# FReD: The floral reflectance spectra database

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**Floral reflectance measurements are of great value to researchers who need consider the real colour of flowers, for example in the context of how the flowers appear to their pollinators. We have thus developed the Floral Reflectance Database (FReD) to assist these researchers, gathering together floral reflectance data in a publicly available, searchable online database. The first version of the database is now available online at http://www.reflectance.co.uk. We anticipate that this resource will be of interest to researchers working on flower colour and animal vision.**



## INTRODUCTION

We introduce the Floral Reflectance Database (FReD), an online, searchable database containing reflectance spectra for over 2000 flower and leaf samples. The purpose of the database is to make these spectra publicly available as a resource for researchers investigating flower colour and pollination ecology.

The database can be accessed at http://www.reflectance.co.uk, where there are search facilities for users to access the data and download specific records if required.

## CONTENTS OF THE DATABASE

The database currently contains 2283 floral reflectance spectra, each spanning the wavelength range of 300 to 700nm in 1nm increments. These records can be searched on the FReD website either by keyword or by an advanced search form (allowing users to specify criteria such as genus, colour or location). These records have been collected on flowers from around the world, and in most cases already been used in publications[2-6] with the largest data sets coming from Germany, Israel[3], Austria and Brazil. There are plans to add more records to expand the database in the future - in particular, datasets from Costa Rica and South Africa once they have been published.

In addition to the reflectance files, each sample has associated information about the characteristics and collection location for the flower. These include the following fields:

- Location information: country, closest town, GPS data where available, elevation of collection site above sea level
- Taxonomy information: family, genus and species of the flower, and herbarium accession where available
- Plant characteristics: corolla diameter, floral tube length and plant height where available, principle pollinators where the information is available, information on colour to both human and bee eyes

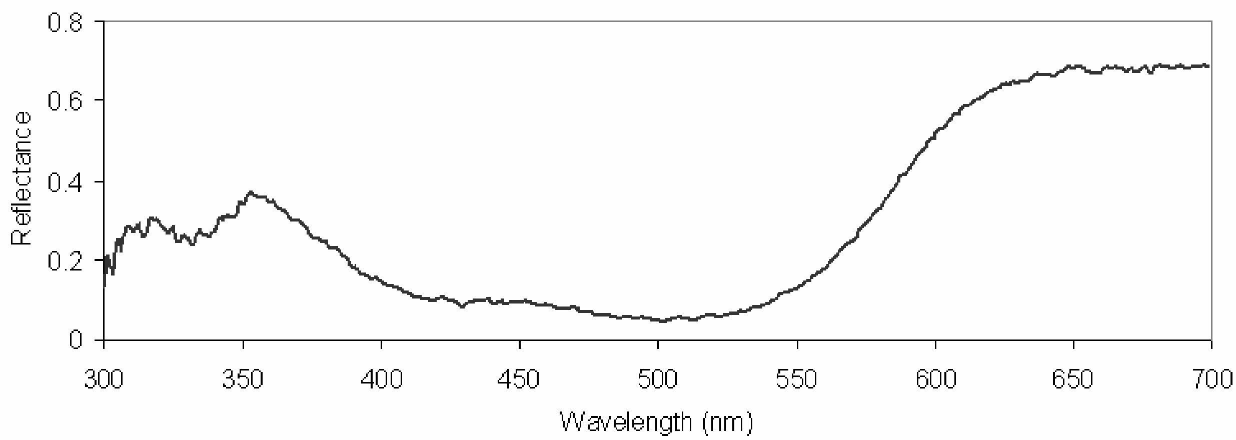


**Figure 1 | Example floral reflectance spectrum.** This shows the reflectance profile of the opium poppy, *Papaver somniferum*, a flower that is red to human eyes but appears UV to a bee.

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- Collector information: name of collector and publication in which the reflectance data were first used (details of voucher specimens are given where available)

## FLOWERS AS PERCEIVED BY INSECTS

Full spectral reflectance measurements constitute a significant improvement over merely considering flowers according to human-judged categories ("pink", "yellow", etc.). Not only are these subjective terms and not always used consistently between people, but they do not reflect how the flowers appear to the organisms to which they should appeal, i.e. their pollinators. By contrast, the information in FReD includes the ultraviolet reflectance of all the flowers measured, as well as their reflectances in the spectrum visible to human observers. This allows us to build an accurate picture of how the flowers are advertising by use of colour, and means that the colours of samples in the database can be modelled according to the visual capabilities of animals with colour vision systems different from humans, e.g. insects with a UV receptor.

