Metabolomics: A Novel Tool to Bridge Phenome to Genome under Changing Climate to Ensure Food Security

Arun Kumar*, Udaykumar Kage†, Kareem Mosa‡ and Dhananjay Dhokane§

1Plant Science Department, McDonald Campus, McGill University, QC, Canada
2Department of Biotechnology, Faculty of Agriculture, Al-Azhar University, Egypt

Global Climate Change Affecting Plant Fitness and Reproductive Success

Anthropogenic activities that contribute to global climate change, thereby affecting plant growth and survival are carbon dioxide (CO2), ozone (O3), and temperature. There has been unprecedented increase in atmospheric CO2 concentration (present atmospheric CO2 concentration is 387 ppm), 40% more than the levels before industrial revolution [1] and is expected to increase to 500-900 ppm by the end of the twenty first century [2]. The concentration of O3 in lower troposphere has increased to 20-50% at an average of 38% since pre-industrial era [3]. The Intergovernmental Panel on Climate Change (IPCC), forecasts a temperature rise of 2.5 to 10 degrees Fahrenheit over the next century [http://climate.nasa.gov/effects]. Plant photosynthetic rates are influenced by these factors which in turn affect subsequent allocation of carbohydrates, cellulose, lignins, tannins pool, which in long term affect CO2 sequestration [4]. Global climate change may directly alter plant fitness, as well as alter the reproductive success of plants and their interactions through impacts on flowering phenology [5-8].

Chemical Ecology and Plant Secondary Metabolites

Plants produce an array of secondary metabolites, which are not directly involved in primary metabolism of plant growth and development. These plant secondary metabolites (PSMs) belong to different chemical groups such as phenylpropanoids, flavonoids, terpenoids, and alkaloids. Chemical ecology is an area that deals with studies of interactions between organisms and their biotic and abiotic environment that are mediated by chemicals. Stahl (1888) is known as an early pioneer of chemical ecology who proposed that the various chemical protective means of plants were shaped and optimized under the selection pressure of the animal kingdom that surrounds the plants [9]. Fifty four years ago, PSMs were placed in an ecological context by Fraenkel [10]. The ability of plants to synthesize secondary compounds has been selected throughout the course of evolution in different plant lineages when such compounds addressed specific needs [11]. For example, floral scent volatiles and pigments were evolved to attract insect pollinators and thus enhanced fertilization rates. The ability to synthesize toxic chemicals was evolved to ward off pathogens and herbivores or to suppress the growth of neighboring plants which involve deterrence/anti-feedant activity, toxicity or acting as precursors to physical defense systems [11-13].

PSMs vis-à-vis Global Climate Change

Stressful environments including adverse climatic effects (e.g. high temperature, elevated CO2 concentration, high doses of UV radiations etc.) may lead to altered production of PSMs due to allocation of fixed carbon to secondary metabolism instead of channelizing it for primary metabolic functions required for growth and survival [14]. The role of PSM among a multitude of anthropogenic forces that influence ecosystems in a global scale is still less recognized. Interactions among organisms and their environment are mediated by PSM at different levels of ecological organization. Therefore, genes encoding for PSM biosynthetic enzymes can have effects from individual organisms to all the way to global environmental processes. Lindroth (2010) has extensively detailed on the effect of global climate change on PSMs [4]. Elevated O3 significantly increased concentrations of phenolic acids and flavonoids in different tree species [15]. Studies have been undertaken to understand the role of either increasing CO2 or temperature on secondary compounds including isoprene, terpenes, tannin, flavonol and/or phenolic production [16-20]. Lignin and tannin concentrations in trees have been shown to be increased by high CO2 levels [4,21].

