Variations in ultraviolet-B-induced DNA damage and tolerance mechanisms among ecotypes, species, and functional groups at different elevations

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URL	http://hdl.handle.net/10097/57681

博 士 論 文 (要約)

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(異なる標高における、紫外線 B による DNA ダメージと耐性機構のエコタイプ間、種間、そして機能群間の変異)

平成 26 年度

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生態システム生命科学専攻

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Abstract:

Mountains are complex and fragile ecosystems characterised by verticality, highly heterogeneous climatic conditions. Any of changes in climate potentially produce various ecological and physiological effects on plants, and may induce far-reaching consequences for ecosystem composition and biogeochemical cycles. Ultraviolet-B radiation (UV-B; 280–315 nm), which generally increases around 8–10% per km with elevation, may be one of important environmental factors that influences plants at high elevations, because enhanced UV-B causes critical damages on DNA and inhibit growth. Plants in turn have several protective and repair mechanisms. However, it is unknown whether DNA damage induced by the natural solar UV-B was greater at higher elevation, and how such damage and tolerance mechanisms vary among species in the fields.

In Chapter 1, I studied whether UV-B damage on DNA is greater at highland. DNA damage was quantified by cyclobutane pyrimidine dimer level (CPD), a major product of UV damage. I frequently sampled two widespread herbs *Polygonum sachalinense* (*Fallopia sachalinensis*) and *Plantago asiatica* growing at 300 and 1700 m above sea level every 2 hours for 11 days across the growing season. The CPD level was significantly influenced by the time of day, date, elevation, and their interactions in both species. The CPD level tended to be higher at noon or on sunny days. DNA damage was more severe at 1700 m than at 300 m: on average, 8.7% and 7.8% greater at high elevation in *P. asiatica* and *P. sachalinense*, respectively. Stepwise multiple regression analysis indicated that the CPD level was explained mainly by UV-B and had no significant relationship with other environmental factors such as temperature and photosynthetically active radiation. Increased UV-B at higher elevations significantly increases damage to DNA. My results indicate that plants growing at higher elevation naturally suffer more from UV-B.

Second, I evaluated that UV-induced DNA damage and UV defense mechanisms in species with different functional groups at different elevations. I collected leaf sample from 26 species belonging to different functional groups coexisting in two moorlands located at 574 and 1285 m a.s.l. in July and August. Photorepair activity (PRA) and concentrations of UV absorbing compounds (UAC) and carotenoids (CAR) were determined as UV tolerance mechanisms. The results indicated that DNA

damage and the tolerance mechanisms considerably varied among species belonging to different functional groups. DNA damage was smaller in monocot than in dicot species and smaller in woody than in herbaceous species. Three Poaceae species possessed a consistently higher PRA with lower UAC concentrations compared to other species. Two gymnosperm species had lower CAR concentrations than other groups. Across species, the variations of DNA damage could not be explained by their PRA or UAC. There were a negative relationship between PRA and UAC, and a positive relationship between CAR and UAC across species. I conclude that UV-B damage varies significantly among species, and a part of the variation is related to the functional groups. UV-tolerance mechanisms also vary among species under evolutionary trade-off and synergism.

Third, I studied *Arabidopsis* ecotypes to evaluate evolutionary adaptations to high elevations. I cultivated cotypes of *A.thaliana* (two ecotypes from highland, Dzi and Sha, and two ecotypes from lowland, Tsu-1 and Col-0) and three ecotypes of *A. halleri* subsp. *gemmifera* (populations from 300, 760 and 1300 m above the sea level in Mt. Ibuki, Japan) with or without supplementary UV-B radiation in the growth cabinet. I harvested plants three times (once before and twice after the treatment) and determined biomass, the relative growth rate (RGR), the concentration of cyclobutane pyrimidine dimer (CPD) as UV damage, and UV absorbing compounds (UAC) as UV protection. At early stage after the treatment, lowland ecotypes of two species were more sensitive to enhanced UV-B radiation than highland ecotypes, as accumulating higher CPD level and greater inhibition in biomass production. On the other hand, at later stage, the CPD level and growth inhibition became similar or even smaller in lowland ecotypes. These results suggest that the response to UV stress was more constitutive in highland ecotypes, but more inducible in lowland ecotypes. RGR was negatively related to the CPD level. UAC had no clear variation with respect to the CPD level and to the elevation of origin. These ecotypic differentiations were common in the two *Arabidopsis* species, suggesting that local adaptation occurred in parallel. It also implies that constitutive defense to UV-B is necessary to inhabit higher elevations.

The present study demonstrates that UV-B radiation is a stressful factor for plants growing at high elevation. Ecotypes of *Arabidopsis* species exhibited a pallalel evolution that highland ecotypes have a constitutive defence to UV stress, suggesting that it is an advantageous strategy to survive and reproduce at high elevations. The actual UV-tolerance mechanisms appeared to vary among species under evolutionary trade-off and synergism. Such variations in UV tolerance between populations and between species may influence future species composition in vegetation and ecosystem functions if ozone depletion continues.