Response to Sinkkonen: Ultraviolet reflectance in autumn leaves and the un-naming of colours

Marco Archetti[1], Thomas F. Döring[2], Snorre B. Hagen[3], Nicole M. Hughes[4], Simon R. Leather[2], David W. Lee[5], Simcha Lev-Yadun[6], Yiannis Manetas[7], Helen J. Ougham[8], Paul G. Schaberg[9] and Howard Thomas[8]

[1] Department of Zoology, University of Oxford, South Parks Road, Oxford OX1 3PS, UK
[2] Division of Biology, Imperial College London, Silwood Park, Ascot SL5 7PY, UK
[3] Department of Biology, University of Tromsø, 9037 Tromsø, Norway
[4] Department of Biology, Wake Forest University, Box 7325, Reynolda Station, Winston-Salem, NC 27109, USA
[5] The Kampong, National Tropical Botanical Garden, Miami, FL 33155, USA
[6] Department of Science Education–Biology, University of Haifa–Oranim, Tivon 36006, Israel
[7] Department of Biology, University of Patras, Patras 26500, Greece
[8] IBERS, Aberystwyth University, Plas Gogerddan, Aberystwyth SY23 3EB, UK
[9] Northern Research Station, Forest Service, US Department of Agriculture, South Burlington, VT 05403, USA

Ultraviolet (UV) vision, first discovered in ants more than a century ago, is a major area of interest for behavioural ecology. Because, unlike humans, many animal species can see UV light, spectrometry in the UV has revealed fascinating signalling systems that remain hidden to the human eye. In his letter to *Trends in Ecology & Evolution*, Sinkkonen [1] argues that UV should also be considered in investigations on autumn colours, particularly when testing hypotheses that involve insect–tree interactions. Because UV vision is a generic feature of insect vision and has been confirmed for aphids [2], the main taxon of interest in the autumn colour debate, we agree with Sinkkonen that the role of UV needs to be explored in this area. Specifically, we need to know: (i) how much UV is reflected by autumn leaves and how much trees vary in UV reflectance; and (ii) how insects respond to UV leaf reflectance in autumn.

With regard to the first question, it is important to consider spectral reflectance in actual leaves rather than the spectral properties of isolated phytochemicals. The presence of UV-reflecting compounds in a leaf does not mean that the leaf itself will be UV reflecting, given the number of other leaf compounds present that might absorb UV light. In senescent leaves of *Gingko biloba* and *Quercus robur*, which Sinkonnen mentions as containing UV-reflecting compounds [1], maximal UV reflectances were found of only 10% and 9%, respectively (unpublished from Ref. [3]). Moreover, the UV-reflective compound in senescent *G. biloba* does not occur widely, especially in woody plants, and it would be misleading to extrapolate to trees as a whole. Indeed, an analysis of 2409 autumnal leaf spectra reveals that 99% have a maximal UV reflectance of <8.6%, whereas at 500–650 nm, half of the spectra exceed 34.4% reflectance (data from Ref. [3]). Thus, all possible UV variability is squeezed into a narrow range of reflectance values.

With regard to the second question, UV is known to be involved in the visual signalling of flowers to pollinators; here, UV reflectance frequently reaches maxima of >30% [4]. By contrast, the low overall UV reflectance in autumn leaves means that the necessarily small differences among leaves would be relatively hard for insects to detect. In fact, a colour choice model developed from trapping migrant aphids in autumn found no effect of UV reflectance, when trap colours, mimicking the situation in leaves, reflected little UV [3]. Further studies are needed to test more thoroughly how aphids respond to UV, but for low UV reflectance (ca. <10%), the blue and green channels have the only significant role in the response of aphids to colours, according to the findings in Ref. [3].

As well as the UV issue, Sinkkonen's comment raises another important question: should leaves be classified by human colour names? Should we just add 'UV' as another category to the range of 'red,' 'brown' and 'yellow' leaves [1], or is there another, more appropriate way of describing leaf colours? Although it has been common practice in plant colour studies to use human colour names, we

Corresponding author: Archetti, M. (marco.archetti@zoo.ox.ac.uk).

believe that a more quantitative and objective description is crucial for progress in this field. Using human colour classification, even if supplemented with a 'UV' category, is inaccurate and ambiguous [5], and is based on the visual system of a species that has no biological connection with the evolution of autumnal leaf colours. Instead, multivariate statistical analyses of leaf spectra would be a more objective way to arrive at a classification system. Here it would certainly be important to include UV data.

In conclusion, UV might not be as important for insect–tree interactions in autumn as suggested by Sinkkonen [1]; for different reasons, however, it might well be worth exploring UV reflectance in leaves further.

References

1 Sinkkonen, A. (2009) Ultraviolet leaf pigments as components of autumn colours: a constructive comment on Archetti *et al*. *Trends Ecol. Evol.* 24, 236–237

2 Döring, T.F. and Chittka, L. (2007) Visual ecology of aphids—a critical review on the role of colours in host finding. *Arthropod-Plant Interact.* 1, 3–16

3 Döring, T.F. *et al.* (2009) Autumn leaves seen through herbivore eyes. *Proc. R. Soc. Lond. B Biol. Sci.* 276, 121–127

4 Arnold, S.E.J. *et al.* (2008) FReD: the floral reflectance spectra database. *Nat. Prec.*, DOI: 10.1038/npre.2008.1846.1

5 Archetti, M. *et al.* (2009) Unravelling the evolution of autumn colours: an interdisciplinary approach. *Trends Ecol. Evol.* 24, 166–173

doi:10.1016/j.tree.2009.01.007 Available online 25 March 2009