the successes of the former Centre, which existed from 2005 to 2013.

The new Centre was showcased at an official launch on the 4th of August, 2014. Dignitaries, including Senator for Western Australia Chris Back, ARC Chief Executive Officer Professor Aidan Byrne, Chief Scientist of Western Australia Professor Peter Klinken and University of Western Australia (UWA) Vice Chancellor Professor Paul Johnson toured laboratory facilities at the Centre's administrating location, UWA. The Centre's research was showcased by Chief Investigators, staff and students representing all four of the Centre's research nodes.

Professor Aidan Byrne (ARC CEO) emphasised that while the Centre shares a name with a previous Centre the ARC does not automatically grant a renewal of funding.

"It is not good enough just to have done excellent research. To succeed again a Centre must be able to build from previous activity, it must identify new challenges and demonstrate the capacity to achieve them – it's not just about more of the same"

Prof. Aidan Byrne.

The ARC Centre of Excellence in Plant Energy Biology 2014-2020 was officially opened by Senator Chris Back.

"The Centre has already produced outstanding research outcomes in the past and will continue to do so for the next seven years that funding that has been assured. I look forward to the continued success of Harvey, PEB colleagues and of course your graduate and postgraduate students. It really gives me great pleasure to launch the Centre."

Senator Chris Back.

The ARC Centre of Excellence in Plant Energy Biology looks forward to undertaking new challenges and making scientific advancements.

Plant Energy Biology Fast Facts 2014

- 4 Collaborating Universities: The University of Western Australia (administrating organisation), The Australian National University, The University of Adelaide and La Trobe University.
- 10 Chief Investigators.
- 8 Partner Investigators in USA, Germany, Finland, Sweden and China.
- Partnerships with Grain Research and Development Corporation, Agilent Technologies, Photon Systems Instruments and Groupe Limagrain.
- Over 140 internationally competitive staff and students.
- $26 million (2014-2020) from the Australian Research Council and $14 million from companies and the partner universities to fund the Centre through to 2020.
- Centre authors contributed to almost 100 publications in 2014.

Our Chief Investigators

PROFESSOR HARVEY MILLAR (DIRECTOR)

Harvey's research aims to understand the role of respiration in primary carbon and nitrogen metabolism in plants, plant response to oxidative stress and the dynamics of plant proteomes under limiting conditions. Harvey is Centre Director and an ARC Future Fellow. In 2014 Harvey was named amongst the world's most highly cited researchers.

PROFESSOR IAN SMALL

Ian's research interests involve understanding how plants coordinate the expression of nuclear and organellar genes, and building computational models of plant metabolism. Ian was Centre Director from 2006 to 2013 and is an ARC Laureate Fellow. He is also Western Australia's 2014 Scientist of the Year and one of the world's most highly cited researchers. He co-leads Research Program 1 with Barry Pogson.

PROFESSOR RYAN LISTER

Ryan's research focus lies in plant and animal epigenomics. Ryan was named as Life Scientist of the Year at the 2014 Australian Prime Ministers awards. He is an ARC Future Fellow and co-leads Research Program 3 with Justin Borevitz.

PROFESSOR RANA MUNNS

Rana's focus is on the mechanisms by which plants adapt to drought and salinity stress. Rana holds a joint position with the University of Western Australia and CSIRO Agriculture, Canberra. Rana is a Fellow of The World Academy of Sciences and is recognised internationally for her insights into the fundamental principles of crop adaptation to salinity, and for applications of these insights.

UNIVERSITY OF WESTERN AUSTRALIA

AUSTRALIAN NATIONAL UNIVERSITY

UNIVERSITY OF ADELAIDE

LA TROBE UNIVERSITY

PROFESSOR BARRY POGSON (DEPUTY DIRECTOR)

Barry's research looks into defining novel roles for carotenoids in plant developmental processes, with complementary research into organelle signalling to identify the mechanisms by which plants perceive and respond to drought and excess light. He in Deputy Director of PEB and co-leads Research Program 1 with Ian Small.

PROFESSOR JUSTIN BOREVITZ

Justin's research applies cutting edge genomics and phenomics approaches to the study of the genetic basis of climate adaptation in plants, and utilises model plants and foundation species in controlled and field environments. Justin co-leads Research Program 3 with Ryan Lister.

PROFESSOR OWEN ATKIN

Owen's research focuses on assessing the impact of environmental gradients on plant physiological processes, particularly respiration.

PROFESSOR JIM WHELAN

Jim's research combines morphological, biochemical, genetic and 'omic' approaches to understand organelle function and biogenesis in plants. Jim co-leads Research Program 2 with Steve Tyerman.

ASSOCIATE PROFESSOR MATTHEW GILLIHAM

Matt's research focuses on the physiological role of solute transport proteins in plant nutrition and in conferring tolerance to various stresses such as salinity, drought and aluminium. He is an ARC Future Fellow.

PROFESSOR STEVE TYERMAN

Steve investigates the links between anion and water transport in plants and, as Wine Industry Chair of Viticulture at the University of Adelaide, he applies his research to grapevine root physiology. Steve is a Fellow of the Australian Academy of Science and co-leads Research Program 2 with Jim Whelan.

Our Partners

(GERMANY)
Max-Planck Institute for Molecular Plant Physiology

The MPI-MP is the elite European institute for research into central plant metabolic pathways, combined with analysis of gene function for development and implementation of phenotyping technologies and system approaches. Mark Stitt and Ralph Bock, two of MPI-MP's Directors, are partner investigators to PEB. MPI-MP has made a substantial commitment to collaborations within the Centre's programs, the provision of facilities for collaboration and to the support of PEB visitors.

(UNITED STATES OF AMERICA)
Salk Institute for Biological Studies

The Salk Institute focuses on discovery, and on mentoring future generations of researchers in genetics, cell and plant biology, and related disciplines. Two of its leading research professors, Joseph Ecker and Joanne Chory are partner investigators in PEB. Salk have made in-kind commitments to staff time for collaborations in all programs, to extensive access to facilities and new datasets for collaborations and to the support PEB visitors.

(SWEDEN)
Umeå Plant Science Centre

UPSC is one of the strongest research environments for basic plant research in Europe and covers a wide range of disciplines in plant biology. UPSC share a common goal to understand the mechanisms driving chloroplast biogenesis and plant adaptation to environments. Åsa Strand, from UPSC, is a partner investigator in PEB. UPSC will provide in-kind commitments in staff time for collaborations, and facilities for collaborations and PEB visits.

(FINLAND)
University of Turku

The University of Turku houses the Finnish Centre of Excellence in Molecular Biology of Primary Producers. Its Director, Eva-Mari Aro, is a partner investigator in PEB. The Centre will participate through research on chloroplast biogenesis and signalling, and chloroplast function. In-kind commitment will be provided in staff time and facilities for collaborations.

(UNITED STATES OF AMERICA)
University of Massachusetts

Umass (Amhurst) is a major US research and teaching university with a strong reputation in plant science innovation. The UMass team, led by Elizabeth Vierling, research temperature responses in plants and will collaborate with PEB to search for new gene networks for temperature tolerance in plants. Additional in-kind commitments will involve follow up work at UMass and the hosting of visiting PEB staff

(FRANCE)
Groupe Limagrain

Groupe Limagrain is an international agricultural cooperative group and the world's fourth-largest seed company. It will fund research on controlling male fertility through the manipulation of mitochondrial gene expression. Limagrain is providing wheat germplasm, testing candidate gene sequences proposed by the Centre, and evaluating lines for male fertility and the ability to produce hybrid wheat. Limagrain will provide plant biotechnology development and licensing expertise to PEB.

(CZECH REPUBLIC)
Photon System Instruments

PSI are a leading developer of new technology for imaging of plant growth and development. They will fund the development of instrumentation and new software for use in the Centre, and for deployment across Australia and will bring imaging expertise to a number of Centre's projects.

(AUSTRALIA)
Agilent Technologies

Agilent Technologies supports advances in life and agricultural sciences, and 'omic analysis and integration as an instrument manufacturer and product developer. The company will work closely with PEB on analytical workflow solutions, automation and robotics in quality control for plant-sample QC analysis, and on refining laboratory management software and analysis. Agilent Technologies will provide analytical product development expertise to PEB's Business Advisory Group.

(AUSTRALIA)
Grain Research and Development Corporation

The GRDC invests in crop science for the Australian grains sector. GRDC will provide PhD scholarships and research costs to PEB and fund projects arising from CIs' discoveries for improving salinity tolerance and drought tolerance in wheat and barley. The GRDC will give advice to the Centre, evaluate new PEB intellectual property for further funding by GRDC, and will provide knowledge and links for PEB to Australia's grains industry.

(CHINA)
Zhejiang University

ZJU is a major Chinese agricultural university and leads a large research program in increasing phosphate use efficiency in rice. ZJU's partnership role will be in the collaborative development of rice varieties, with emphasis on use of its extensive field sites to facilitate translation from PEB's discoveries.

The Director's View

In 2014 Plant Energy Biology was funded by the Australian Research Council as a new centre with a seven year timeline. This will see us pursuing a challenging new research agenda through to 2020! Our ten chief investigators and many new Centre staff have been working hard this year to establish new research programs across four Australian Universities and with our international Partner Investigators.

So what have we been up to?

New Research Programs

Our three research programs provide a wider and more strategic focus to our research than we have had in the past. We are still focused on pursuing novel discoveries in plant biology, but with an eye to their impact and application, both within and outside the bounds of plant science.

The genome wide association mapping we are doing to understand genes for energy efficiency will also shape new approaches to genome scale breeding approaches.

Our work on temperature responses in plants is informing not just our understanding of plant stress tolerance but also influencing climate prediction models. Our leading work on transport systems is successfully identifying factors that enhance whole plant drought and salinity tolerance.

Finally, our exploration of epigenomic mechanisms is not just about discovering its role in plant adaptation and evolution, but also about developing non-genetic approaches in plant biotechnology and using epigenetics in medical research.

Centre Integration is Underway

To keep a larger Centre on track and performing well we've built a wider administrative team, based across the country, to coordinate the work and play of the Centre and to communicate what we do to the wider community.

This support for the science is vital to ensure the maximum return on tax payer investment and to communicate what we think, find and explore to the public, students, policy makers, governments and potential future supporters.

Attracting the very best young scientists

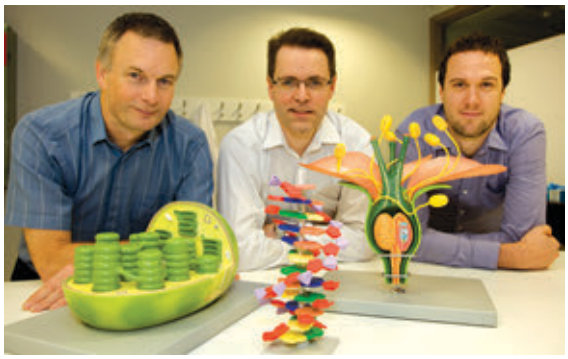
To develop the programs of the Centre in exciting new directions there is no better catalyst than new internationals joining our team and home grown researchers leading new groups!

This makes maximum use of the exciting intellectual environment and the wonderful modern facilities at each of our university nodes. The injection of new ideas, novel ways of solving problems and exciting expertise is of great benefit to the growth of the Centre.

At the beginning of 2014, three new Future Fellows (Monika Murcha, Nicolas Taylor and Shaobai Huang) and five existing DECRA fellows (Sandra Tanz, Kate Howell, Adriana Prizinska, Marna van der Merwe and Ozren Bogdanovic) joined as affiliates to the Centre and began developing their own research programs.

At the end of 2014 a remarkable round of DECRA and international fellowships saw six new fellows funded to join the Centre in 2015.

We look forward to everything that these enthusiastic researchers will bring!



New Opportunities

With changes to funding, people and equipment comes exciting opportunities for the Centre and its staff. New research on transport systems, that use so much of the chemical energy transformed in cells, was initiated in 2014.

Much wider use of environmental simulation facilities and of genomics and epigenomic profiling of plants will be undertaken as we seek to explore the gene networks that control energy efficiency in plants.

Experimental flux analysis and mathematical modelling activities will begin to merge as we seek to quantify the cellular economy of plant systems.

Proven performance and research impact.

The Centre's papers remain highly sought after in top plant science journals. Using citations as a metric, the Centre rivals many of the world's best known and respected plant science Centres, and Centre investigators remain in demand as presenters at international conferences.

This year has seen Ian Small and Barry Pogson recognised for their research citations by Thomson Reuters and by the American Society of Plant Biologists, respectively, Ryan Lister awarded medals from the Australian Academy of Science and the Australian Prime Ministers Prize for Life Sciences, and Rana Munns being inducted into the World Academy of Sciences for her work in developing nations.