Insects are the main pollinators of many species of flower[7]. These can be attracted to flowers by a variety of means, but most principally appearance (colour, shape) of the flower and odour[7]. Flower colours have thus been influenced by the preferences and sensory abilities of insect pollinators[4], including their colour vision, which differs from that of humans. The overwhelming majority of insects possess, along with blue and green receptors, visual receptors sensitive to UV light[8]. Some (e.g. some butterflies) possess additional types of receptors, including those maximally sensitive in the red spectral domain[8].

Bees are not only well-studied visual model systems[9], but also a tremendously important pollinator type in habitats worldwide, and thus this database provides information on how the flowers sampled would appear to trichromatic bee eyes, using to the colour hexagon model of colour vision[1].

## SPECTRAL REFLECTANCE MEASUREMENTS

The spectral reflectance measurements in FReD were measured with spectrophotometers, which measure the proportion of light reflected by the sample at wavelengths typically between 300 and 700nm. Outputs are standardised so all records in FReD are in the same format. Measurements are taken from several parts of a flower in some cases – where this has occurred, each record specifies what flower part was measured and whether this could be taken as the main colour of a flower (i.e. the dominant petal colour) or merely a secondary marking (e.g. nectar guides). A typical floral reflectance spectrum is given in Fig. 1.

## COLOUR SPACE MODELLING

Colour information can be modelled in colour space of a study organism in order to gain and understanding of how particular colours appear to that animal. The colour hexagon[1] works on the principle that the relative excitations of the three photoreceptor types present in a trichromatic animal such as the honeybee can be presented on a two-dimensional colour opponent space, taking into account the spectral composition of illuminating light and background surface. Individual colours are rendered as point loci on the space (Fig. 2).

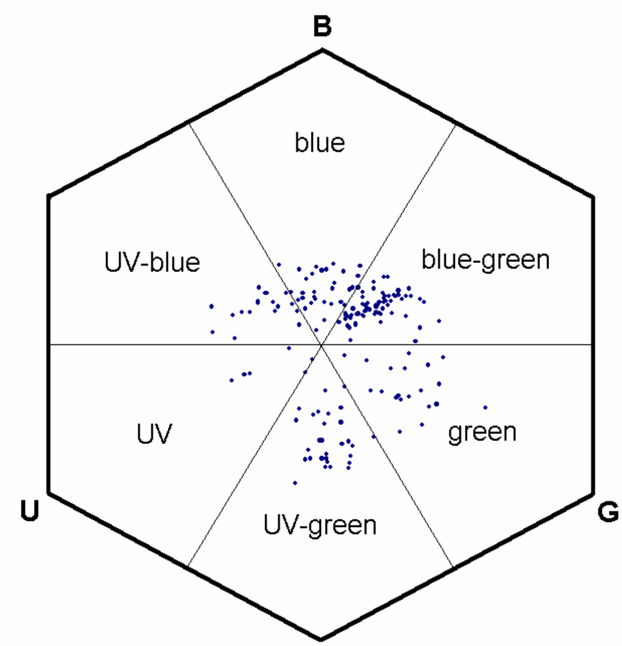


**Figure 2 | Colour hexagon.** Colour hexagon loci[1] shown plotted on to the model colour space. The selection of points shown represent the colours of flowers present in a range of habitats in a nature reserve near Strausberg, Germany[2].

In the colour hexagon, the distance between any two loci in the space is proportional to the discriminability of the two colours to a bee[1]. Additionally, the distribution of flower colours, when their spectra are rendered as hexagon loci, falls roughly into the six segments of the colour space. Relatively few colours fall on category boundaries, whilst many fall towards the centre of these categories[4]. Consequently, although dividing the hexagon into colour "categories" remains arbitrary until more information is available on bee colour categorisation, it is practical to use the six colour groups shown by the hexagon: blue, blue-green, green, UV-green, UV and UV-blue. Flowers in the database are categorised accordingly. Blue-green (frequently appearing white or pale pink to humans) is the commonest flower colour as perceived by bees – overall 24% of the current samples fall into this group.

