Resilient **trees**

Dr Yadong Qi has been teaching urban forestry for over two decades. In her latest pursuits, she is exploring tree species' ability to react and respond to UV and a changing climate

Could you provide an overview of your research activities and objectives? Why is research on tree tolerance to ultraviolet (UV) radiation important?

Future uncertainty of ozone recovery and global climate change has precipitated a critical need for the systematic evaluation over the impact of UV on trees and urban forest ecosystems. My team has been taking biophysical, anatomical and biochemical approaches to assessing how tree species interact with UV radiation in their natural setting. The goal is to discover UVB protection strategies, leading to a better understanding of the UVB tolerance mechanisms of various broadleaf trees in the Southern US.

Can you clarify the difference between UVA, UVB and UVC radiation?

UV radiation is electromagnetic radiation from the Sun with a wavelength of 100-400 nm. This is classified into three subtypes: UVA (315-400 nm), which is not absorbed by the stratospheric ozone layer, UVB (280-315 nm) and UVC (100-280 nm). Most UVB is absorbed by the ozone layer but only some reaches the Earth's surface; and UVC is completely absorbed by the ozone layer and atmosphere. The level of UV radiation that reaches the Earth's surface depends on a number of factors, including ozone, time of day and year, latitude, altitude, weather conditions and reflection. Both UVA and UVB cause problems to public health and the environment.

What characteristics were you looking for when you began studies of UV tolerance at whole leaf level?

We looked at the leaf optical properties of 35 broadleaf species using a UV-visible spectroradiometer and an integrating sphere. We discovered that, at whole-leaf level, tree leaves can generally absorb 91-95 per cent, reflect 5-9 per cent and transmit <1 per cent of incident UVB radiation, regardless of tree species or leaf age. Even though leaf surface reflectance provides the first line of defence against UVB radiation, this tells us that leaves absorb a large amount of UVB.

How much have you uncovered about UV penetration and absorption within leaves at an anatomical scale?

Since leaves absorb over 90 per cent of UVB radiation, we were keen to figure out where and how such a high amount of UVB is absorbed. As a result, we used a fibre optic microprobe system combined with our own anatomical knowledge of the leaf to measure the depth of UVB light penetration. We identified 23 broadleaf tree species that can attenuate 92-99 per cent of the UVB absorbed through their epidermal layers. Epidermal attenuation is shown to be the dominant UVB screening characteristic in most species studied, though our results show that other species allow UVB to penetrate through to palisade tissues, which may cause damage to the leaf's photosynthetic apparatus. This underlines the importance

of effective epidermal function in protecting broadleaf trees from UVB radiation.

Have you faced any significant challenges over the course of this project?

While we have enjoyed strong support from the US Department of Agriculture – National Institute of Food and Agriculture (USDA-NIFA), securing additional funding has been a challenge. Studies of this nature, involving multifaceted tasks which are time consuming and encompass a number of species, require long-term institutional commitment and significant external funding. We will continue to seek extramural funds and expand our research through existing and new collaborations, nationally and internationally.

Finally, what is the anticipated impact of this research?

Having established laboratory protocols to investigate leaf optical properties; a mobile UV monitoring station to study tree canopy influence on UV transfer; and a large database for more than 30 southern broadleaf species, we will comprehensively analyse all available data and compare all the species studied. It is anticipated that the research will generate new insight into UVB screening strategies and the biophysical and biochemical UVB tolerance mechanisms in certain southern trees. This information will enhance the ability to predict the role of UV and climate change on both wild and urban forests and select UV tolerant species to maintain healthier and more sustainable forests in the future.

Turning a new leaf

The link between excessive UVB and skin cancer has long been established, yet its impact on plants and trees remained elusive. The latest research conducted by the **Southern University Agricultural Research and Extension Center**, USA, is set to change this scenario; shedding light on UVB tolerance in trees

THE OZONE LAYER is critical for sustaining life. Absorbing most of the ultraviolet (UV) entering the stratosphere, ozone layer protects plants and animals from the most harmful effects of solar radiation.

However, since the mid-20th Century, statistics have shown that ozone levels over the Northern Hemisphere have decreased by 4 per cent per decade. Ozone depletion can be caused by free radical catalysts, many of which are naturally occurring. However, a number of synthetic compounds – most famously chlorofluorocarbons (CFCs), which were once used widely in aerosol sprays and refrigeration technology – have been responsible for significant damage to the ozone layer. Widespread anthropogenic ozone depletion is seen to have contributed heavily to the formation of the Antarctic ozone hole, discovered in 1985 by independent scientist James Lovelock.

