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Natural Genetic Variation for Seed Size in Maize

The electronic form of this issue, available as of June 6, 2014, at www.plantphysiol.org, is considered the journal of record.

On the Cover: Exploiting natural variation by selecting desirable phenotypes is key to the genetic improvement of complex traits. In this issue, Sekhon et al. (pp. 658–669) demonstrate that extreme phenotypic variants for component traits can be used to provide insight into underlying molecular, physiological, and developmental determinants. Using maize (*Zea mays*) populations and inbred lines derived from divergent selection for seed size, the authors examined development of large and small seeds using transcriptomic, compositional, and phenotypic analyses. The authors show that onset and rate of grain fill are key determinants of seed size and, through transcriptional networks, identify novel candidate genes regulating seed size in maize. Cover image credits: Rajandeep Sekhon (design), Matthew Wisniewski (photography), and Matthew Breitzman (assistance).

ON THE INSIDE

Peter V. Minorsky

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BREAKTHROUGH TECHNOLOGIES

[W][OPEN] High-Resolution Inflorescence Phenotyping Using a Novel Image-Analysis Pipeline, PANorama. Samuel Crowell, Alexandre X. Falcão, Ankur Shah, Zachary Wilson, Anthony J. Greenberg, and Susan R. McCouch

Image analysis facilitates high-resolution phenotyping and complements dense genetic marker data to improve quantitative trait locus mapping of inflorescence traits in rice.

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[C][W][OPEN] Quantifying Shape Changes and Tissue Deformation in Leaf Development. Anne-Gaëlle Rolland-Lagan, Lauren Remmler, and Camille Girard-Bock

A computational method for quantifying three-dimensional surfaces and local surface deformations of leaves during development provides a new tool to investigate the control of leaf morphogenesis.

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[C][W][OPEN] Integrated Analysis Platform: An Open-Source Information System for High-Throughput Plant Phenotyping. Christian Klukas, Dijun Chen, and Jean-Michel Pape

An open-source information system for high-throughput plant phenotyping enables large-scale image analysis for different species based on real-time imaging data obtained from different spectra.

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RESEARCH REPORTS

[OPEN] What Is Stress? Dose-Response Effects in Commonly Used *In Vitro* Stress Assays. Hannes Claeys, Sofie Van Landeghem, Marieke Dubois, Katrien Maleux, and Dirk Inzé

Responses to abiotic stress strongly depend on the stress level, and novel parameters, such as shoot growth inhibition and marker genes, are needed to accurately study and quantify mild stress responses.

519

[W][OPEN] Two Mitogen-Activated Protein Kinases, MPK3 and MPK6, Are Required for Funicular Guidance of Pollen Tubes in Arabidopsis. Yuefeng Guan, Jianping Lu, Juan Xu, Bruce McClure, and Shuqun Zhang

Two Arabidopsis mitogen-activated protein kinases are involved in the funicular guidance phase of pollen tube growth in plant reproduction.

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RESEARCH ARTICLES

BIOCHEMISTRY AND METABOLISM

[C][W][OPEN] Posttranslational Modification of Maize Chloroplast Pyruvate Orthophosphate Dikinase Reveals the Precise Regulatory Mechanism of Its Enzymatic Activity. *Yi-Bo Chen, Tian-Cong Lu, Hong-Xia Wang, Jie Shen, Tian-Tian Bu, Qing Chao, Zhi-Fang Gao, Xin-Guang Zhu, Yue-Feng Wang, and Bai-Chen Wang*

Change in light intensity, rather than light/dark transition, regulates the activity of pyruvate orthophosphate dikinase in maize via reversible phosphorylation at Thr-527. 534

[C][W][OPEN] Production of a *Brassica napus* Low-Molecular Mass Acyl-Coenzyme A-Binding Protein in *Arabidopsis* Alters the Acyl-Coenzyme A Pool and Acyl Composition of Oil in Seeds. *Olga Yurchenko, Stacy D. Singer, Cory L. Nykiforuk, Satinder Gidda, Robert T. Mullen, Maurice M. Moloney, and Randall J. Weselake*

An acyl-CoA-binding protein changes the acyl-CoA and oil composition in seeds of transgenic Arabidopsis. 550

[W] A UDP-Glucose:Monoterpenol Glucosyltransferase Adds to the Chemical Diversity of the Grapevine Metabolome. *Friedericke Bönisch, Johanna Frotscher, Sarah Stanitzek, Ernst Rühl, Matthias Wüst, Oliver Bitz, and Wilfried Schwab*