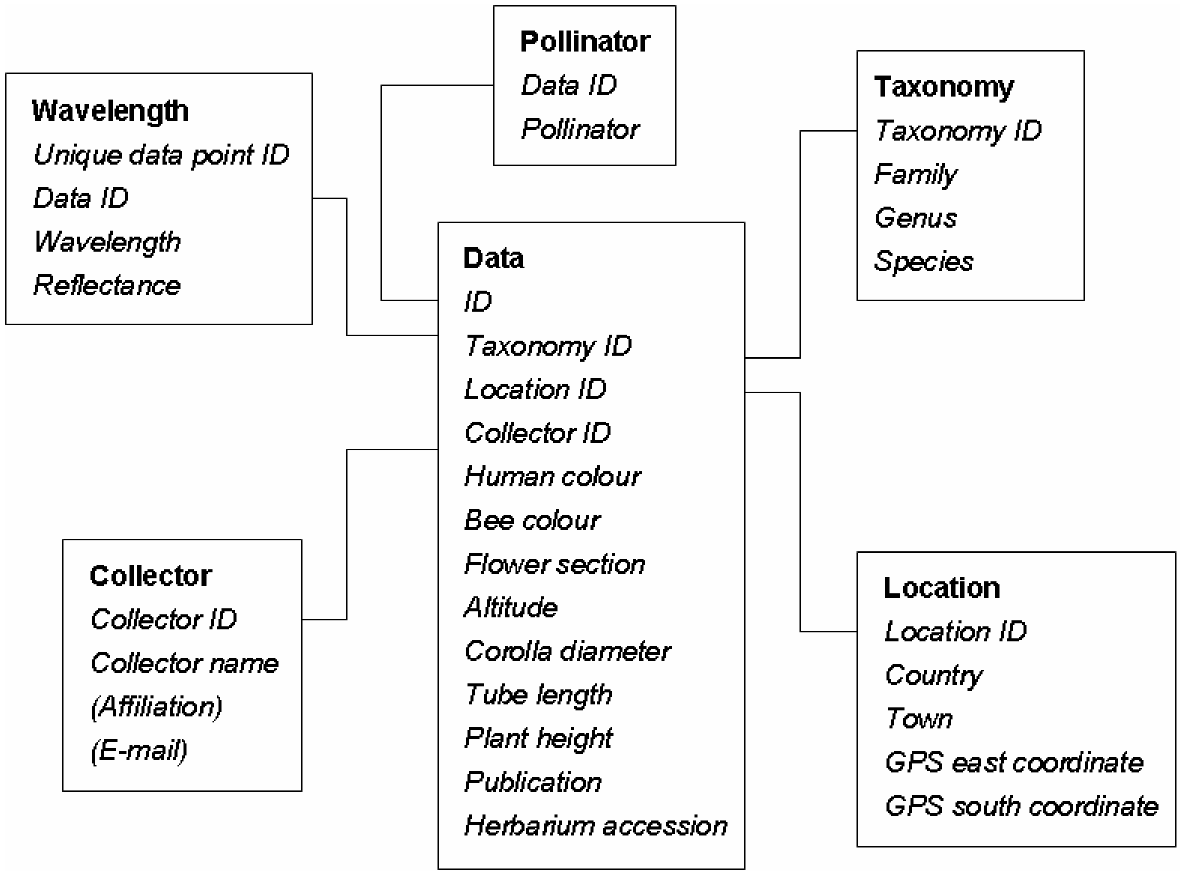


**Figure 3 | Table structure of FReD.** The database consists of 6 data tables, "Data" (with general flower information), "Taxonomy" (species information), "Location" (information on site of collection), "Pollinator" (containing pollinator information), "Collector" (details of the researcher who collected the sample), and "Wavelength" (containing the reflectance data).

## FORMAT AND USE OF THE DATABASE

A beta version of the database is currently hosted at the URL provided above. This is a basic, functional test version and makes the current data set publicly available. There are plans to release future versions with more functionality and a more advanced user interface. When the final release of the database is produced, the existing site will redirect users to the correct location of the newest version.

The beta version of the database consists of a MySQL database with 6 tables (Fig. 3), and a Java ServerPages (JSP) user interface, with which the user interacts. The user interface includes a basic keyword search (which will call all records containing a given word, for example "Asteraceae" or "green"), and also an advanced search, with a search form and options to select fields to display in the results. A user running either of these types of search will then be presented with a page of hits (Fig. 4), with basic details for each record. Each record also includes a link to the full flower collection and referencing details, and also to an HTML file displaying the full spectral reflectance. Pollinator information is given where available, in a coded format – a pop-up window linked from the sidebar explains the codes used throughout the database. The list of hits can be sorted according to any of the fields returned (e.g. by genus) by clicking on the field label at the top of the column ("Genus").

## USES FOR THE DATABASE

We expect the database to be invaluable for those requiring background data to investigate the selective pressures on flower colour and its interaction with insect vision – it contains information on a large set of real stimuli from a variety of habitats. It is also suited to those wishing to compare flower colours within and between habitats.

