AHW28-15 Room:103 Time:May 20 15:30-15:45

The adaptation mechanisms by the altitude-versatile plant, *Arabidopsis kamchatica*: ecology, physiology and genes

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Arabidopsis kamchatica ssp. *kamchatica* (Brassicaceae) is a perennial plant and versatile in terms of the altitudinal range of its habitats. However, its subspecies *kawasakiana* is an annual plant and lives only under 100 m alt. How the subspecies *kamchatica* adapt to wide altitudinal range? Why are these subspecies so contrasting in life-history and altitudinal range? Answering these questions advances our understanding to the mechanisms of plants' adaptation along altitude and the impact of global warming to plants. These subspecies are not only ecologically interesting but also genetically tractable because these are most closely related to the plant model, *A. thaliana*. We have been studying (1) life-history and natural selection in wild populations, (2) genetic differentiation in traits of life-history, resistance and stress tolerance using common garden experiments, (3) local adaptation using transplant experiment and (4) genes relevant to these differentiation and adaptation.

(1) We set permanent quadrats in 28 populations of the subspecies *kamchatica* in five mountain regions and monitored all focal plants by individual marking for three years. Life-history parameters such as survival, growth, fecundity and herbivory changed along altitude, indicating the natural selection and the population maintenance mechanism change along altitude. Although low-altitude populations exhibit almost annual-type life-form high-altitude populations show typical perennial life form within the same perennial subspecies.

(2) We collected seeds from 29 wild populations of the both subspecies and grew them in the common laboratory. Life-history traits (flowering timing, germination timing, growth and plant size), herbivory resistance (trichome) and stress tolerance (heat tolerance) were measured and most of them showed clines along original altitude, indicating historical natural selection and consequent genetic differentiation along altitude.

(3) We transplanted 12 and four populations of the subspecies *kamchatica* and the subspecies *kawasakiana* to low- (150 m), middle- (1300 m) and high-altitude (2700 m) gardens and monitored their survival, fecundity and herbivory for two years. All plants dyed in the first winter at the high-altitude garden. At the remaining gardens, plants from lower population showed better performance at lower garden whilst plants from higher population showed better performance at higher garden, indicating home-site advantage and that populations have evolutionary adapted to their altitude.

(4) For genome-wide screening of polymorphic genes, we used genome-tiling-array for eight and four populations of the subspecies *kamchatica* and the subspecies *kawasakiana*. We detected $>$3000 polymorphic genes either between subspecies and between *kamchatica* populations. Significantly more disease-resistance and temperature-inducible genes were found in those polymorphic genes compared to neutral expectation. We also used next-generation sequencer to simultaneously analyse many plants for candidate genes and found GL1, that control trichome production, to be important for altitudinal adaptation. The genes showed correlation between allele frequency and altitude, and strong disruptive selection between populations.

Keywords: altitudinal adaptation, adaptive evolution, local adaptation, cline, disruptive selection, home-site advantege