A glucosyltransferase forms geranyl and neryl glucosides during grape ripening. 561

[W] The Biosynthetic Pathway of Indole-3-Carbaldehyde and Indole-3-Carboxylic Acid Derivatives in *Arabidopsis*. *Christoph Böttcher, Alexandra Chapman, Franziska Fellermeier, Manisha Choudhary, Dierk Scheel, and Erich Glawischnig*

Arabidopsis synthesizes, in addition to camalexin, an array of defense metabolites from indole-3-acetonitrile in substantial quantities dependent on a specific Arabidopsis Aldehyde Oxidase. 841

[C][W][OPEN] *Arabidopsis* Glutathione Transferases U24 and U25 Exhibit a Range of Detoxification Activities with the Environmental Pollutant and Explosive, 2,4,6-Trinitrotoluene. *Vanda Gunning, Kyriakos Tzafestas, Helen Sparrow, Emily J. Johnston, Andrew S. Brentnall, Jennifer R. Potts, Elizabeth L. Rylott, and Neil C. Bruce*

Two glutathione transferase enzymes are involved in making the explosive, environmental pollutant, 2,4,6-trinitrotoluene less toxic in Arabidopsis plants. 854

[W][OPEN] Glucan, Water Dikinase Exerts Little Control over Starch Degradation in *Arabidopsis* Leaves at Night. *Alastair W. Skeffington, Alexander Graf, Zane Duxbury, Wilhelm Gruissem, and Alison M. Smith*

A starch-phosphorylating enzyme that catalyzes an essential first step in leaf starch degradation plays only a minor role in controlling flux through this pathway. 866

CELL BIOLOGY

[W][OPEN] Identification and Characterization of Maize *floury4* as a Novel Semidominant Opaque Mutant That Disrupts Protein Body Assembly. *Guan Wang, Weiwei Qi, Qiao Wu, Dongsheng Yao, Jushan Zhang, Jie Zhu, Gang Wang, Guifeng Wang, Yuanping Tang, and Rentao Song*

A maize semidominant mutant that results from a storage protein with defective signal peptide disrupts protein body assembly, triggers ER stress, and elevates programmed cell death in endosperm. 582

[W][OPEN] Photobody Localization of Phytochrome B Is Tightly Correlated with Prolonged and Light-Dependent Inhibition of Hypocotyl Elongation in the Dark. *Elise K. Van Buskirk, Amit K. Reddy, Akira Nagatani, and Meng Chen*

Photobody localization of Arabidopsis phytochrome B is tightly correlated with the degradation of a phytochrome-interacting factor and the inhibition of hypocotyl growth in the dark.

595

[C][W] PHYTOCHROME AND FLOWERING TIME1/MEDIATOR25 Regulates Lateral Root Formation via Auxin Signaling in Arabidopsis. *Javier Raya-González, Randy Ortiz-Castro, León Francisco Ruíz-Herrera, Kemal Kazan, and José López-Bucio*

The transcriptional Mediator complex plays an important role in regulating root system architecture through auxin-related mechanisms in Arabidopsis.

880

ECOPHYSIOLOGY AND SUSTAINABILITY

[W][OPEN] A Limited Role for Carbonic Anhydrase in C₄ Photosynthesis as Revealed by a *ca1ca2* Double Mutant in Maize. *Anthony J. Studer, Anthony Gandin, Allison R. Kolbe, Lin Wang, Asaph B. Cousins, and Thomas P. Brutnell*

Maize plants with significantly reduced carbonic anhydrase activity have impaired growth at subambient CO₂, but photosynthesis in these plants is not limited under current atmospheric conditions.

608

[W] Cytochrome P450 CYP81A12 and CYP81A21 Are Associated with Resistance to Two Acetolactate Synthase Inhibitors in *Echinochloa phyllopogon*. *Satoshi Iwakami, Masaki Endo, Hiroaki Saika, Junichi Okuno, Naoki Nakamura, Masao Yokoyama, Hiroaki Watanabe, Seiichi Toki, Akira Uchino, and Tatsuya Inamura*

Resistance to two herbicides in Echinochloa phyllopogon is associated with overexpression of two cytochrome P450s that are simultaneously controlled by a putative single genetic element.