The Centre rightly prides itself not only on excellent science coming from its labs, but also strives to make sure that its discoveries are relevant to society. Partnerships with industry from 2014 onwards on selected topics of interest to stakeholders are being initiated to value-add to the expertise of the Centre's researchers.

Salinity tolerance, drought tolerance, phenomics of energy traits, biomarkers in metabolism and plant hybrid systems are the current focus of these efforts.

I look forward to all that the ARC Centre of Excellence in Plant Energy Biology will achieve over the next seven years.

Professor Harvey Millar
Director

Our three research programs provide a wider and more strategic focus to our research than we have had in the past.

We are still focused on pursuing novel discoveries in plant biology, but with an eye to their impact and application, both within and outside the bounds of plant science.

The expertise at PEB spans the whole of the plant energy system, from photosynthesis to respiration, but further to this it spans from genomics to whole plant physiology to molecular biology.

Working across disciplines allows us to make the most of the rapid evolving toolkits of modern science, but keeps us grounded in research that will have an impact on global issues such as world food security and the effects of climate change.

Dr Pip Wilson | ARC Centre of Excellence in Plant Energy Biology

Research

What is Plant Energy Biology?

Most of our food, feed, fibre and fuel is sourced directly or indirectly from plants as energy-containing and nutrient-rich molecules, e.g. sugars, amino acids, proteins, starch, oils and cellulose. The synthesis, transport, storage and use of these molecules during growth and development is the plant energy system and it determines the final yield of plant products.

The efficiency of the plant energy system can be measured at different levels:

- In cells, as the proportion of energy used for cell maintenance versus growth.
- In whole plants, as the ratio of input resources versus harvestable product.
- In the environment, as the degree of adaptation within plant populations needed to grow successfully in variable conditions.

These measures are proxies for plant energy efficiency, a very complex but essential plant trait. The world urgently requires plants that can more efficiently procure the resources provided by nature and farmers to generate more harvestable products, and on agricultural soils that are decreasing in area and fertility. Furthermore, it needs plants that are able to maintain this performance in harsh and variable environments.

Energy efficiency, which sits at the centre of this requirement, can be gained or lost at multiple levels:

- At the molecular level, in the control of gene expression and metabolic processes.
- At the cellular level, through specialisation and signalling.
- At the developmental level, through physiological responses to the environment.

These gains and losses cumulatively impact across spatial scales, from tissues, to whole plants to plant populations.

Presently, even under ideal conditions, elite crops only convert 10–15% of the carbon fixed by photosynthesis into harvestable yield, with even less efficiency seen under harsh environments. Under suboptimal environments and in certain seasons actual crop yields well below potential maxima are observed.

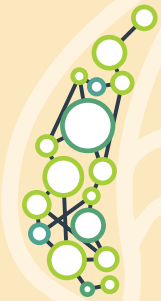
In Australia, 60% yield gaps between potential and actual yield are now common. Yields have varied more greatly since 2000 than in any period since 1950. Droughts of moderate severity lead to a 30–70% yield decrease. The impact of saline soils and temperature extremes ranges from small losses up to complete crop failure, and nutrient-limitation can lead to an 80% decrease in yield.

Many of these partial losses occur due to limitations and reduced efficiency in interconnected metabolic processes. Therefore small efficiency gains in the multitude of processes beyond carbon capture, but before harvest, can combine to have a magnified benefit to yield.

Discovering the interconnected signalling processes that dictate and limit how plants perform in variable environments is critical to gaining the sustainable increases in actual yields that are needed for our future.

Major targets for efficiency gains include the energy spent on: translocation of carbohydrates and nutrients from leaves to roots and seeds; uptake and storage of nutrients from soils; assimilation and allocation of phosphate, nitrogen and sulphur into proteins, lipids and organics; protein synthesis and turnover and maintenance of cellular ion-gradients.

Tackling plant energy research requires a team with expertise ranging from genes and proteins through to plant physiology. Through our combined expertise and using technological innovation the Centre can enhance the energy efficiency of plants.

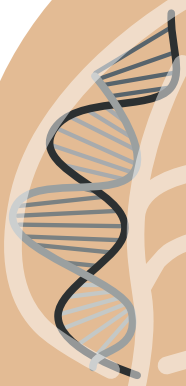


PROGRAM 1
WHAT NEEDS CHANGING

Metabolic modelling
Signal networks as enviromental sensors
Tuning energy systems in cells for response and resiliance

PROGRAM 2
WHERE IT NEEDS TO BE

Gatekeeper cells
Transport and storage
Improving specific cells for whole plant performance



PROGRAM 3
HOW WE CAN ALTER IT

Genetic networks
Epigenetic control of plant adaptation
Modifying whole plant genetic networks for variable environments

The Centre is investigating plant energy biology through three Programs of research.

Program 1 will define *what* elements in energy metabolism are the best targets for increasing energy capture and conversion in specific conditions.

Program 2 will define *where* energy use for resource acquisition in specific cells can have a maximal benefit for the whole plant.

Program 3 will define *how* networks of genes governing these processes can be identified and manipulated in plant populations for robust responses in limiting environments.

Program 1 Energy Metabolism and Signalling

Program leaders: Ian Small and Barry Pogson
Program 1 focuses on cellular functions.

Background

The two major organelles in plant cells are the chloroplast/plastid (photosynthetic/biosynthetic functions) and the mitochondrion (for respiration). These organelles co-operate to direct plant cell energy capture and storage in the form of sugars, starch, oils, protein and fibre - all of which are major agricultural products. Futile metabolic cycles are common during resource acquisition, storage and metabolism by plants, but are still very poorly understood.

The metabolism of plant organelles underlies the growth and performance of plants, including their ability to withstand environmental stresses. The Centre has previously shown that chloroplasts and mitochondria are environmental sensors that control growth.

The complex and ancient ways in which organelle function and efficiency are influenced and respond to the environment are based on intracellular signalling, and this forms the foundation of how plants control conversion of energy to functionally useful forms. Environmental variables such as light, temperature, water and nutrient availability all interact with energy systems via signalling processes.

Program aim

To maximise the efficiency of energy organelles by modelling the efficiency of metabolic strategies in plants, altering the biogenesis of energy organelles, and co-opting the signalling processes that control the activity of energy organelles during environmental challenges and recovery.

- **Modelling energy processes under varied conditions to choose optimal energy efficiency strategies.**
  Good estimates of energy capture and expenditure at a whole plant or organ level can be made from measurements of photosynthetic and respiratory rates. However, sufficiently detailed information about the energy requirements of internal processes does not yet exist to guide the development of optimal strategies to improve energy efficiency under target conditions.

  The Centre's previous developments in metabolic modelling, organelle composition and protein turnover analysis provide a technical foundation on which to investigate the energy requirements of internal processes.

- **Modifying energy organelle number, quality and function to improve energy processes in variable environments.**
  The Centre has previously defined 'switches' that control energy organelle biogenesis and function in the processes of respiration and photosynthesis. PEB is now utilising these to change metabolic outcomes in plant cells, through collaborative research with our partners.

  The Centre also has a number of established resources, including plant lines with altered organelle biogenesis or growth characteristics. Collectively, this provides new opportunities to measure and modify cellular costs and identify new signals of interest.

- **Using the receptors and transducers of organelle signals to integrate changes across whole plants.**
  The Centre has identified key signals that build a strong case for the existence of overlapping cell signalling pathways that contribute to environmental sensing by organelles.

  The Centre is now undertaking research to address whether organelle number or composition can be optimised by regulating signalling networks and whether this can, in turn, optimise plant performance.

  PEB researchers are investigating networks to define what evolutionary boundaries can be jumped and which networks can be rewired without compromising other aspects of energy efficiency.

Regulators of energy efficiency are not directly selected for by most current breeding strategies, meaning there is substantial potential for improvement. Future, assisted breeding of crops requires knowledge of networks of molecular targets that are yet to be discovered.

The Centre's research will aid in identifying such targets and aims to optimise plant energy efficiency for yield by focusing on improvements that can be stacked together for gains in crops.

Personal Success

Dr Sandra Tanz
Since joining PEB in 2007, Sandra has established herself as an ambitious postdoctoral researcher. Sandra's research focuses on understanding and enhancing photosynthesis. 2014 saw her carry out her third year of research as an ARC Discovery Early Career Researcher Award recipient, investigating the photosynthetic mechanisms that exist in known high performing C4 crops, for application in plants used in adverse climates.

Sandra was awarded the 2014 UWA Vice Chancellor's Research Award for Early Career Investigators and a UWA Faculty of Science Award for Research Excellence in the category of "furthering human knowledge and enhancing society".

"PEB provides an excellent environment for research mentoring and research facilities. While there are opportunities for plant biologists all around the world, there is no question to me that PEB is the place to be for organelle plant research, particularly if one's goal is to develop crops for hostile climates" she said.

Personal Success

Dr Sophia Ng
Originally from Malaysia, Sophia joined PEB in 2007 as an honours student. She has remained as a productive PEB researcher, completing a PhD project which resulted in a 2014 cover article in the journal Molecular Plant.

"I had a great experience during my honours. I had a supportive supervisor and was surrounded by friendly staff. PEB provides a very good research environment. I therefore stayed to continue my PhD and postdoctoral studies" said Sophia.

Her postdoctoral role as a Research Assistant Professor has seen her study genes that regulate phosphate intake in rice and Arabidopsis as part of a joint project between PEB's UWA node and partner organisation, Zhejiang University (ZJU). Sophia also acts as an ambassador for UWA at ZJU. She was awarded a Research Fund for International Young Scientists 2014-2015 prize by the National Natural Science Foundation of China.

Research Highlight
Factors affecting leaf respiration

Plant respiration is an important flux in the global carbon cycle, returning roughly half of the carbon fixed by photosynthesis to the Earth's atmosphere. Linked climate and vegetation models that seek to represent existing climate conditions - and help us make projections into the future – need better and more detailed information about which factors influence rates of plant respiration globally.

Through an international collaboration, a dataset of field-based leaf respiration measurements from a broad range of plants around the world was compiled.

Analyses confirmed the existence of global patterns that are linked to spatial differences in growth temperature and aridity, and show leaf respiration rates are higher for plants growing in colder and drier habitats.

Explanatory variables for predicting leaf respiration rates that were identified from the study include temperature, vegetation type (broad leafed tree, grass etc.), measures of photosynthetic capacity and the level of leaf macro-nutrients: nitrogen and phosphorus.

These facilitate predictive equations for leaf respiration tailored to a global suite of plant types which can be incorporated into developing climate models.

Atkin OK, Bloomfield KJ, Reich PB, Tjoelker MG, et al. (2015) Global variability in leaf respiration among plant functional types in relation to climate and leaf traits. NEW PHYTOLOGIST 206(2) 614-36.

A thorough understanding of energy efficiency requires a careful accounting of the energy budget for all the key processes in the plant.

Research Highlight
The importance of carotenoid metabolites

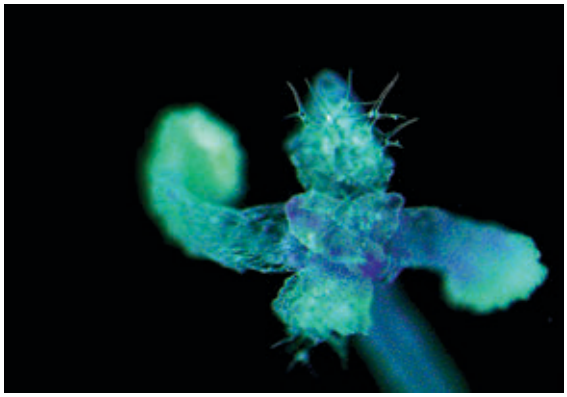
Carotenoids, the second most abundant, naturally occurring pigments on earth, participate in various plant biological processes including photosynthesis, photoprotection and development. Apocarotenoids, carotenoid cleavage products, are an exciting class of molecules, the known numbers and functions of which continues to grow.

Our work suggests carotenoids and their cleavage derivatives exert a biological effect on chloroplast and leaf development in a critical way that defines leaf morphology. In Arabidopsis a novel apocarotenoid signaling molecule in the chloroplast that is generated through the disruption of ζ-carotene desaturase (ZDS, the third intermediate in carotenoid biosynthesis) results in abnormal needle-like, translucent leaves with altered chloroplast development.

This disruption also triggers retrograde signalling that disturbs transcription of nuclear and plastidial genes essential for early chloroplast development, photosynthesis and carotenoid biosynthesis.

This work suggests the importance of carotenoid metabolites in generating regulatory signals that, beyond well-established functions, can also affect major developmental processes such as leaf development and function as feedback signals responding to the status of organelle development.