Studies on the effects of high temperature and enriched CO2 on phenolic composition of three deciduous tree species revealed that the level of total phenolic compounds decreased under high temperature but increased under enriched CO2 [22]. Interestingly, there was no effect on phenolic compounds when high temperature and enriched CO2 were combined [23]. Moreover, it has been reported that high temperature resulted in a significant decrease of apple peel anthocyanin concentration through modulation of the anthocyanin regulatory complex [24]. Albert et al. showed that increased phenolic composition of Arnica montana is associated with lower temperature [25]. Ultraviolet radiation (UV) is also influencing the production of different secondary metabolites such as phenolics, flavonoids, alkaloids, terpenoids, and glucosinolates [26]. UV-B radiation enhanced the rosmarinic and carnosic acids concentrations in rosemary plants [27]. Contents of peppermint flavonoids; eriocitrin, hesperidin, and kaempferol 7-O-rutinoside have been reported to be increased by UV-B induction [28]. UV- A and UV-B radiation induction exhibited increased content of caffeoylquinic acids and iridoids in Lonicera japonica Thunb [29]. However, the effect of global climate change on PSM does not show any definitive trend and appear to be specific to plant species and environmental stress under study [30]. Detailed studies with focus on individual and combination of stresses will provide a clearer picture.

Importance of Metabolomics in Ensuring Food Security

Feeding the world by next 50-100 years is a great challenge for scientists and people involved in food and agriculture industry, and particularly the challenge is even more difficult keeping in mind the ever-increasing population and limited availability of agricultural land. Scientist from various fields, which include but are not limited

*Corresponding author: Arun Kumar, Plant Science Department, McDonald Campus, McGill University, QC, Canada; Tel: 4389362388; E-mail: arunihbt@gmail.com

Received October 16, 2014; Accepted October 18, 2014; Published October 20, 2014

Citation: Kumar A, Kage U, Mosa K, Dhokane D (2014) Metabolomics: A Novel Tool to Bridge Phenome to Genome under Changing Climate to Ensure Food Security. Med Aromat Plants 3: e154. doi: 10.4172/2167-0412.1000e154

Copyright: © 2014 Kumar A, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.
to agriculture, breeding and biotechnology are putting their hands together to meet the challenge. Biotechnological interventions that utilize various OMICs approaches (e.g. genomics, transcriptomics, proteomics, metabolomics etc.) have an important role to play along with classical agricultural approaches. Next generation sequencing and other OMICs technologies has enabled to sequence large and complex genomes in very less time in a very precise manner. However, assigning function to such a large pool of genes is yet another challenging task. Post-genomic era depends heavily on many related technologies to bridge the information gap however, none delivers an effective route to assign exact function of genes. A number of post-transcriptional and post-translational modifications at gene and enzyme level are involved and therefore, none of the approach leads to the identification of genes with final outcome with regard to phenotypic traits. Metabolomics is the study of complete set of metabolites in a cell, organ or an individual and serves as an excellent tool to bridge the information gap [31]. It is accomplished by analytic tools such as gas-chromatography or liquid-chromatography and is comparatively cheaper, rapid and has wide range of applications than other OMICS approaches. Since metabolites are close to phenotype and are the actual representatives of any visible change, metabolic profiling of crops, in response to climate change will provide useful insights into genetic mechanisms of plants adaptation. The information obtained from the systematic metabolic studies on response of plants to climate change can be exploited to identify candidate genes responsible for conferring specific traits of stress tolerance. The identified stress induced metabolites can be mapped on the metabolic pathways to pinpoint their rate limiting catalytic enzymes. Further, the publically available genome databases are searched to identify respective genes of the rate limiting enzymes. These genes can be further exploited to alter or divert the metabolic flux of plants for increasing the production, nutrition versatility and/or the adaptive plasticity of the plants by means of either cis- or transgenic technologies. Different parameters of climate change studied alone and/or in combination, will provide significant information on metabolic adjustments in response to environmental variables that can be used to prepare predictive models and interaction networks. This will help the scientific community and policy makers to design strategies to mitigate the adverse climatic effects. Especially it will be of great value for application in crop plants, wherein genes can be mapped in the quantitative trait loci (QTLs) [32], which further can be used for breeding programmes to mitigate the adverse effects of climate change. Since metabolites affect the complex organizations of ecosystems, it will help us predict the ecosystem organization in response to global climate change. Hence, there is a need to conduct systematic studies in order to get deeper insights and to develop a wholistic and rationally approach wherein, metabolomics can play a pivotal role.