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[W][OPEN] Cavitation Resistance in Seedless Vascular Plants: The Structure and Function of Interconduit Pit Membranes. *Craig Brodersen, Steven Jansen, Brendan Choat, Christopher Rico, and Jarmila Pittermann*

Interconduit pit membranes in ferns and lycophytes are functionally similar to angiosperms with respect to cavitation resistance, although significantly more permeable to water.

895

GENES, DEVELOPMENT, AND EVOLUTION

[W][OPEN] Distinct Copy Number, Coding Sequence, and Locus Methylation Patterns Underlie *Rhg1*-Mediated Soybean Resistance to Soybean Cyst Nematode. *David E. Cook, Adam M. Bayless, Kai Wang, Xiaoli Guo, Qijian Song, Jiming Jiang, and Andrew F. Bent*

A multiple-gene locus in soybean conferring disease resistance has evolved three locus types defined by copy number, protein coding, expression, and DNA methylation differences.

630

[W][OPEN] The Pea Photoperiod Response Gene *STERILE NODES* Is an Ortholog of *LUX ARRHYTHMO*. *Lim Chee Liew, Valérie Hecht, Frances C. Sussmilch, and James L. Weller*

Early flowering and insensitivity to daylength in garden pea is caused by disruption of a gene important for circadian rhythms.

648

[W][OPEN]Phenotypic and Transcriptional Analysis of Divergently Selected Maize Populations Reveals the Role of Developmental Timing in Seed Size Determination. *Rajandeep S. Sekhon, Candice N. Hirsch, Kevin L. Childs, Matthew W. Breitzman, Paul Kell, Susan Duvick, Edgar P. Spalding, C. Robin Buell, Natalia de Leon, and Shawn M. Kaeppler*

The onset and rate of seed development are key determinates of seed size and are regulated by coexpression networks for this trait.

658

[W][OPEN]Global Regulation of Embryonic Patterning in Arabidopsis by MicroRNAs. *William F. Seefried, Matthew R. Willmann, Rachel L. Clausen, and Pablo D. Jenik*

MicroRNAs are required for the patterning and specification of most tissues in the Arabidopsis embryo, with the exception of the protoderm, with various regions of the embryo requiring different levels of microRNAs.

670

[C][W]TRANSPARENT TESTA8 Inhibits Seed Fatty Acid Accumulation by Targeting Several Seed Development Regulators in Arabidopsis. *Mingxun Chen, Lijie Xuan, Zhong Wang, Longhua Zhou, Zhilan Li, Xue Du, Essa Ali, Guoping Zhang, and Lixi Jiang*

A maternal factor affects seed fatty acid biosynthesis and inhibits seed lipid accumulation by targeting seed development and down-regulating a group of genes critical to embryonic development.

905

MEMBRANES, TRANSPORT, AND BIOENERGETICS

[C][W]Overexpression of a Calcium-Dependent Protein Kinase Confers Salt and Drought Tolerance in Rice by Preventing Membrane Lipid Peroxidation. *Sonia Campo, Patricia Baldrich, Joaquina Messeguer, Eric Lalanne, María Coca, and Blanca San Segundo*

A calcium-dependent protein kinase at the plasma membrane prevents membrane lipid peroxidation and confers tolerance to salt and drought stress in rice plants.

688

[W][OPEN]Phycobilisome-Deficient Strains of *Synechocystis* sp. PCC 6803 Have Reduced Size and Require Carbon-Limiting Conditions to Exhibit Enhanced Productivity. *David J. Lea-Smith, Paolo Bombelli, John S. Dennis, Stuart A. Scott, Alison G. Smith, and Christopher J. Howe*

*Gradual reduction of the light-harvesting complex in *Synechocystis*, the phycobilisome, results in decreased cell size and chlorophyll levels, lower photosynthesis, photoinhibition, and respiration, with increased productivity and biomass accumulation under carbon-limited conditions.*

705

[W][OPEN]Expression of Sucrose Transporter cDNAs Specifically in Companion Cells Enhances Phloem Loading and Long-Distance Transport of Sucrose but Leads to an Inhibition of Growth and the Perception of a Phosphate Limitation. *Kasturi Dasgupta, Aswad S. Khadilkar, Ronan Sulpice, Bikram Pant, Wolf-Rüdiger Scheible, Joachim Fisahn, Mark Stitt, and Brian G. Ayre*

Increased expression of selected sucrose/proton symporters above wild-type levels in phloem companion cells enhances phloem loading and long-distant transport but unexpectedly results in an inhibition of growth that is associated with perception of a phosphate limitation.