Avendaño-Vázquez AO, Cordoba E, Llamas E, San Román C, Nisar N, De la Torre S, Ramos-Vega M, Gutiérrez-Nava MD, Cazzonelli CI, Pogson BJ, León P (2014) An Uncharacterized Apocarotenoid-Derived Signal Generated in ζ-Carotene Desaturase Mutants Regulates Leaf Development and the Expression of Chloroplast and Nuclear Genes in Arabidopsis. THE PLANT CELL 26(6):2524-2537.



Program 2 Gatekeeper Cells and Specialisation

Program Leaders: Steve Tyerman and Jim Whelan
Program 2 focuses on cell types and their interactions in plants.

Background

Australia is the most saline continent on Earth. Approximately 69% of the Australian wheat belt is susceptible to the build-up of salts, which are inhibitory to plant growth. The extent of worldwide salinity is forecast to increase in the coming decades due to climate change and a greater reliance on marginal land. Meanwhile, phosphate global supplies are running out, yet this is an essential macronutrient for plants that can severely limit growth and yield unless supplied as a fertilizer.

Acquisition of necessary nutrients, control of resource transport and the exclusion and cellular detoxification of toxic substances are energy intensive for plants. To secure our future we require plants which are more efficient at these processes. Key cell-types often form rate-limiting steps within the transport pathway of nutrients, metabolites and toxins in plant. We call these strategically located cells "gatekeepers".

Program aim

To improve the efficiency of plant energy use during the acquisition and partitioning of key resources by manipulating the transport properties of gatekeeper cells for water, carboxylates, phosphate, and salt. Single-cell analysis and modification will be used to harness the profound impact these cells have on whole plant energy efficiency in response to deficit or oversupply of nutrients, metabolites and toxins.

- **Optimising energy use in resource acquisition processes.**
  Water and fixed carbon, as resources, are intimately linked to plant energy status. The Centre's research into water and carboxylate transport is exploring the inter-relationship of this with metabolism in specialised gatekeeper cells. The control of genes that code for water and carboxylate transport proteins are the new frontier for nutrient acquisition gains.

  These transport proteins are highly regulated and linked to the energy status of cells, as well as to stresses such as salinity and extreme pH. Reasons for these links are not understood, and the Centre is exploring them as an untapped resource for plant improvement.

- **Maintaining cellular energetics optimised under saline conditions through exclusion and tissue tolerance.**
  Soil salinity reduces the energy efficiency of cellular processes, including lowering photosynthesis and raising respiration, resulting in reduced crop yield.

  The Centre has previously demonstrated how a single gene can confer improved salt tolerance in wheat without penalty to yield, when expressed in specific gatekeeper cells. PEB are now discovering parallel pathways to further optimise crop productivity within saline environments through specialised cell types. This work is enhanced by the Centre's access to unique Australian cereal genotypes and the mapping of populations differing in key traits that underpin salinity tolerance.

- **Altering phosphate uptake, storage and use as keys to the energy currency of cells.**
  Phosphate is needed in plant energy metabolism as a component of high-energy molecules. The Centre, however, aims to design proof-of-concept plants that maintain biomass and yield under low phosphate conditions.

  Approaches combine cell specific targets for compounds involved in phosphate status signalling, regulators of the proteins that control phosphate homeostasis, and the regulatory genes for phosphate starvation identified through genome and epigenome analysis. This multi-faceted approach aims to avoid the trade-offs in phosphate responses that impact plant growth.

Program 2 will link to Program 1 through the use of cell specific energy flux measurements, and through the assessment of organelle enhanced plants on nutrient acquisition and toxin tolerance. Findings will inform the generation of crops better suited to a changing agricultural landscape.

Personal Success

Dr Caitlin Byrt
Caitlin was recruited by the Centre in 2014 for her expertise in plant physiology, particularly vascular and cell wall biology.

"Today's scientific research gathers the information that will directly influence the lifestyle of our children – what they eat, what they wear and how much energy they will have" says the mother of two.

In 2014 Caitlin was awared the inaugural Edith Dornwell Medal for Early Career Research Excellence by the University of Adelaide, and an ARC Discovery Early Career Researcher Award.

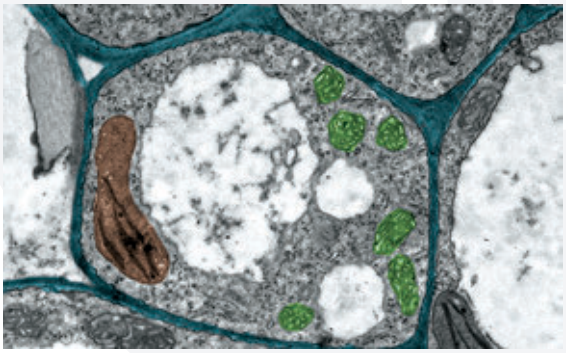
"PEB is an excellent environment for scientific research. I am relishing the opportunity to develop my ideas, expand my knowledge and be part of a highly productive and innovative team of scientists" she said.

Personal Success

Sam Henderson
Having found himself fascinated by plant membrane biology while working in Adelaide Sam committed himself to PhD studies with PEB. Here he investigated the transport processes that plants use, in an effort to establish their role in shoots ion exclusion.

Sam completed his PhD studies in 2014, receiving a Dean's Commendation for Thesis Excellence and publishing his research in the journal BMC Plant Biology. "I am now studying ion transport in grapevine to understand mechanisms of salinity tolerance in this species" Sam, now a postdoctoral researcher with the Centre, said.

"It is great to work in the Centre with enthusiastic colleagues and excellent facilities".



Research Highlight
Engineering wheat for better salt tolerance

When excessive sodium builds up in leaves it can become toxic to a plant and reduce plant yield. As many agricultural soils are becoming more salty, a major boost for food security will come from improving the salt tolerance of our food crops.

We reported the discovery of the gene that underpins a major salt tolerance trait locus in wheat. Having characterised the function and cellular localisation of a candidate gene (TaHKT1;5-D) it was found that it encodes a sodium transporter protein that localised to the inner root. Experimental reduction of TaHKT1;5-D expression causes an increase in sodium accumulation in the shoot, leading to the conclusion that TaHKT1;5-D is able to hold back sodium in the roots and prevent it from reaching the shoots.

This information can be applied in crop breeding to control sodium transport and to increase the salinity tolerance of wheat.

Byrt CS, Xu B, Krishnan M, Lightfoot DJ, Athman A, Jacobs AK, Watson-Haigh NS, Munns R, Tester M, Gilliham M (2014) The Na(+) transporter, TaHKT1;5-D, limits shoot Na(+) accumulation in bread wheat. THE PLANT JOURNAL 80(3):516-26.

We know that key cell-types often form a rate-limiting step within the transport pathway of nutrients, metabolites and toxins in plants.

Research Highlight
Co-ordination of root and shoot

Plant shoots transpire water to the atmosphere in the process of capturing energy and converting carbon dioxide during photosynthesis. The demand for water by the shoot in this process must be matched to the supply sourced at the roots. The shoot and the root systems are, however, each subject to very different environmental constraints.

Prior work in the Centre has uncovered evidence for a rapid signalling process from shoot to root that controls aquaporin expression and activity. Aquaporins regulate resistance of water flow through the roots.

An integrated model of how shoot to root signals may work to match shoot demand with root supply of water has been described, emphasising the central role played by aquaporins in regulating plant water relations.

The model presents for the first time an integrated picture of how the plant shoot demand for water is integrated with the roots' ability to supply water. The hypothesis forms the foundations of ongoing work in the Centre, with concepts being tested in the model plant Arabidopsis.

Chaumont F, Tyerman SD (2014) Aquaporins: highly regulated channels controlling plant water relations. PLANT PHYSIOLOGY 164(4):1600-18.

Program 3 Gene Variants and Epigenetics

Program Leaders: Ryan Lister and Justin Borevitz
Program 3 will focus on plants in populations and across generations.

Background

Across diverse habitats plant populations fine-tune their energy systems to withstand and exploit changing environmental conditions. Natural genetic diversity contains many useful traits, the molecular basis of which can now be mined from plant genomes by unifying modern genomics technologies with precision phenotyping and sensitive environmental observation, at both the individual and population levels.

In addition to determining the genetic complement of an organism, it is critical to understand the epigenetic codes that govern where and when the genetic information is used.

Epigenetic modifications do not alter the genome sequence, but can regulate the readout of the underlying genetic information, can be environmentally sensitive and heritable.

Project aim

To identify genetic and epigenetic control of energy efficiency during plant growth by dissecting out how this couples with phenomic variation in natural populations of plants using genome wide association mapping, and through (epi)genome profiling in a variety of environments.

- **Exploiting (epi)genetic variation to define the gene networks and gene variants that determine energy efficiency.**
  The historical selection of plants for their growth in less challenging environments than today has resulted in bred plants that do not possess the resilience found in natural populations due to their largely untapped bank of genetic and epigenetic solutions to challenging environments.

  The Centre is driving major advances in tools to precisely dissect out these (epi)genetic solutions from natural populations of plants. This will clarify the contribution of the (epi)genome to natural variation in plant energy systems and the molecular basis of how plants transform energy to grow and survive in changing and challenging environments.

- **Uncovering the role of epigenetics through multigenerational responses to environments.**
  It has recently been proposed that epigenetic modifications in plant genomes can change rapidly, in an apparently stochastic manner, and may transmit to subsequent generations of plants. Mounting evidence also suggests plant epigenomes undergo specific changes in response to challenging environmental conditions.

  It is critical to understand the role of epigenetic plasticity in plant multigenerational responses to challenging environments.

  Understanding how multigenerational epigenomic variability influences genetic and phenotypic variation under challenging conditions will allow control of the process to generate stable and resilient plants in the future.

- **Developing new tools for precision editing of the epigenome to engineer plant energy efficiency.**
  To further study and manipulate genes and cellular signalling pathways the Centre aims to specifically transfer (epi)alleles across plants. Through novel approaches to precision editing of epigenetic patterns, such powerful genome editing technologies will allow the transfer of advantageous genetic variants.

  By further modification of new genome editing systems we will develop innovative targeted epigenome engineering tools to deliberately reprogram the epigenome.

We will target dynamic plant responses to changing environments and conditions, with specific focus on light, drought, temperature extremes and nutrient-limitation. Our approaches will enable the design, breeding or selection of plants that achieve significantly higher efficiency under limiting conditions and when conditions change in the future.

Personal Success

Dr David Secco
While David's background is in plant nutrition and physiology, he now uses next generation sequencing at PEB to assess how DNA methylation is affected upon the abiotic stress of plants.

David initially joined the Centre in 2011 as an ARC Super Science Fellow. He was awarded an ARC Discovery Early Career Researcher Award in 2014 to support his studies into phosphate stress-induced DNA methylation changes.

"During all my time at PEB, the Centre has provided me with great support, access to state of the art equipment as well as enabled me to gain highly valuable technical and personal skills" David said.

Personal Success

Dr Pip Wilson
Pip has played a key role in establishing PEB's dynamic climate chambers, in Canberra, as well as helped to create a global set of Brachypodium for the Centre and combine phenotyping, contrasting variable environments and genotyping to perform genome wide association studies (GWAS) for agriculturally-relevant traits.

"Using contrasting climatic conditions allows us to examine the plasticity of traits that affect plant growth and yield, an important consideration in Australia where climates are very variable" she said.

Research Highlight
What will plants do?

As climate change accelerates, what will plants do? Will they adapt, move or die? To answer this current and future fall growing conditions were simulated in PEB climate chambers. Flowering output was measured in a diverse set of Arabidopsis. The genes sensing the changes in growing seasons were measured, identifying both known signalling pathways and new loci.

These genes, together with the background population genetic variation, were used to predict future flowering times and likelihood of success in future climates.

Such predictions can be used to estimate which populations are pre-adapted and which require "help". This study demonstrates an approach to pre-breeding climate ready crops and highlights how important genetic diversity is for future adaptation.

Li Y, Cheng R, Spokas KA, Palmer AA, Borevitz JO (2014) Genetic variation for life history sensitivity to seasonal warming in Arabidopsis thaliana. GENETICS 196(2):569-77.

Knowledge of the variation governing complex plant functions will allow us to select and engineer plants with far more precision for future variable environments.

Plants can adapt to challenging environments through both genetic and epigenetic modification of their genomes.