References

1. Petit J-R, Jouzel J, Raynaud D, Barkov NI, Barnola J-M, et al (1999) Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. Nature 399: 429-436.
2. Karl TR, Melillo JM, Peterson TC (2009) Global climate change impacts in the United States. Cambridge University Press.
3. Wang Y, Jacob DJ (1998) Anthropogenic forcing on tropospheric ozone and OH since preindustrial times. J Geophys Res: Atmos (1984–2012) 103: 31123-31135.
4. Lindroth RL (2009) Impacts of elevated atmospheric CO$_2$ and O$_3$ on forests: phytochemistry, trophic interactions, and ecosystem dynamics. J Chem Ecol 36: 2-21.
5. Woomer P, Parsons A, Welker J, Potter J, Callaghan T, et al (1993) Comparative responses of phenology and reproductive development to simulated environmental change in sub-arctic and high arctic plants. Oikos 67: 490-502.
6. Hughes L (2000) Biological consequences of global warming: is the signal already apparent? Trends Ecol Evol 15: 56-61.
7. Bishop JG, Schemske DW (1998) Variation in flowering phenology and its consequences for luperines colonizing Mount St. Helens. Ecology 79: 534-546.
8. Gairola S, Shariff NM, Bhatt A, Kaia CP (2010) Influence of climate change on production of secondary chemicals in high altitude medicinal plants: Issues needs immediate attention. J Med Plants Res 4: 1825-1829.
9. Hartmann T (2007) From waste products to ecochemicals: fifty years research of plant secondary metabolism. Phytochemistry 68: 2831-2846.
10. Fraenkel GS (1959) The Raison d’Etre of Secondary Plant Substances; These odd chemicals arose as a means of protecting plants from insects and now guide insects to food. Science 129: 1466-1470.
11. Pichersky E, Gang DR (2000) Genetics and biochemistry of secondary metabolites in plants: an evolutionary perspective. Trends Plant Sci 5: 439-445.
12. Ziska L, Ernche S, Johnson E, George K, Reed D, et al (2005) Alterations in the production and concentration of selected alkaloids as a function of rising atmospheric carbon dioxide and air temperature: implications for ethno-pharmacology. Glob Change Biol 11: 1798-1807.
13. Bennett RN, Wallisgrove RM (1994) Secondary metabolites in plant defence mechanisms. New Phytol 127: 617-633.
14. Mooney H, Drake B, Luxmoore R, Oechel W, Pitekia L (1991) Predicting ecosystem responses to elevated CO$_2$ concentrations. BioScience 41: 96-104.
15. Valkama E, Koricheva J, Oksanen E (2007) Effects of elevated O$_3$, alone and in combination with elevated CO$_2$, on tree leaf chemistry and insect herbivore performance: a meta-analysis. Glob Change Biol 13: 184-201.
16. Kainulainen P, Holopainen J, Holopainen T (1998) The influence of elevated CO$_2$ and O$_3$ concentrations on Scots pine needles: changes in starch and secondary metabolites over three exposure years. Oecologia 114: 455-460.
17. Heyworth C, Iason G, Temperton V, Jarvis P, Duncan A (1998) The effect of elevated CO$_2$ concentration and nutrient supply on carbon-based plant secondary metabolites in Pinus sylvestris L. Oecologia 115: 344-350.
18. Geibauer RL, Strain BR, Reynolds JF (1997) The effect of elevated CO$_2$ and N availability on tissue concentrations and whole plant pools of carbon-based secondary compounds in loblolly pine (Pinus taeda). Oecologia 113: 29-36.
19. Lavola A, Julkunen-Titto R, de la Rosa TM, Lehto T, Aghalo PJ (2000) Allocation of carbon to growth and secondary metabolites in birch seedlings under UV-B radiation and CO$_2$ exposure. Physiol Plant 109: 260-267.
20. Zavala J, Ravetta D (2001) Allocation of photoassimilates to biomass, rain and carbohydrates in Grindelia chilensis as affected by light intensity. Field Crop Res 69: 143-149.
21. Cobléaux M-M, Kurz C, Böttner P, Raschi A (1999) Influence of increased atmospheric CO$_2$ concentration on quality of plant material and litter decomposition. Tree Physiol 19: 301-311.
22. Zvereva E, Kozlov M (2006) Consequences of simultaneous elevation of carbon dioxide and nitrogen for plant--herbivore interactions: a metaanalysis. Glob Change Biol 12: 27-41.
23. Vetelli T, Mattson W, Niemelä P, Julkunen-Titto R, Kellomäki S, et al (2007) Do elevated temperature and CO$_2$ generally have counteracting effects on phenolic phytochemistry of boreal trees? J Chem Ecol 33: 287-296.
24. LIN-WANG K, Micheletti D, Palmer J, Volz R, Lozano L, et al (2011) High temperature reduces apple fruit colour via modulation of the anthocyanin regulatory complex. Plant Cell Environ 34: 1176-1190.
25. Albert A, Sareenedi V, Heller W, Seidlitz HK, Zidorn C (2009) Temperature is the key to altitudinal variation of phenolics in Arnica montana L. cv. ARBO. Oecologia 160: 1-8.
26. Zhang WJ, Björn LO (2009) The effect of ultraviolet radiation on the accumulation of medicinal compounds in plants. Fitoterapia 80: 207-218.
27. Luís J, Pérez RM, González FV (2007) UV-B radiation effects on foliar concentrations of rosmarinic and carnosic acids in rosemary plants. Food Chem 101: 1211-1215.
28. Dolzhenko Y, Bertea CM, Occhipinti A, Bossi S, Maffei ME (2010) UV-B modulates the interplay between terpenoids and flavonoids in peppermint (Mentha piperita L.). J Photochem Photobiol B: Biol 100: 67-75.
29. Ning W, Peng X, Ma L, Cui L, Lu X, et al (2012) Enhanced secondary metabolites production and antioxidant activity in postharvest Lonicera japonica Thunb. in response to UV radiation. Innovative Food Science & Emerging Technologies 13: 231-243.