Strict regulations introduced in 1989, namely the Montreal Protocol on Substances that Deplete the Ozone Layer, have since curbed the use and production of CFCs and recent analyses suggest that ozone depletion has recovered In correspondence. However, it is predicted that the ozone layer may not recover to pre-1980 levels until the mid to late 21st Century – and both natural and anthropogenic N_2O emissions remain a significant threat to the stability of the ozone layer.

Ozone depletion in the upper atmosphere has resulted in a significant increase in solar UVA and UVB radiation on the Earth's surface. Whilst UV radiation is essential for life and is a crucial component in the human body's ability to produce vitamin D, increased levels of UV can raise the risk of skin cancers and eye disease. According to the World Health Organization (WHO), 20 per cent of the 12-15 million yearly cases of blindness through cataracts may be due to, or have been enhanced by, increased exposure to UV radiation. The need to reduce these impacts is crucial, but without understanding nature's ability to regulate and potential curb these damaging properties scientists are unable to devise preventative mechanisms. The most promising biome for further study is the world's forests, both natural and managed. Seen as the Earth's lungs, they could not only help absorb potentially ozone-depleting substances, but may go some way to regulating UVB radiation.

ANSWERING THE CALL FOR RESEARCH

Dr Yadong Qi, a Professor at Southern University (SU) Urban Forestry Program and a Research Scientist at SU Agricultural Research and Extension Center (SUAREC) in Louisiana, has more than 20 years of research experience in tree physiology, forest ecology and urban forestry. Having served as a forestry expert on a number of US and Chinese advisory panels, she has a particular interest in urban and community forestry management and urban ecosystem analysis. Qi has already contributed substantially to the field, but in her current research she now seeks to explore tree species ability to absorb UVB, and what this means for society and the environment.

Dr Gordon Heisler, retired meteorologist from USDA-FS Northern Station studies the urban tree influences on urban climate variables includingultraviolet (UV), air temperature, wind andhumidity.

In addition to leading a talented and multidisciplinary team at SUAREC, Qi is collaborating with researchers at a national level, including the US Department of Agriculture (USDA) Forest Service, USDA UVB

Monitoring UVA and UVB reduction by the tree canopy of live oak.

Monitoring and Research Program, and the University of Vermont. By studying leaf UVB tolerance, Qi and her team could make wider contributions to climate change research and urban forestry policy.

DEVELOPING A METHODOLOGY

From their research base in East Baton Rouge Parish, a US city with relatively high annual levels of UVA and UVB, Qi's team selected 35 popular subtropical broadleaf tree species including many species of oak, ash, elm, magnolia, hickory, birch, beech and maple. To ensure that this project, the first of its kind in a southern US state, was accurate, comprehensive and comparative, all leaf samples were collected from a local arboretum and urban tree farm on the SU campus.

In order to assess the epidermal UVB screening effectiveness and depth of UVB penetration in a number of tree species, the SUAREC team first measured leaf reflectance, transmittance and UVB absorption at the whole-leaf level using the state-of-the-art UV-visible (UV-Vis) spectroradiometer with an integrating sphere.

Subsequently, the researchers studied leaf morphology and anatomy to assess how UVB is absorbed and then penetrated into leaves of various species. Together with a fibre optic microprobe system, they were able to assess the depth of UVB penetration within leaf tissues. Whilst a UV-Vis spectrophotometer and a high performance liquid chromatography (HPLC) were employed to investigate UV absorbing compounds, the group used the chemical reagent Naturstoffreagenz A (NA) to stain the leaf sample before studying each sample under high-end fluorescent microscopy in order to localise and visualise these compounds.

PROMISING RESULTS

As well as showing that leaves can absorb over 90 per cent of UVB radiation, the research has differentiated species of tree with a higher tolerance to UVB radiation. In particular, Qi's investigations have demonstrated that leaves of the pecan tree (*Carya illinoinensis*) have a high tolerance to UVB thanks to its upper epidermis, which absorbs nearly all the UVB radiation, while some UVA is absorbed by the mesophyll tissue, and blue and red light are able to penetrate deeper for effective biological functions.