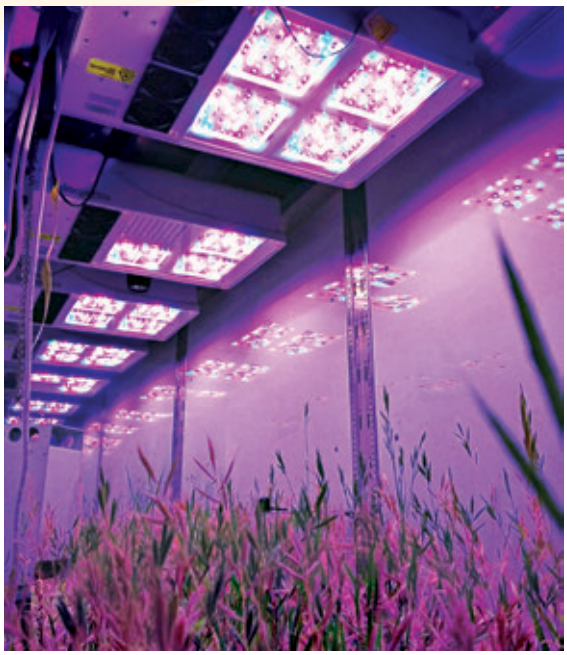
Research Highlight
Capturing traits

Modern techniques provide the potential for plant scientists to identify both heritable traits and the complex regulatory networks underlying adaptive phenotypic variation in plants. Advances in plant phenomics, genomics and environmental control and sensing can now be used to directly identify yield and resilience traits. However, there is a need for software that can integrate these technologies.

A team from the Centre has described a pipeline, called TraitCapture, for the integration of advanced imaging equipment, feature detection from image data, genomic analysis of complex traits and functional structural plant models (FSPMs).

TraitCapture therefore allows the "capture of traits" throughout development and across environments, from multi-dimensional phenotypes. It is envisioned that TraitCapture will be applicable to both controlled and field environments and will allow breeders to simulate regional variation in trials to pre-select for increased productivity under challenging environments.

Brown TB, Cheng R, Sirault XR, Rungrat T, Murray KD, Trtilek M, Furbank RT, Badger M, Pogson BJ, Borevitz JO (2014) TraitCapture: genomic and environment modelling of plant phenomic data. CURRENT OPINION IN PLANT BIOLOGY 18:73-9.



New Research Technologies

Our ability to answer scientific questions is always constrained by the technology available. With the advent of new technologies answers that were once out of reach become attainable. An important function of our Centre is to develop and apply new technologies, and where possible, make them available for other researchers across Australia.

Epimodification Tools

Epigenetic systems play critical roles in the genomic functions of plants. Epigenetic modifications such as DNA methylation can influence gene expression without modifying the underlying DNA sequence. Techniques to accurately map DNA methylation throughout the entire genome at unprecedented resolution are now being used in the Centre to study plant epigenomes and look at the involvement of the epigenome in plant growth, cellular identity and function, in maintaining energy systems and in response to challenging environments.

The next step along this research path is to develop novel molecular tools to deliberately and precisely engineer the epigenome, something which has not previously been possible.

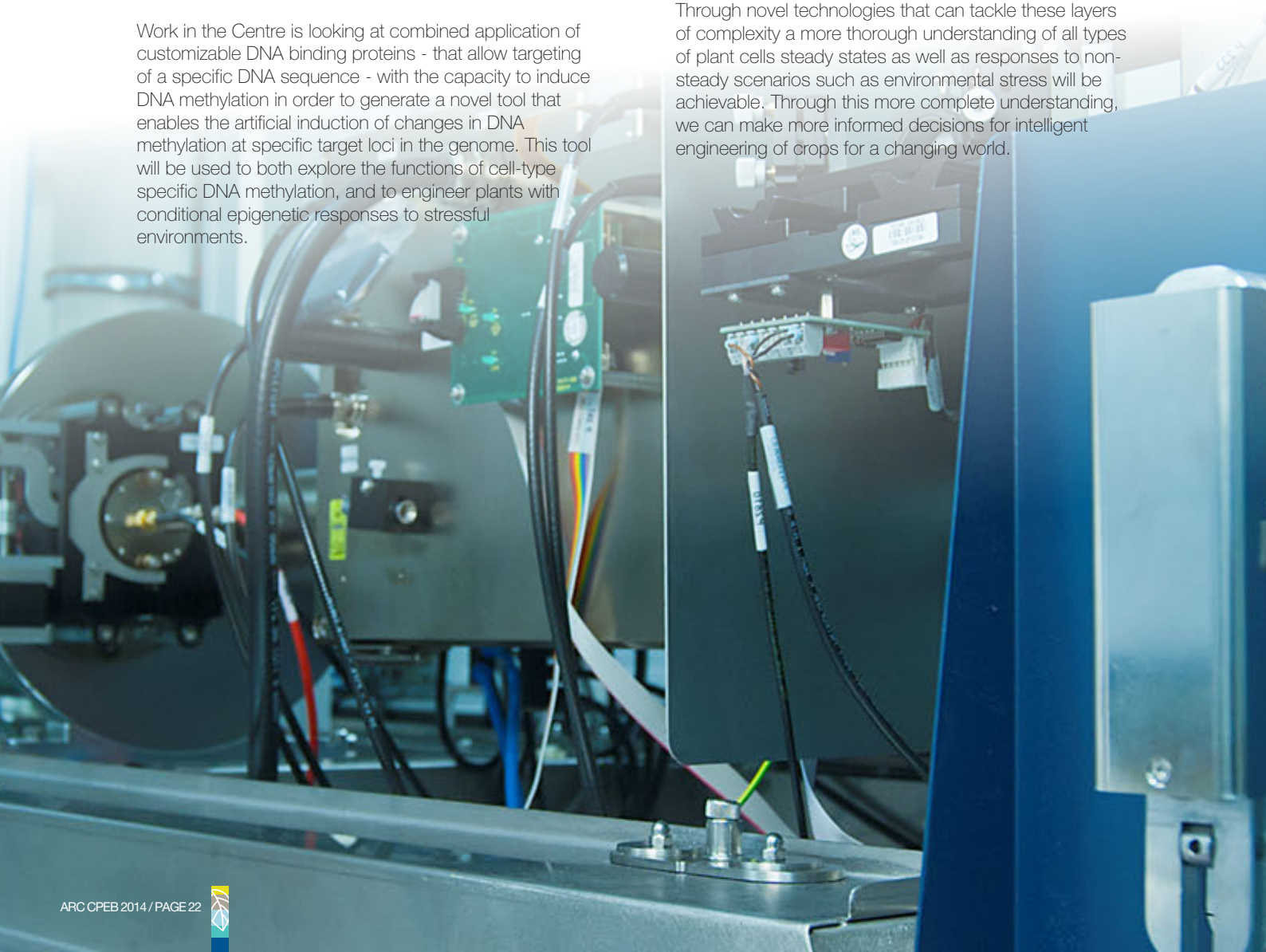
Work in the Centre is looking at combined application of customizable DNA binding proteins - that allow targeting of a specific DNA sequence - with the capacity to induce DNA methylation in order to generate a novel tool that enables the artificial induction of changes in DNA methylation at specific target loci in the genome. This tool will be used to both explore the functions of cell-type specific DNA methylation, and to engineer plants with conditional epigenetic responses to stressful environments.

Measuring Protein Turnover

Proteins are constantly being synthesised and degraded as plants grow and develop. A thorough understanding of protein turnover is essential to clarify the responses of plants to environmental and developmental cues. Technology currently exists to measure changes in the relative amounts of proteins from plant tissues of interest under given sets of conditions. What is lacking is the ability to determine whether abundance changes are due to alterations in protein synthesis, degradation, or both.

Work by one group in the Centre is attempting to address this through technology that allows the tracking of a specific protein's abundance and the attribution of observed changes in abundance to shifts in synthesis and/or degradation. This technology, a sub-discipline of proteomics, combines stable-isotope labelling with mass spectrometry and attempts to measure these values for all of the proteins in a tissue. The existence of differently modified forms of a protein, multiple subcellular localisations of proteins within a cell, and variable protein populations within the many cell types that make up a tissue is also being considered, and addressed, with this work.

Through novel technologies that can tackle these layers of complexity a more thorough understanding of all types of plant cells steady states as well as responses to non-steady scenarios such as environmental stress will be achievable. Through this more complete understanding, we can make more informed decisions for intelligent engineering of crops for a changing world.



Phenomic Monitoring Pipelines

Plant physiology research is progressing from the detailed study of a few different genotypes at a time, to high throughput, quantitative, phenomic studies on populations with fully sequenced genomes. The current challenge, however, is integrating these new techniques into a package that can be implemented across phenomics platforms, on different plant species, and that can be applied to field data.

Combining new technologies and adapting existing ones to new functions in plant biology provide innovative data for systems biology approaches, start new fields of research in knowledge gaps , and generate the hypotheses of tomorrow

The Centre uses climate-mimicking growth environments with sophisticated LEB lighting and cameras to build monitor-able climate scenarios, and is now coupling this with software pipelines to comprehensively measure and record plant responses and integrate different data sources.

One group in the Centre is actively developing software tools to integrate new cameras with advanced image analysis, genetic dissection, and plant models - pieces that each interact to enhance one other.

Online data visualisation and analysis tools are core components in the approach. Web-based visualisation will allow real-time graphing of environment data with associated time-lapse movies. Employing open-source and web-based software integration approaches will allow phenomic data to be remotely processed and easily shared facilitate widespread use and collaboration between researchers, both locally and internationally.

Translation of Research to Application

Tools for hybrid crop breeding

The use of hybrid crop varieties is increasing because of their attractive agronomic traits. Development of hybrid breeding systems requires a means to control self-pollination in plants such as wheat. Cytoplasmic male sterility (CMS) and fertility restoration is one approach that has been exploited, but the lack of suitable restorer genes has been a major limiting factor. Work by the Centre has identified PPRs as the major group of *restorer of fertility (Rf)* genes in plants and is developing approaches to design them.

Finding *Rf* genes in genomic data or designing them for different wheat cultivars, in collaboration with Limagrain will aid the use of this approach to restore male fertility. This will be tested in field trials and the approach will be valuable to plant breeding companies keen to develop new hybrid varieties, particularly in crops where such hybrids have been difficult to create.

Relevant modelling of climate

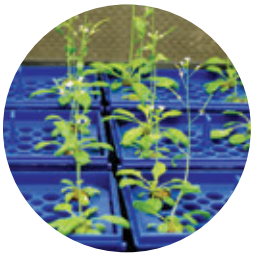
The Centre is working at the frontline of plant research that utilises systems to model dynamic climatic conditions in physiologically and ecologically relevant ways. Our team has developed pipelines that enable high throughput studies under dynamic environmental conditions using growth chamber technology.

Spectral climate chamber facilities enable the fine control of light intensity and spectrum, temperature and moisture to simulate local and regional field-like conditions from particular locations and seasons. Refining the use of such systems equips the Centre with the means to perform future work in climate analogues that mimic specific growth regions or climate change scenarios, greatly enhancing translation of the Centre's discoveries to real-world application.

Mapping human epigenomes

Technologies developed in plant models can be applied to other organisms. Application of the Centre's advances in epigenome analysis is not limited to plant and agricultural research.

Collaboration with the Salk Institute for Biological Studies has demonstrated that epigenetic mapping technologies and study of de novo methylation patterns in plants can be applied to generate complete epigenome maps and better understand methylation patterns in human cells. Unlocking the secrets of plant biology thus has far reaching benefits even for human development and health.



Targeted proteomics for crop research

Research in wheat at the protein level has been restricted for many years by the limited availability of suitable antibodies and the lack of genomic data. Research being carried out by a team in the Centre has established an exciting new method to accurately quantify proteins in wheat using a targeted strategy. The SRM mass spectrometry, or "targeted proteomics" approach dispenses with animal-produced antibodies for protein quantitation, and instead makes use of a triple quadrupole mass spectrometer and newly available genome sequences for wheat.

The Centre's team have shown the feasibility and accuracy of this approach in *Arabidopsis*, and have generated a toolkit for other researchers wishing to utilise the approach. Focus is now on establishing this approach in wheat, as targeted proteomics has the power to rapidly accelerate evaluation of both genetically engineered and naturally bred variants of this important crop plant.

Building salt tolerant crops

Many commercial crops are sensitive to soil salinity, causing major yield losses. The Centre has led a number of studies aimed at increasing salinity tolerance in crop plants important to the Australian economy, including wheat, barley, grapevine and soybean. A collaborative research project with the Chinese Academy of Agricultural Sciences has identified *GmSALT3*, a gene conferring salt tolerance to soybean plants.

By identifying the gene, genetic markers can now be used in breeding programs to ensure that tolerance is maintained in future cultivars of soybean that will be grown in areas prone to soil salinity. Furthermore, the novel way in which this gene was found to confer salt tolerance will drive the search for similar genes in different crops such as wheat and grapevine to selectively breed for their own enhanced salt tolerance.

Improving soybean yield

Soybean is the fifth largest crop in the world in terms of both crop area planted and amount harvested. Through studies the Centre has conducted with Zhejiang University the function of soybean plasma membrane intrinsic protein 1;6 (GmPIP1;6) in growth regulation and salt tolerance in soybean was discovered.