30. Bidart-Bouzat MG, Imeh-Nathaniel A (2008) Global change effects on plant chemical defenses against insect herbivores. J Integr Plant Biol 50: 1339-1354.

31. Kushalappa AC, Gunnaiah R (2013) Metabolo-proteomics to discover plant biotic stress resistance genes. Trends Plant Sci 18: 522-531.

32. Gunnaiah R, Kushalappa AC, Duggavathi R, Fox S, Somers DJ (2012) Integrated metabolo-proteomic approach to decipher the mechanisms by which wheat QTL (Fhb1) contributes to resistance against Fusarium graminearum. PloS one 7: e40695.

Submit your next manuscript and get advantages of OMICS Group submissions

Unique features:
- User friendly/feasible website-translation of your paper to 50 world’s leading languages
- Audio Version of published paper
- Digital articles to share and explore

Special features:
- 350 Open Access Journals
- 30,000 editorial team
- 21 days rapid review process
- Quality and quick editorial, review and publication processing
- Indexing at PubMed (partial), Scopus, EBSCO, Index Copernicus and Google Scholar etc
- Sharing Option: Social Networking Enabled
- Authors, Reviewers and Editors rewarded with online Scientific Credits
- Better discount for your subsequent articles

Submit your manuscript at: http://www.omicsonline.org/submission