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SIGNALING AND RESPONSE

[W]The Polyadenylation Factor Subunit CLEAVAGE AND POLYADENYLATION SPECIFICITY FACTOR30: A Key Factor of Programmed Cell Death and a Regulator of Immunity in Arabidopsis. *Quentin Bruggeman, Marie Garmier, Linda de Bont, Ludovine Soubigou-Taconnat, Christelle Mazubert, Moussa Benhamed, Cécile Raynaud, Catherine Bergounioux, and Marianne Delarue*

A mutation in an Arabidopsis mRNA polyadenylation factor suppresses the cell death associated with the immunity response mediated by salicylic acid and defective myoinositol biosynthesis.

732

[W]A Positive Regulator of Nodule Organogenesis, NODULE INCEPTION, Acts as a Negative Regulator of Rhizobial Infection in *Lotus japonicus*. Emiko Yoro, Takuya Suzuki, Koichi Toyokura, Hikota Miyazawa, Hidehiro Fukaki, and Masayoshi Kawaguchi

A transcription factor, known as a positive regulator of nodule organogenesis in root cortex, acts as a negative regulator of epidermal infection by rhizobia.

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[W]Reactive Oxygen Species-Dependent Nitric Oxide Production Contributes to Hydrogen-Promoted Stomatal Closure in *Arabidopsis*. Yanjie Xie, Yu Mao, Wei Zhang, Diwen Lai, Qingya Wang, and Wenbiao Shen

Hydrogen-mediated stomatal closure in Arabidopsis and drought tolerance involves RbohF-dependent ROS production, subsequent NR-associated NO production, and GORK activation.

759

[W]A Shoot-Specific Hypoxic Response of *Arabidopsis* Sheds Light on the Role of the Phosphate-Responsive Transcription Factor PHOSPHATE STARVATION RESPONSE1. Maria Klecker, Philipp Gasch, Helga Peisker, Peter Dörmann, Hagen Schlicke, Bernhard Grimm, and Angelika Mustroph

Oxygen and phosphate deficiency trigger overlapping changes in gene expression, including genes for galactolipid metabolism, which are mediated by a common transcription factor.

774

[W]Contrasting Roles of the Apoplastic Aspartyl Protease APOPLASTIC, ENHANCED DISEASE SUSCEPTIBILITY1-DEPENDENT1 and LEGUME LECTIN-LIKE PROTEIN1 in *Arabidopsis* Systemic Acquired Resistance. Heiko H. Breitenbach, Marion Wenig, Finni Wittek, Lucia Jordá, Ana M. Maldonado-Alconada, Hakan Sarioglu, Thomas Colby, Claudia Knappe, Marlies Bichlmeier, Elisabeth Pabst, David Mackey, Jane E. Parker, and A. Corina Vlot

Proteins accumulating in the apoplast of Arabidopsis during the emission of systemic immune signals include an aspartyl protease that dampens systemic acquired resistance and a legume lectin-like protein that promotes it.

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[W][OPEN]Hemoglobin Control of Cell Survival/Death Decision Regulates *In Vitro* Plant Embryogenesis. Shuanglong Huang, Robert D. Hill, Owen S.D. Wally, Giuseppe Dionisio, Belay T. Ayele, Sravan Kumar Jami, and Claudio Stasolla

Hemoglobins modulate embryogenesis by regulating programmed cell death.

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SYSTEMS AND SYNTHETIC BIOLOGY

[W][OPEN]Genome-Wide Analysis of Heat-Sensitive Alternative Splicing in *Physcomitrella patens*. Chiung-Yun Chang, Wen-Dar Lin, and Shih-Long Tu

Alternative splicing is responsive to elevated temperature in nonvascular plants and can be rapidly modulated in specific genes for plants to cope with heat stress.

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[C][W][OPEN]A Diel Flux Balance Model Captures Interactions between Light and Dark Metabolism during Day-Night Cycles in C_3 and Crassulacean Acid Metabolism Leaves. C.Y. Maurice Cheung, Mark G. Poolman, David. A. Fell, R. George Ratcliffe, and Lee J. Sweetlove

A diel flux balance modeling framework that integrates temporally separated metabolic networks provides realistic descriptions of light and dark metabolism in C_3 and CAM leaves and suggests that energetics and nitrogen use efficiency are unlikely to have been drivers for the evolution of CAM.

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[C] Some figures in this article are displayed in color online but in black and white in the print edition.

[W] The online version of this article contains Web-only data.

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