Results suggested that GmPIP1;6 may be a multifunctional aquaporin, involved in root water transport, photosynthesis and seed loading. Soybean plants over expressing GmPIP1;6 were grown in the field and demonstrated increased yield resulting mainly from an increase in seed size. This is a promising gene for genetic engineering to improve soybean yield under field conditions.

When we teach, we learn.

Karina Price | Science Communications Officer, ARC Centre of Excellence in Plant Energy Biology

Education, Outreach & Training

Education, Outreach & Training

Science and innovation are an important part of everyone's future. At PEB we believe that providing the community with access to accurate information and creating a positive public dialogue about science is vital.

To facilitate a better and more widespread understanding of the importance of plants the Centre uses targeted Education, Outreach and Training programs and resources to link the community with plant energy biology research. The Centre continues to explore and engage with new opportunities to communicate its science.

Science Communications Officer: Karina Price (UWA)

The Science Communications Officer manages and co-ordinates PEB's science communication and outreach activity nationally, working with each of PEB's four Australian nodes to ensure communication of the Centre's science throughout the country.

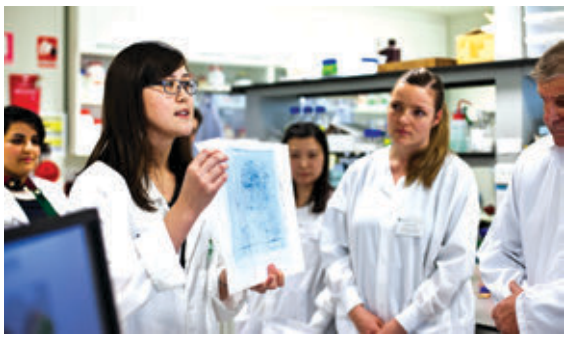
"I help to build a bridge between PEB's scientists and a wide audience. It helps when you work with a team who are as enthusiastic about communicating their science as they are about performing it! We all see the value in letting the world know what we do at the Centre, and why. In my role I get to explore the most creative and effective ways of achieving this!

The Centre aims to inspire students, teachers, end-users and the general public, across Australia, through the delivery of engaging, informative and unique science programs".

Highlight

Launch of the Centre for 2014- 2020

The launch of the ARC Centre of Excellence in Plant Energy Biology for 2014-2020 offered a unique opportunity to educate and inform an influential audience about the Centre's science. Visitors attending the launch included dignitaries from Government and academia, and representatives from science industry and agriculture.



PEB Chief Investigators, staff and students showcased their research against the backdrop of the Centre's UWA laboratory spaces. Lab coats were donned and visitors were walked and talked through many of the technologies and experimental techniques used by PEB researchers including climate controlled growth cabinets, novel ways of genetically engineering plants and instrumentation to sequence genomes and measure photosynthesis and respiration.

Informative presentations were given by passionate PEB scientists about their projects and programs of study, providing detail of how this research will address big picture issues in agriculture and food security.

"As someone from an agricultural background it was so interesting to hear the dialogue this afternoon"

Senator for Western Australia Chris Back.

PEB engage school aged students in a number of ways to educate and inform them about our research.

Powerful Plants, our hands-on program that teaches primary and secondary students and teachers scientific method, critical thinking and the importance of plant research engaged 150 primary and secondary students from WA and ACT schools in 2014.

Students learned about the power of plants, how they grow, what DNA actually is and took part in messy and exciting hands-on experiments.

"I explained plants, their functions and their significance to humans and the environment. The kids really enjoyed it and there were lots of surprises during question time - I have never faced that many questions simultaneously!"

Arun Yadav, visiting PEB scientist to Turner School's Year 1 class.

Highlight

The Chanelle Carter Memorial Fund, 2014

PEB had the pleasure of hosting six high achieving, science-interested, female year ten students from Newton Moore SHS at their UWA laboratories in 2014. The Powerful Plants excursion had the enthusiastic students participate in an interactive presentation, ask questions of PEB scientists and tour laboratory facilities, before performing their own experimentations. To extract DNA from plant cells the young scientists generated their own experimental reagents, discussing the components and how they acted upon plant cells to open up the cell wall and membranes to release the DNA housed inside the cell nucleus.

The Chanelle Carter Memorial Fund supported the participation of these students in a stimulating educational experience that allowed them to move beyond the class room and gain insight into what a career in science is like.

"Thanks for the awesome activities, it was exciting!"

Year 10 student, Powerful Plants.

Enthusing young people about science careers and creating advocates for scientific discovery is a major aim of the Centre. PEB scientists have been actively involved in many opportunities to engage school-aged learners in science.

Centre staff and students from PEB's ANU node contributed to Melrose High School's award winning Academic Curriculum Enrichment (ACE) science program, an advanced, novel science program for year 8 to 10 students. PEB's involvement with the program included a seminar and tour of PEB's laboratories and plant genomics facility for 30 students, as well as school visits and presentations from PEB scientists.

The Science Mentor project saw Year 12 Canberra College student Emily England perform a research project assessing the interactive effects of elevated CO_2 and nutrient supply on growth of a cereal crop. PEB provided expert mentorship and guidance, as well as access to hardware for measuring CO_2 concentrations, allowing Emily to complete her project at a level mirroring academic research.

A week long experience for two year 11 students from Canberra Senior High School at PEB's ANU node immersed them in the life of a plant energy biologist. The students spent time handling plants in the greenhouse, recording plant phenotypes, testing growth cabinets and assisting with DNA extractions, as well as reading through scientific literature.

Highlight

Estee Tee: Educating and Inspiring.

Estee is a PEB PhD student who is passionate about the communication of science and about inspiring a new generation of young scientists. Estee provided a link between PEB and the students at Melrose High School, where she formerly studied, by visiting the school to present as part of the ACE science program. She regaled 25 year 8 students with the story of her University life and science experience.

"It really gives a fantastic platform to inspire students and show that science is a dialogue, and that it is an interactive and accessible process" she said.

"My former high school teacher was the first to encourage and inspire me to pursue science" says Estee. In recognising the impact that communication of science can have on someone's future she feels privileged to have the opportunity now as a scientist to pay this forward and be part of an avenue of engagement for high school students with the scientific community.

As well as programs for school students, Centre researchers share their insights and knowledge with undergraduate students in lectures and laboratories.

Outreach

Our Public Outreach programs communicate our research to a range of community groups and end users. Our programs are innovative, creative and comprehensive outreach products that create opportunities to communicate current research and demonstrate the role of plant energy biology in everyday life.

In 2014 PEB undertook a range of activities that allowed the Centre to engage and educate public audiences in various aspects of plant and molecular science. Bio-Bounce, a unique PEB resource, is the world's biggest and bounciest plant cell! The 10 metre by 13 metre inflated structure incorporates all the elements needed for the molecular function of plants, and allows for an immersive and hands-on educational experience led by PEB staff.

Plant Powerstation is a key resource for PEB's community education and outreach. Our staff facilitate visitor participation in hands-on educational activities, and interact with members of the community as part of public display stalls.

Bio-Bounce, together with Plant Powerstation featured at a number of public events in 2014 including university open days and The South West Super Science Spectacular in Bunbury, WA which was attended by over 5000 members of the community. By getting the public engaged with and excited about science we help the community to make more informed choices on new technologies in biology.

Highlight

UWA Open Day

UWA Open Day 2014 offered a fantastic opportunity for PEB to showcase some of its exciting research at the Centre's administering campus and a chance for PEB staff to interact one on one with members of the community.

In excess of 500 visitors, including parents, children and prospective university students visited one or more of PEB's three displays. Using two Plant Powerstations and the Bio-Bounce passionate PEB researchers communicated how the plant energy system works and the reasons why we study it.

Visitors were given the opportunity to examine plant cells using a microscope, explore genes and DNA, view fascinating and educational photographic works by PEB scientists, immerse themselves in the (inflated) components of a plant cell, and experiment with the effect of different salt concentrations on plant growth.

Public presentations were another means by which PEB created opportunities for access to accurate scientific information and stimulated informed public dialogue about science in 2014. PEB staff presented a number of scientific talks to public and specialist group audiences throughout Australia on a variety of topics including; DNA and plant classification; Understanding drivers for crop survival and maintaining production in changing climatic conditions; Plants and salty soils; and Exploring of the epigenome.

Over 200 members of the public in Western Australia, South Australia and the Australian Capital Territory were reached in this way.

PEB recognises that the Australian media is an avenue to achieve broad community reach for the communication of its science. The Centre's media coverage in 2014 included one hundred print and web articles and radio and television segments due to the Centre's scientific achievements.

PEB scientists and science featured in Australasian Science magazine, Science Network WA, The Conversation, The Australian newspaper, ABC News (online, radio and television), ABC's Gardening Australia television series and on our own website (14,990 unique visitors attracted in 2014). PEB uses two social media forums, Twitter and Facebook, to promote its science and educate the community. By the end of 2014 PEB social media had acquired over 500 followers.

Collaborative Endeavours, Training & Future Initiatives

Collaborative Endeavours

In 2014 the Centre participated in a number of education and outreach initiatives that were created and hosted by other organisations sharing an interest in disseminating accurate and engaging science. Such opportunities broaden PEB's science communication capabilities, stimulate fresh ideas and provide access to different audiences.

The Centre's Plant Powerstation made an appearance at Scitech, a Western Australian public science centre, along with several PEB staff in 2014. PEB's Meet the Scientist session on the Scitech main floor drew visitors in the hundreds. Curious young minds used a magnifying glass to compared the back of their hands with the back of a leaf, before examining the stained cells of an onion down a microscope.

Young scientists and their parents got their hands dirty while extracting DNA from strawberries and discussed the question "do all plants contain genes?" with PEB scientists.

Profs and Pints, hosted by Scitech, is a "science discussion with a public audience" event, held in a WA pub. PEB participated in Profs and Pints by providing a scientist to engage in a stimulating and informative discussion centred around the theme of "It's the end of the world as we know it: what will Perth 2050 look like?". PEB's Professor Harvey Millar gave his view on the way plant energy research might play a role in shaping the nation's future.

A number of PEB scientists participated in the Women of Science Wikibomb event hosted by the Australian Academy of Science. The event aimed to increase the profiles of women scientists and improve access to information through the creation of Wikipedia pages. PEB's participants created profiles for ten Australian female scientists including the Centre's own Chief Investigator Professor Rana Munns.

Science Café, organised by Scitech and hosted at UWA was attended by several hundred WA high school students. Three of PEB's scientists participated in the event, engaging small groups of enthusiastic students in conversations about science and science careers.

In late 2014 PEB established a valuable partnership with the Australian Science Media Centre (AusSMC, http://www.smc.org.au/). AusSMC is an independent, not-for-profit service for the news media that provides journalists with direct access to evidence-based science and expertise. AusSMC aims to improve links between media and the scientific community. This partnership will greatly enhance PEB's ability to make far-reaching science communication impact through the media in the future.

Training

Professional training provides our staff and students with both tools and confidence to enhance their communication skills. To equip our staff and students with the capacity to effectively communicate to a broad range of audiences Centre staff participated in The Art and Science of Communications, a science communication workshop delivered by David Salt, a science writer and communicator for over 25 years.

A number of PEB staff took part in a media training workshop delivered by AusSMC to become more comfortable working with the media. By building a stronger understanding of best practice interaction with the media, the Centre will strengthen its ability to reach Australians with accurate scientific information in the future.

Future initiatives

In 2014 PEB commenced work towards producing a unique public education and outreach resource that will utilise a very distinctive space for immersing audiences in science; a planetarium! The Centre has been working with a science visualisations expert and staff from the Scitech Planetarium to create Plantarium, a short, full-dome movie. Plantarium will screen in 2015 in the Scitech Planetarium and offers a means to visually showcase, explore and explain some of PEB's research.

The groundwork for a 2015 partnership between PEB, the ARC Centre of Excellence in Translation Photosynthesis and the Australian Science Teachers Association (ASTA) was laid in 2014. In recognising that many common goals exist in the science communication agendas of the two Centres of Excellence we will combine our energies in 2015 to produce a number of resources for science teachers.

ASTA's expertise will be drawn on to help identify best links with Australian curriculum and provide broad access to teachers.

Preparation of the Centre's next photography exhibition got underway in 2014. The series of photographs will go on display in Science Centres around Australia in 2015. Photographs include exciting, educational and unusual images taken by PEB researchers to showcase plants and plant science.

PEB provides a multi-cultural, multi-disciplinary research environment that stimulates innovative research. It is an exceptionally productive place, with fruitful discussions that ensure the spreading of knowledge and expertise.