The project has also shed light on the biochemical mechanisms which protect leaves from excessive UVB. Through HPLC assays, which differentiated UV absorbing compounds within the leaf, the group has identified 10 'natural sunscreen' compounds in 12 tree species: two major phenolic acids and eight major flavonoids, including chlorogenic acid, gallic acid, quercetin hydrate, rutin, kaempferol, apigenin, myricetin, naringenin, kaempferol-3-o-glucoside and kaempferol-3-o-rutinoside. Indeed, in many of the species studied, there was a strong presence of UV-absorbing compounds in the upper and lower epidermis, the vascular bundles and the leaf hairs, if present. Thus, the leaf epidermal layers play an important role in attenuation of harmful UVB radiation.

Significantly, Qi's research has shown that the concentration of UVB absorbing compounds in leaves increases as UV radiation rises during the growing season. As such, the scientists are a step closer to understanding the biochemical mechanisms which help plants tolerate enhanced UVB levels.

A COLLABORATIVE APPROACH

Effective partnerships and collaborations have been key to the success of the project so far. Whilst Qi has been supported by the knowledge and expertise of Drs Vanessa Ferchaud, Kit Chin, Wesley Gray, Shuju Bai and Kamran Abdollahi at SU, these studies have involved researchers and specialists from across the US. Of note, Dr Gordon Heisler from the USDA Forest Service played an important role in project planning, development and implementation, and his background in urban tree influences on urban microclimates has been indispensable. Meanwhile guidance from Dr Thomas Vogelmann of the University of Vermont led to the successful establishment of a robust fibre optic microprobe protocol.

Finally, Dr Wei Gao of the USDA's UVB Monitoring and Research Program was instrumental in providing the ambient UVB data and technical support necessary for the UVB mobile station and data calibration. "This project has certainly benefitted from enhanced intellectual interaction and long-term research collaboration between scientists and collaborators," Qi concludes.

Dr Yadong Qi and her students measuring depth of light penetration into leaf.

POSITIVE APPLICATIONS

Many years of analysis have illuminated some of the biochemical processes involved in UVB protection strategies in leaves and provide much-needed information on the impact of ozone depletion and increased UVB exposure on forest ecosystems. Not only will this aid future climate negotiations, but will support landscape-scale forest management, enabling landowners to maintain forests to buffer harmful compounds, harvest the aforementioned medicinal properties and continue to provide wood and fibre resources.

Promoting the most UVB-tolerant species could also bring social benefits in urban areas, since incorporating trees into the urban landscape could help protect inhabitants from excessive UV radiation. "The ability of

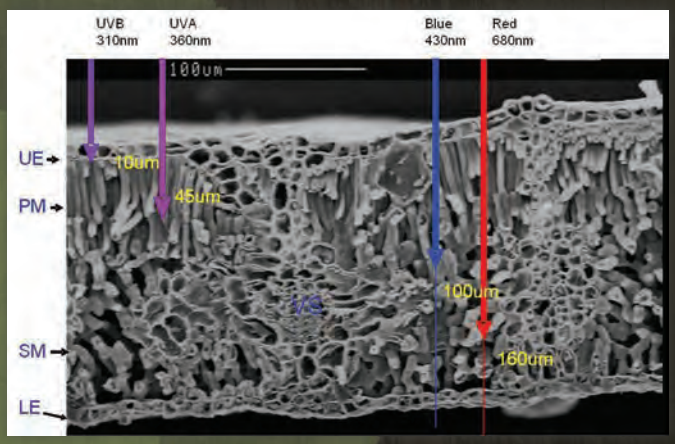


Illustration of depths of UVA, UVB, blue and red light penetration into leaf tissues of Pecan tree. UE: upper epidermis, PM: palisade mesophyll, SM: sponge mesophyll, LE: lower epidermis, VS: vascular system.

trees to absorb UV radiation can significantly benefit the urban environment, explains Qi. "Our research has shown that tree leaves in general can absorb over 90 per cent UV radiation and individual tree canopies such as southern live oak (*Quercus virginiana*) can reduce solar irradiance by an average of 60-80 per cent, the canopy's UV reduction power rises significantly with an increase in leaf area index." Greening urban spaces is by no means a new concept, yet it has grown in popularity as the effects of pollution, and indeed UV, on residents have become more apparent. If a high tree canopy is encouraged, the health of increasingly urbanised societies could improve significantly.

Dr Vanessa Ferchaud, postdoc research scientist at SUAREC studies the UV absorbing compounds identified from tree leaves.

LOOKING TO THE FUTURE

As the research project led by SU enters its second phase, the group aims to investigate seasonal UVA and UVB induced genetic changes in selected urban tree species in order to determine how UV tolerance relates to DNA damage and repair mechanism in trees. Having already established an outdoor mobile UV monitoring station, they will be able to study UVA and UVB transfer at the tree canopy level to see if they can further verify results.