Dr Sandra Tanz | Research Assistant Professor,
ARC Centre of Excellence in Plant Energy Biology

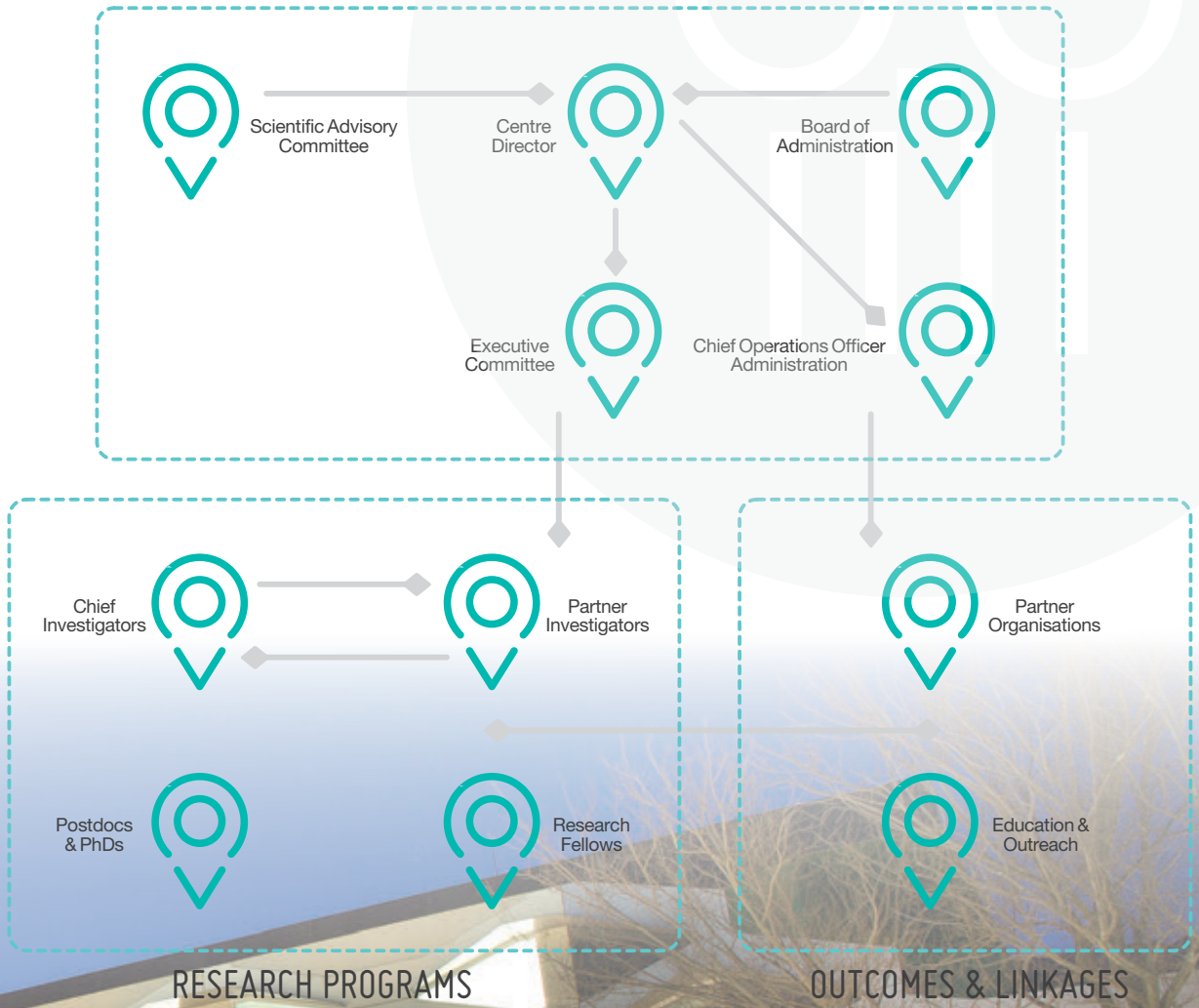
People

01

Personal Successes

Laura Boykin	TED Fellowship	TED
Caitlin Byrt	Edith Emily Dornwell Early Career Research Medal	University of Adelaide
Kai Xun Chan	2014 EMBL Australia PhD Travel Grant	European Molecular Biology Organization, Australia
Kai Xun Chan	Young Scientist Award	9th International Workshop, Sulfur Metabolism in Plant
Diep Ganguly	EMBL Australia PhD Course acceptance	European Molecular Biology Laboratory, Australia
Ryan Lister	Frank Fenner Prize for Life Scientist of the Year	Prime Minister's Prizes for Science, Government of Australia
Ryan Lister	2014 Ruth Stephens Gani Medal	Australian Academy of Sciences
Harvey Millar	Plant Physiology Highly Cited Author Award	American Society of Plant Biologists
Harvey Millar	Thomson Reuters 2014 Highly Cited Researcher	Thomson Reuters
Rana Munns	Fellow of the World Academy of Sciences	The World Academy of Sciences
Sophia Ng	Research Fund for International Young Scientists recipient	National Natural Science Foundation of China
Barry Pogson	The Plant Cell Highly Cited Author Award	American Society of Plant Biologists
John Rivers	EMBL Australia PhD Course acceptance	European Molecular Biology Laboratory Australia
Ian Small	Australian Laureate Fellow	Australian Research Council
Ian Small	2014 Scientist of the Year	Premier's Science Awards, Government of Western Australia
Ian Small	Thomson Reuters 2014 Highly Cited Researcher	Thomson Reuters
Sandra Tanz	Vice Chancellor's Research Award for Early Career Investigators	University of Western Australia
Lasantha Weerasinghe	2014 Tree Physiology Award for the Best Graduate Student Paper	Tree Physiology

ADMINISTRATION AND MANAGEMENT



Administration Team

The Administration Team has roles in both strategic and functional contexts of PEB, supporting research staff and their work and facilitating the effective co-operation of the four Centre nodes. The team is responsible for supporting the Centre's role as a research focused operation with reporting responsibilities to university and government and with a role in public education and engagement, at both a local and national level.
In 2014 PEB welcomed a new administrative staff structure into the fold.

The **Chief Operations Officer** (COO) role was created at UWA to lead the Centre in administrative good practice, and to ensure compliance with ARC and University regulations and procedures. In addition PEB has appointed two **Operation Managers** at ANU and the University of Adelaide. The new structure enables effective operational management between PEB's four Centre nodes. Working together with the operational managers, the COO supports administrative processes at each of the node universities and liaises with node leaders.

At UWA, the Centre's administering node, a local administrative team consists of the COO, an **Administrative Officer** who is responsible for a range of functions including personnel, events and student management activities, and an **Accounts and Purchasing Officer** who provides administrative support for the financial accounting and reporting needs of PEB.

The Centre's UWA-based **Senior I.T. Officer** provides support for local I.T. needs, including administration and maintenance of computational resources ranging from desktop to server infrastructure and networking. The Centre's public face, the PEB website (www.plantenergy.edu.au) is also maintained by the Senior I.T. Officer. The Senior I.T. Officer along with a **Database and Systems Engineer** also contributes expertise to computing-related research tasks.

Laboratory Technicians at each of the Centre nodes manage the technical aspects of laboratory spaces and support research staff and students through the maintenance of these working spaces.

The **Science Communications Officer** manages and co-ordinates PEB's education, outreach and training activity in Western Australia and nationally, liaising with key personnel at each of PEB's nodes and working with all PEB staff and students to ensure a common approach and uniformity of message in regards to the Centre's science communication initiatives.

PEB recognises that its ability to function as a collaborative, national Centre and maintain itself as a world-leading research facility is reliant on the support of a strong administrative team. PEB's team comprises a broad range of skills and personalities, enabling it to draw on solid experience and inject innovation and fresh ideas to enhance the Centre's capabilities.

Scientific Advisory Committee

A Scientific Advisory Committee (SAC) of six scientists and end-user representatives assist and guide the Centre.

Emeritus Professor Ian W. Dawes FAA (SAC Chair)
School of Biotechnology and Biomolecular Sciences, UNSW Australia

Emeritus Professor Dawes' research career has focused on the response of eukaryotic organisms to oxidative stress and ageing, the molecular analysis of control of one-carbon and folate metabolism in yeast and the mechanisms involved in initiation and timing of cell development. He is an editor of the journal FEMS Yeast Research and a member of the editorial boards of Yeast and the Journal of Microbiology.

Em. Prof. Dawes has been a Board Member of the Victor Chang Cardiac Research Institute and of the Australian Proteomic Analytical Facility and Chairman of the International Yeast Genetics and Molecular Biology Community. He has a BSc from the University of New South Wales, a DPhil from the University of Oxford in the UK and is a Fellow of the Australian Academy of Science.

Professor Elizabeth S. Dennis FAA FTSE
Division of Plant Industry and Distinguished Professor, UTS

Professor Dennis is one of the world's leading plant molecular biologists. She is a CSIRO Fellow whose plant research has led to tangible outcomes in Australian agriculture. Her research focuses on gene regulation, both genetic and epigenetic. As Chairman of the Multinational Arabidopsis Genome Project Prof. Dennis played a key role in mapping one of the first plant genomes.

Prof. Dennis's scientific excellence is acknowledged through numerous awards and distinctions, including election as a Fellow of the Australian Academy of Technological Sciences and Engineering; election as a Fellow of the Australian Academy of Science; the Lemberg Medal for distinguished contributions to biochemistry; the Pharmacia LKB/Biotechnology Medal of the Australian Biochemical Society for contributions to Biochemical Research and the inaugural Prime Minister's Prize for Science.

Emeritus Professor Margaret Clayton
School of Biological Sciences, Monash University

Emeritus Professor Clayton has previously held the positions of Head of the School of Biological Sciences, Deputy Dean of the Science Faculty and the Faculty's Associate Dean (Research) at Monash University. Her research career has been on the functional importance of phenolic compounds in brown algae, the reproductive biology of marine algae and molecular phylogeny of brown algae.

Em Prof Clayton was the ARC's Executive Director of Biological Sciences and Biotechnology from 2006 till 2009.

Professor Dale Sanders FRS
Sohn Innes Centre, Norwich Research Park.

Professor Sanders is Director of the John Innes Centre, internationally regarded as one of most prestigious plant and microbial sciences research centres. His career has focused on plant cell responses to environment and on plant cell nutrient acquisition and storage. He is a leading authority on mechanisms for the transport of chemical elements across plant cell membranes - mechanisms that have key roles in the control of crucial crop traits such as nutritional value, seed germination, response to drought conditions and plants response to toxins.

Prof. Sanders also works on the fundamental science of specialised plant transport mechanisms involved in signalling which have important, but poorly understood roles in plant biology. In 2001 he was elected as a Fellow of the Royal Society and awarded the European Science Prize of the Kärber Foundation.

Dr. Steve Thomas
Executive Manager - Commercial, Grain Research and Development Corporation (GRDC)

Dr Thomas is responsible for the GRDC's increased focus on partnerships with commercial enterprises and overseas research entities. As the previous Executive Manager of GRDC's Research Program portfolio he led the development and implementation of a long-term strategy for maximising the impact of research investment.

Dr Thomas has held numerous roles across the agricultural research sector, including Director level roles at the New South Wales Department of Primary Industries and research positions in plant molecular biology with the Australian Centre for Necrotrophic Fungal Pathogens and with the Carlsberg Research Laboratories in Copenhagen.

Professor Dr. Detlef Weigel FRS
Department of Molecular Biology, Max Planck Institute for Developmental Biology

Professor Weigel is a Director of the Max Planck Institute for Developmental Biology in Tübingen, Germany. His research focuses on mechanisms which are responsible for adaptive variation of plants, discovered through the interface of plant biology, developmental genetics and evolutionary genomics.

Prof. Weigel has received numerous honours for his contributions to plant and evolutionary biology, including the Otto Bayer Award (2010) and the State Research Prize Baden-Württemberg (2011). He is an elected member of the European Molecular Biology Organisation (EMBO), the German National Academy of Sciences, Leopoldina, the US National Academy of Sciences and the Royal Society of London.

UWA NODE

Alexova	Rali	Affiliated Researcher S/Science Fellow
Baer	Boris	Affiliated ARC Future Fellow
Belt	Katharina	PhD student
Bernath-Levin	Kalia	Affiliated Research Fellow
Bogdanovich	Ozren	Affiliated Researcher DECRA
Boykin	Laura	Research Associate
Cahn	Jonathan	PhD student
Castleden	Ian	Data Base Engineer
Che Othman	Hafiz	PhD student
Colas des Francs	Cathie	Postdoctoral Researcher
Corral	Max	PhD student
Doselli	Ryan	Affiliated Researcher
Duncan	Owen	Affiliated Postdoctoral Researcher - ECR
Farthing	Rosemarie	Laboratory Technician
Fenske	Ricarda	Research Officer
Fisher	Mark	Honours Student
Ford	Ethan	Affiliated Postdoctoral Researcher
Franklin	Amy	PhD student
Gillett	Jennifer	Administrative Officer
Grassl	Julia	Affiliated Postdoctoral Researcher
Gutmann	Bernard	EMBO Fellow
Heidarvand	Leila	PhD student
Hooper	Cornelia	Research Associate
Howell	Katharine	Affiliated Researcher DECRA
Huang	Shaobai	Affiliated ARC Future Fellow
Kerbler	Sandra	PhD student
Kindgren	Peter	Visiting Research Fellow
Kubiszewski-Jakubiak	Szymon	PhD student
Lee	Chun Pong	Postdoctoral Researcher ECR
Li	Lei	Affiliated Postdoctoral Researcher ECR
Li	Jing	Affiliated Postdoctoral Researcher
Lister	Ryan	Chief Investigator
Mann	Julia	PhD student
Melonek	Joanna	Postdoctoral Researcher ECR
Millar	A. Harvey	Director and Chief Investigator
Mohamed	Sufyaan	PhD student
Morelle	Geoffrey	PhD student (Co-tutelle)
Munns	Rana	Chief Investigator
Murcha	Monika	Affiliated ARC Future Fellow
Mylne	Josh	Affiliated ARC Future Fellow
Nelson	Clark	Research Fellow
Ng	Sophia	Postdoctoral Researcher ECR
Nonis	Sam	Honours Student
Paynter	Ellen	PhD student
Peng	Yan	PhD student
Peso	Marianne	Affiliated Postdoctoral Researcher
Petereit	Jakob	Research Assistant
Porri	Aimone	Postdoctoral Researcher
Pouvreau	Benjamin	PhD student
Price	Karina	Science Communications Officer
Pruzinska	Adrianna	Affiliated Researcher DECRA
Sanjeevanie Jayasena Mederian Kotuwe	Achala	PhD student
Secco	David	Affiliated Researcher S/Science Fellow
Sew	Michelle	PhD student
Shute	Geetha	Chief Operations Officer
Small	Ian	Chief Investigator
Small	Ghislaine	PhD student
Srivastava	Akanksha	PhD student
Stroeher	Elke	Affiliated Researcher ARC APDF
Stuart	Tim	PhD student
Tan	Dennis	PhD student
Tanz	Sandra	Affiliated Researcher DECRA
Taylor	Nicolas	Affiliated ARC Future Fellow
Troesch	Josua	Technical Officer
Vacher	Michael	PhD student/Research Associate
Van Aken	Olivier	Affiliated Researcher ARC APDF
van der Merwe	Marne	Affiliated Researcher DECRA
Walker	Hayden	Senior Computer Officer
Waters	Mark	Affiliated Postdoctoral Researcher
Yap	Aaron	PhD student
Yeoman	Deborah	Purchasing Officer
Zhou	Wenxu	Affiliated Postdoctoral Researcher

ANU NODE

Abdul Bahar	Nur	PhD Student
Atkin	Owen	Chief Investigator
Au	Eng Kee	Honours student
Bloomfield	Keith	Postdoctoral Researcher
Borevitz	Justin	Chief Investigator
Brown	Tim	Postdoctoral Researcher
Chan	Kai Xun	PhD Student
Cheng	Riyan	Postdoctoral Researcher
Chi Khin	Nay	Honours Student
Chong	Caroline	Postdoc
Collinge	Derek	Laboratory Manager
Copas	Patricia	Honours Student
Crisp	Peter	PhD student
Eichten	Steve	HFSP Fellow - ECR
Ganguly	Diep	PhD Student
Hayes	Lucy	Laboratory Technician
Hou	Xin	PhD student
Kariyawasam	Buddhima	PhD Student
Kee Au	Eng	Honours Student
Khin	Nay Chi	Honours student
Murray	Kevin	PhD Student
Negrini	Ana Clarissa	PhD student
Nguyen	Chuong	Postdoctoral Researcher
Nisar	Nazia	Affiliated Postdoctoral Researcher
Phua	Su Yin	PhD Student
Pogson	Barry	Deputy Director and Chief Investigator
Rivers	John	PhD Student
Rungrat	Tepsuda	PhD Student
Stewart	Tricia	Honours student
Streich	Jared	PhD Student
Supple	Megan	Postdoctoral Researcher - ECR
Tee	Estee	PhD Student
Warthmann	Norman	Postdoctoral Researcher - ECR
Wilson	Pip	Postdoctoral Researcher
Worcester	Corey	Operations Manager
Xiang	Jen	Laboratory Technician
Xiong	Xiaofeng	PhD Student
Yadav	Arun	Postdoctoral Researcher - ECR
Zhu	Ling Ling	Postdoctoral Researcher

UNIVERSITY OF ADELAIDE NODE

Athman	Asmini	Laboratory Manager
Bayer	Luciano Caravia	PhD Student
Byrt	Caitlin	Postdoctoral Fellow - ECR
Gilliham	Matt	Chief Investigator
Henderson	Sam	Postdoctoral Fellow - ECR
Hocking	Bradleigh	PhD Student
Kamran	Muhammad	PhD Student
Kaur	Satwinder	Masters Student
Qiu	Jiaen	PhD Student
Qu	Yue	PhD Student
Ramesh	Sunita	Postdoctoral Researcher
Scharwies	Johannes	PhD Student
Sullivan	Wendy	Laboratory Manager
Tyerman	Stephen	Chief Investigator
Vandeleur	Rebecca	Operations and Research Manager
Wege	Stephanie	Postdoctoral Fellow - ECR
Wignes	Jonathan	PhD Student
Xu	Bo	Independent (Waite Research Institute) Postdoctoral Fellow

LA TROBE NODE

De Clercq	Inge	Research Fellow
Harris	Hayden	Laboratory Technician
Ivanova	Aneta	Research Fellow
Li	Lu	PhD Student
Linn	Josh	PhD Student
Lyu	Wenhui	PhD Student
Marina	Osorio	PhD Student
Narsai	Reena	Postdoctoral Researcher
Radomilljac	Jordan	Research Officer
Wang	Yan	Postdoctoral Researcher
Whelan	James	Chief Investigator
Zanganeh	Fatemeh	Honours Student
Zhang	Botao	Research Fellow

Selected 2014 Centre Publications

Alexova R, Nelson CJ, Jacoby RP, Millar AH (2014) Exposure of barley plants to low Pi leads to rapid changes in root respiration that correlate with specific alterations in amino acid substrates. NEW PHYTOLOGIST (in press)

Athman A, Tanz SK, Conn VM, Jordans C, Mayo GM, Ng WW, Burton RA, Conn SJ, Gilliham M (2014) Protocol: a fast and simple in situ PCR method for localising gene expression in plant tissue. PLANT METHODS 10:29

Atkin OK, Meir P, Turnbull MH (2014) Improving representation of leaf respiration in large-scale predictive climate-vegetation models. NEW PHYTOLOGIST 202(3):743-8

Avendaño-Vázquez AO, Cordoba E, Llamas E, San Román C, Nisar N, De la Torre S, Ramos-Vega M, Gutiérrez-Nava MD, Cazzonelli CI, Pogson BJ, León P (2014) An Uncharacterized Apocarotenoid-Derived Signal Generated in ζ-Carotene Desaturase Mutants Regulates Leaf Development and the Expression of Chloroplast and Nuclear Genes in Arabidopsis. THE PLANT CELL 26(6):2524-2537

Ayub G, Zaragoza-Castells J, Griffin KL, Atkin OK (2014) Leaf respiration in darkness and in the light under pre-industrial, current and elevated atmospheric CO_2 concentrations. PLANT SCIENCE 226:120-30

Baby T, Hocking B, Tyerman SD, Gilliham M, Collins C (2014) Modified method for producing grapevine plants in controlled environments. AMERICAN JOURNAL OF ENOLOGY AND VITICULTURE 65(2): 261-7

Bainbridge K, Bennett T, Crisp P, Leyser O, Turnbull C (2014) Grafting in Arabidopsis. METHODS IN MOLECULAR BIOLOGY 1062:155-63

Blanco NE, Guinea-Díaz M, Whelan J, Strand Ĺ (2014) Interaction between plastid and mitochondrial retrograde signalling pathways during changes to plastid redox status. PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON B: BIOLOGICAL SCIENCES 369(1640):20130231

Boussardon C, Avon A, Kindgren P, Bond CS, Challenor M, Lurin C, Small I (2014) The cytidine deaminase signature HxE(x)n CxxC of DYW1 binds zinc and is necessary for RNA editing of ndhD-1. NEW PHYTOLOGIST 203(4):1090-5

Boykin LM, De Barro PJ (2014) A practical guide to identifying members of the Bemisia tabaci species complex: and other morphologically identical species. FRONTIERS IN ECOLOGY AND EVOLUTION 2

Boykin LM (2014) Bemisia tabaci nomenclature: lessons learned. PEST MANAGEMENT SCIENCE 70(10):1454-9

Brown GG, Colas des Francs-Small C, Ostersetzer-Biran O (2014) Group II intron splicing factors in plant mitochondria. FRONTIERS IN PLANT SCIENCE 5:35

Brown TB, Cheng R, Sirault XR, Rungrat T, Murray KD, Trtilek M, Furbank RT, Badger M, Pogson BJ, Borevitz JO (2014) TraitCapture: genomic and environment modelling of plant phenomic data. CURRENT OPINION IN PLANT BIOLOGY 18:73-9

Byrt CS, Xu B, Krishnan M, Lightfoot DJ, Athman A, Jacobs AK, Watson-Haigh NS, Plett D, Munns R, Tester M, Gilliham M (2014) The Na(+) transporter, TaHKT1;5-D, limits shoot Na(+) accumulation in bread wheat. THE PLANT JOURNAL 80(3):516-26

Cazzonelli CI, Nisar N, Roberts AC, Murray KD, Borevitz JO, Pogson BJ (2014) A chromatin modifying enzyme, SDG8, is involved in morphological, gene expression, and epigenetic responses to mechanical stimulation. FRONTIERS IN PLANT SCIENCE 5:533

Chaumont F, Tyerman SD (2014) Aquaporins: highly regulated channels controlling plant water relations. PLANT PHYSIOLOGY 164(4):1600-18

Cheah MH, Millar AH, Myers RC, Day DA, Roth J, Hillier W, Badger MR (2014) Online oxygen kinetic isotope effects using membrane inlet mass spectrometry can differentiate between oxidases for mechanistic studies and calculation of their contributions to oxygen consumption in whole tissues. ANALYTICAL CHEMISTRY 86(10):5171-8

Chiasson DM, Loughlin PC, Mazurkiewicz D, Mohammadidehcheshmeh M, Fedorova EE, Okamoto M, McLean E, Glass AD, Smith SE, Bisseling T, Tyerman SD, Day DA, Kaiser BN (2014) Soybean SAT1 (Symbiotic Ammonium Transporter 1) encodes a bHLH transcription factor involved in nodule growth and NH4+ transport. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES U.S.A. 111(13):4814-9

Cohen S, Zmudjak M, Colas des Francs-Small C, Malik S, Shaya F, Keren I, Belausov E, Many Y, Brown GG, Small I, Ostersetzer-Biran O (2014) nMAT4, a maturase factor required for nad1 pre-mRNA processing and maturation, is essential for holocomplex I biogenesis in Arabidopsis mitochondria. THE PLANT JOURNAL 78(2):253-68

Colas des Francs-Small C, Falcon de Longevialle A, Li Y, Lowe E, Tanz SK, Smith C, Bevan MW, Small I (2014) The Pentatricopeptide Repeat Proteins TANG2 and ORGANELLE TRANSCRIPT PROCESSING439 Are Involved in the Splicing of the Multipartite nad5 Transcript Encoding a Subunit of Mitochondrial Complex I. PLANT PHYSIOLOGY 165(4):1409-1416

Donoghue MT, Fort A, Clifton R, Zhang X, McKeown PC, Voigt-Zielinksi ML, Borevitz JO, Spillane C (2014) C(m)CGG methylation-independent parent-of-origin effects on genome-wide transcript levels in isogenic reciprocal F1 triploid plants. DNA RESEARCH 21(2):141-51

Estavillo GM, Verhertbruggen Y, Scheller HV, Pogson BJ, Heazlewood JL, Ito J (2014) Isolation of the plant cytosolic fraction for proteomic analysis. METHODS IN MOLECULAR BIOLOGY 1072:453-67

Fitz Gerald JN, Carlson AL, Smith E, Maloof JN, Weigel D, Chory J, Borevitz JO, Swanson RJ (2014) New Arabidopsis advanced intercross recombinant inbred lines reveal female control of nonrandom mating. PLANT PHYSIOLOGY 165(1):175-85

Gauthier PP, Crous KY, Ayub G, Duan H, Weerasinghe LK, Ellsworth DS, Tjoelker MG, Evans JR, Tissue DT, Atkin OK (2014) Drought increases heat tolerance of leaf respiration in Eucalyptus globulus saplings grown under both ambient and elevated atmospheric [CO2] and temperature. JOURNAL OF EXPERIMENTAL BOTANY 65(22):6471-85