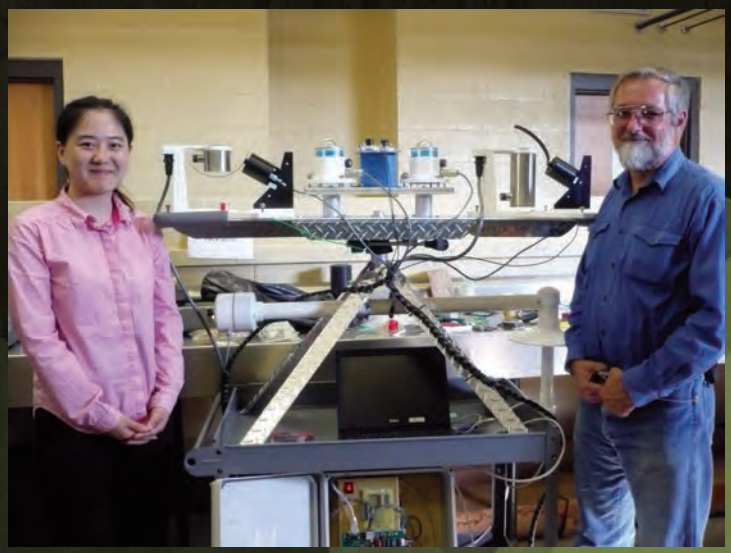
Qi sees this second phase as necessary to understand trees coping mechanisms to increased UVB exposure: "Another aspect of biochemical research is now needed to investigate UVB-induced genetic changes in tree species, assessing UV tolerance relative to DNA damage and the tree's repair mechanism. Only when all these approaches are put together will we be able to gain a better understanding of UV tolerance mechanisms in trees".

DISSEMINATION

The conversation sparked by these studies is one to watch in the coming years. With more people living in cities than ever before, and the repair process of the polar ozone holes still far from complete, this area of climate and forestry research leaves many unanswered questions for the new generation of scientists. SUAREC actively promotes training opportunities for graduate students and scholars, and attracts interested parties from further afield.

The studies carried out by the collaborative team have culminated in presentations at a number of conferences organised by the International Society of Arboriculture, the International Society of Optics and Photonics, the American Society of Plant Biologists, USDA-NIFA, the USDA Agricultural Research Service (USDA-ARS) and the Chinese Academy of Forestry. In addition, the work has generated four journal articles and a book chapter as well as three MS and one PhD theses.

The data collected is of such value that the USDA Forest Service Northern Research Station is currently using them to support ongoing UV-iTREE modelling. SUAREC's UVB mobile station has also become a satellite research station for the USDA UVB Monitoring and Research Program and will undoubtedly lead to yet more insight into a once little known function of forests.



Graduate Student Meng Wang and George Janson USDA UVB Monitoring Network scientist assembled the first comprehensive UV monitoring mobile station at SU.

INTELLIGENCE

THE UV RADIATION PROTECTION STRATEGIES EXHIBITED BY A DIVERSE GROUP OF BROADLEAF TREES

OBJECTIVES

Ozone depletion in the upper atmosphere has resulted in a significant increase in solar ultraviolet (UV)B radiation (280-315 nm) on the Earth's surface. Effects of the enhanced UVB on living organisms and ecosystems have been a major concern for more than three decades. The goal of this research is to understand how tree species, especially the southern broadleaf trees of the USA, interact with UV radiation, what kind of protective strategies or mechanisms they possess in order to cope with the harmful UVB radiation. This information is useful for predicting the impact of future uncertainty of ozone recovery and global climate change on forest trees, the largest biomass on the Earth.

KEY COLLABORATORS

Dr Gordon Heisler, US Department of Agriculture (USDA) Forest Service • **Dr Wei Gao**, USDA UVB Monitoring and Research Program, Colorado State University • **Dr Thomas C Vogelmann**, University of Vermont • **Dr Vanessa Ferchaud**; **Dr Kit L Chin**, Southern University Agricultural Research and Extension Center • **Dr Shuju Bai**; **Dr Wesley Gray**; **Dr Kamran Abdollahi**, Southern University and A&M College

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YADONG QI is Professor in Urban Forestry at Southern University A&M College and Research Project Director at Southern University Agricultural Research and Extension Center. She received her BSc and MS from China, and PhD from Stephen F Austin State University, USA, in 1991. She joined SU a year later and has since played a key role in establishing the nation's first BSc in Urban Forestry, and subsequent MS and PhD programmes.