Gavrin A, Kaiser BN, Geiger D, Tyerman SD, Wen Z, Bisseling T, Fedorova EE (2014) Adjustment of host cells for accommodation of symbiotic bacteria: vacuole defunctionalization, HOPS suppression, and TIP1g retargeting in Medicago. THE PLANT CELL 26(9):3809-22

Grabowski PP, Morris GP, Casler MD, Borevitz JO (2014) Population genomic variation reveals roles of history, adaptation and ploidy in switchgrass. MOLECULAR ECOLOGY 23(16):4059-73

Guan R, Qu Y, Guo Y, Yu L, Liu Y, Jiang J, Chen J, Ren Y, Liu G, Tian L, Jin L, Liu Z, Hong H, Chang R, Gilliham M, Qiu L (2014) Salinity tolerance in soybean is modulated by natural variation in GmSALT3. THE PLANT JOURNAL 80(6):937-50

Henderson SW, Baumann U, Blackmore DH, Walker AR, Walker RR, Gilliham M (2014) Shoot chloride exclusion and salt tolerance in grapevine is associated with differential ion transporter expression in roots. BMC PLANT BIOLOGY 14:273

Heskel MA, Bitterman D, Atkin OK, Turnbull MH, Griffin KL (2104) Seasonality of foliar respiration in two dominant plant species from the arctic Tundra: response to long-term warming and short-term temperature variability. FUNCTIONAL PLANT BIOLOGY 41:287-300

Heskel MA, Greaves HE, Turnbull MH, O'Sullivan OS, Shaver GR, Griffin KL, Atkin OK (2014) Thermal acclimation of shoot respiration in an Arctic woody plant species subjected to 22 years of warming and altered nutrient supply. GLOBAL CHANGE BIOLOGY 20(8):2618-30

Hooper CM, Tanz SK, Castleden IR, Vacher MA, Small ID, Millar AH (2014) SUBAcon: a consensus algorithm for unifying the subcellular localization data of the Arabidopsis proteome. BIOINFORMATICS 30(23):3356-64

Hooper CM, Hawes SM, Kees UR, Gottardo NG, Dallas PB (2014) Gene expression analyses of the spatio-temporal relationships of human medulloblastoma subgroups during early human neurogenesis. PLOS ONE 9(11):e112909

Huang S, Jacoby RP, Millar AH, Taylor NL (2014) Plant mitochondrial proteomics. METHODS IN MOLECULAR BIOLOGY 1072:499-525

Ivanova A, Law SR, Narsai R, Duncan O, Lee JH, Zhang B, Van Aken O, Radomiljac JD, van der Merwe M, Yi K, Whelan J (2014) A Functional Antagonistic Relationship between Auxin and Mitochondrial Retrograde Signaling Regulates Alternative Oxidase1a Expression in Arabidopsis. PLANT PHYSIOLOGY 165(3):1233-1254

Jayasena AS, Secco D, Bernath-Levin K, Berkowitz O, Whelan J, Mylne JS (2014) Next generation sequencing and de novo transcriptomics to study gene evolution. PLANT METHODS 10(1):34

Law SR, Narsai R, Whelan J (2014) Mitochondrial biogenesis in plants during seed germination. MITOCHONDRION 19 Pt B:214-21

Li Y, Cheng R, Spokas KA, Palmer AA, Borevitz JO (2014) Genetic variation for life history sensitivity to seasonal warming in Arabidopsis thaliana. GENETICS 196(2):569-77

Li XJ, Zhang YF, Hou M, Sun F, Shen Y, Xiu ZH, Wang X, Chen ZL, Sun SS, Small I, Tan BC (2014) Small kernel 1 encodes a pentatricopeptide repeat protein required for mitochondrial nad7 transcript editing and seed development in maize (Zea mays) and rice (Oryza sativa). THE PLANT JOURNAL 79(5):797-809

Liu G, Sun A, Li D, Athman A, Gilliham M, Liu L (2014) Molecular identification and functional analysis of a maize (Zea mays) DUR3 homolog that transports urea with high affinity. PLANTA (in press)

Looney TJ, Zhang L, Chen CH, Lee JH, Chari S, Mao FF, Pelizzola M, Zhang L, Lister R, Baker SW, Fernandes CJ, Gaetz J, Foshay KM, Clift KL, Zhang Z, Li WQ, Vallender EJ, Wagner U, Qin JY, Michelini KJ, Bugarija B, Park D, Aryee E, Stricker T, Zhou J, White KP, Ren B, Schroth GP, Ecker JR, Xiang AP, Lahn BT (2014) Systematic mapping of occluded genes by cell fusion reveals prevalence and stability of cis-mediated silencing in somatic cells. GENOME RESEARCH 24(2):267-80

Millar AH, Taylor NL (2014) Subcellular proteomics-where cell biology meets protein chemistry. FRONTIERS IN PLANT SCIENCE 5:55

Munns R (2014) Protocols and phenotyping: new wikis and manuals. FUNCTIONAL PLANT BIOLOGY 41(3): V-VI

Eds. Munns R, Schmidt S, Beveridge C (2014) Plants in Action, 2nd Edition.

Nelson CJ, Li L, Millar AH (2014) Quantitative analysis of protein turnover in plants. PROTEOMICS 14(4-5):579-92

Nelson CJ, Alexova R, Jacoby RP, Millar AH (2014) Proteins with high turnover rate in barley leaves estimated by proteome analysis combined with in planta isotope labeling. PLANT PHYSIOLOGY 166(1):91-108

Ng S, De Clercq I, Van Aken O, Law SR, Ivanova A, Willems P, Giraud E, Van Breusegem F, Whelan J (2014) Anterograde and retrograde regulation of nuclear genes encoding mitochondrial proteins during growth, development, and stress. MOLECULAR PLANT 7(7):1075-93

Nisar N, Cuttriss AJ, Pogson BJ, Cazzonelli CI (2014) The promoter of the Arabidopsis PIN6 auxin transporter enabled strong expression in the vasculature of roots, leaves, floral stems and reproductive organs. PLANT SIGNALING AND BEHAVIOR 9(1):e27898

Noutsos C, Borevitz JO, Hodges SA (2014) Gene flow between nascent species: geographic, genotypic and phenotypic differentiation within and between Aquilegia formosa and A. pubescens. MOLECULAR ECOLOGY 23(22):5589-98

Okuda K, Shoki H, Arai M, Shikanai T, Small I, Nakamura T (2014) Quantitative analysis of motifs contributing to the interaction between PLS-subfamily members and their target RNA sequences in plastid RNA editing. THE PLANT JOURNAL 80(5):870-82

Pogson BJ, Albrecht V (2014) An overview of chloroplast biogenesis and development. In: Theg SM, Wollman F-A ADVANCES IN PLANT BIOLOGY, PLASTID BIOLOGY. Springer 115-28

Polston JE, De Barro P, Boykin LM (2014) Transmission specificities of plant viruses with the newly identified species of the Bemisia tabaci species complex. PEST MANAGEMENT SCIENCE 70(10):1547-52

Shingaki-Wells R, Millar AH, Whelan J, Narsai R (2014) What happens to plant mitochondria under low oxygen? An omics review of the responses to low oxygen and reoxygenation. PLANT, CELL AND ENVIRONMENT 37(10):2260-77

Simmons LW, Beveridge M, Li L, Li L, Tan YF, Millar AH (2014) Ontogenetic changes in seminal fluid gene expression and the protein composition of cricket seminal fluid. EVOLUTION & DEVELOPMENT 16(2):101-9

Small I, Puchta H (2014) Emerging tools for synthetic biology in plants. THE PLANT JOURNAL 78(5):725-6

Tanz SK, Castleden I, Hooper CM, Small I, Millar AH (2014) Using the SUBcellular database for Arabidopsis proteins to localize the Deg protease family. FRONTIERS IN PLANT SCIENCE 5:396

Taylor NL, Ströher E, Millar AH (2014) Arabidopsis organelle isolation and characterization. METHODS IN MOLECULAR BIOLOGY 1062:551-72

Taylor NL, Fenske R, Castleden I, Tomaz T, Nelson CJ, Millar AH (2014) Selected reaction monitoring to determine protein abundance in Arabidopsis using the Arabidopsis proteotypic predictor. PLANT PHYSIOLOGY 164(2):525-36

Tian Q, Zhang X, Ramesh S, Gilliham M, Tyerman SD, Zhang WH (2014) Ethylene negatively regulates aluminium-induced malate efflux from wheat roots and tobacco cells transformed with TaALMT1. JOURNAL OF EXPERIMENTAL BOTANY 65(9):2415-26

Van Norman JM, Zhang J, Cazzonelli CI, Pogson BJ, Harrison PJ, Bugg TD, Chan KX, Thompson AJ, Benfey PN (2014) Periodic root branching in Arabidopsis requires synthesis of an uncharacterized carotenoid derivative. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES U.S.A. 111(13):E1300-9

Wang C, Li S, Ng S, Zhang B, Zhou Y, Whelan J, Wu P, Shou H (2014) Mutation in xyloglucan 6-xylosytransferase results in abnormal root hair development in Oryza sativa. JOURNAL OF EXPERIMENTAL BOTANY 65(15):4149-57

Wang HL, Yang J, Boykin LM, Zhao QY, Wang YJ, Liu SS, Wang XW (2014) Developing conversed microsatellite markers and their implications in evolutionary analysis of the Bemisia tabaci complex. SCIENTIFIC REPORTS 4:6351

Weerasinghe LK, Creek D, Crous KY, Xiang S, Liddell MJ, Turnbull MH, Atkin OK (2014) Canopy position affects the relationships between leaf respiration and associated traits in a tropical rainforest in Far North Queensland. TREE PHYSIOLOGY 34(6):564-84

Welch MD, Lister R (2014) Epigenomics and the control of fate, form and function in social insects. CURRENT OPINIONS IN INSECT SCIENCE 1:31-8.

Xin X, Tian Q, Yin G, Chen X, Zhang J, Ng S, Lu X (2014) Reduced mitochondrial and ascorbate-glutathione activity after artificial ageing in soybean seed. JOURNAL OF PLANT PHYSIOLOGY 171(2):140-7

Yu W, Briones V, Lister R, McIntosh C, Han Y, Lee EY, Ren J, Terashima M, Leighty RM, Ecker JR, Muegge K (2014) CG hypomethylation in Lsh-/- mouse embryonic fibroblasts is associated with de novo H3K4me1 formation and altered cellular plasticity. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES U.S.A. 111(16):5890-5

Yu W, McIntosh C, Lister R, Zhu I, Han Y, Ren J, Landsman D, Lee E, Briones V, Terashima M, Leighty R, Ecker JR, Muegge K (2014) Genome-wide DNA methylation patterns in LSH mutant reveals de-repression of repeat elements and redundant epigenetic silencing pathways. GENOME RESEARCH 24(10):1613-23

Zhang B, Van Aken O, Thatcher L, De Clercq I, Duncan O, Law SR, Murcha MW, van der Merwe M, Seifi HS, Carrie C, Cazzonelli C, Radomiljac J, Höfte M, Singh KB, Van Breusegem F, Whelan J (2014) The mitochondrial outer membrane AAA ATPase AtOM66 affects cell death and pathogen resistance in Arabidopsis thaliana. THE PLANT JOURNAL 80(4):709-27

Zhou L, Wang C, Liu R, Han Q, Vandeleur RK, Du J, Tyerman S, Shou H (2014) Constitutive overexpression of soybean plasma membrane intrinsic protein GmPIP1;6 confers salt tolerance. BMC PLANT BIOLOGY 14:181

2014 Publication Fast Facts

- Total number of publications by Centre staff: 97
- Average impact factor: 6.03
- Number of Journals published in: 52
- Publications in top journals (impact factor 10 and above): 10
- Top journals include Proceedings of the National Academy of Science, The Plant Cell, Nature Chemical Biology and Annual Reviews in Plant Biology.

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The University of Western Australia

Faculty of Science
4th Floor Bayliss Building
35 Stirling Highway, Crawley, 6009 WA
Phone: 61 8 6488 4416
Fax: 61 8 6488 4401

Australian National University

Research School of Biology
Linnaeus Building, Building 134
Linnaeus Way, Acton, 0200 ACT
Phone: 61 2 6125 3741
Fax: 61 2 6125 5075

The University of Adelaide

School of Agriculture Food and Wine
Waite Campus
Private Mail Bag 1, Glen Osmond, 5064 SA
Phone: 61 8 8303 6663
Fax: 61 8 8303 7116

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School of Life Science
AgriBio
5 Ring Road, Bundoora, 3086 VIC
Phone: 61 3 9032 7488

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