### References

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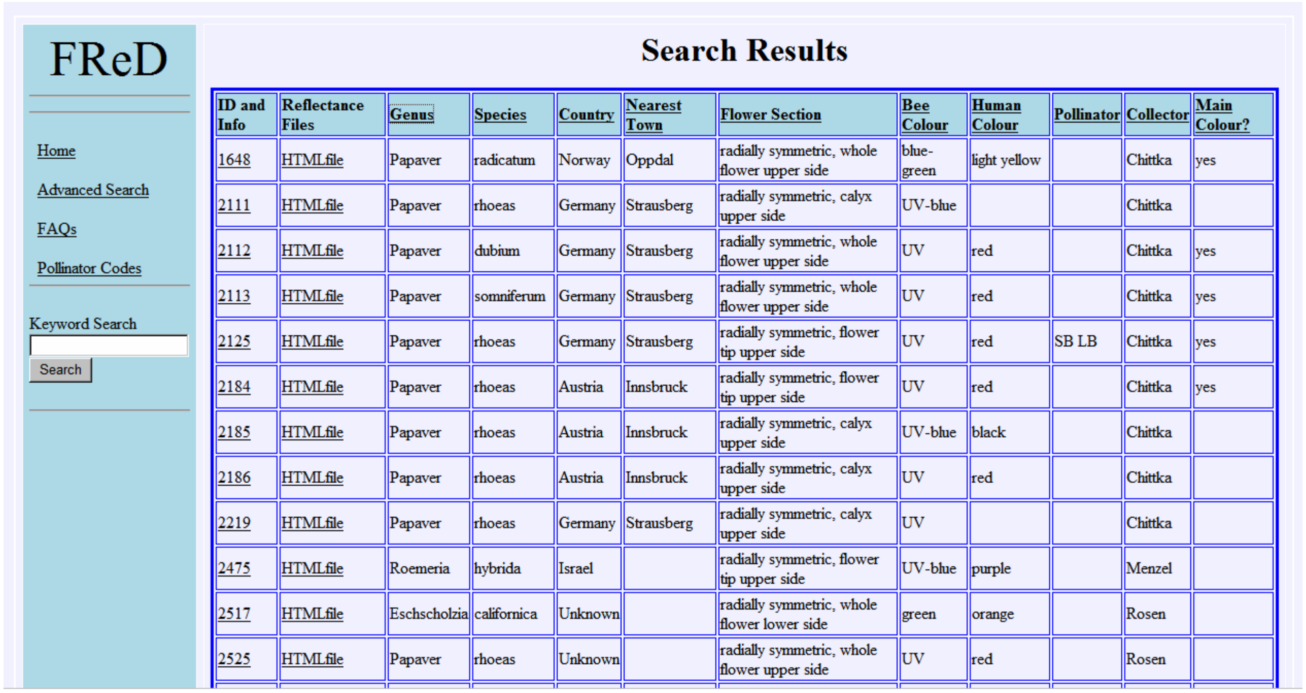

FReD

Home

Advanced Search

FAQs

Pollinator Codes

Keyword Search

Search

Search Results

| ID and Info | Reflectance Files | Genus | Species | Country | Nearest Town | Flower Section | Bee Colour | Human Colour | Pollinator | Collector | Main Colour? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1648 | HTMLfile | Papaver | radicatum | Norway | Oppdal | radially symmetric, whole flower upper side | blue-green | light yellow | | Chittka | yes |
| 2111 | HTMLfile | Papaver | rhoeas | Germany | Strausberg | radially symmetric, calyx upper side | UV-blue | | | Chittka | |
| 2112 | HTMLfile | Papaver | dubium | Germany | Strausberg | radially symmetric, whole flower upper side | UV | red | | Chittka | yes |
| 2113 | HTMLfile | Papaver | somniferum | Germany | Strausberg | radially symmetric, whole flower upper side | UV | red | | Chittka | yes |
| 2125 | HTMLfile | Papaver | rhoeas | Germany | Strausberg | radially symmetric, flower tip upper side | UV | red | SB LB | Chittka | yes |
| 2184 | HTMLfile | Papaver | rhoeas | Austria | Innsbruck | radially symmetric, flower tip upper side | UV | red | | Chittka | yes |
| 2185 | HTMLfile | Papaver | rhoeas | Austria | Innsbruck | radially symmetric, calyx upper side | UV-blue | black | | Chittka | |
| 2186 | HTMLfile | Papaver | rhoeas | Austria | Innsbruck | radially symmetric, calyx upper side | UV | red | | Chittka | |
| 2219 | HTMLfile | Papaver | rhoeas | Germany | Strausberg | radially symmetric, calyx upper side | UV | | | Chittka | |
| 2475 | HTMLfile | Roemeria | hybrida | Israel | | radially symmetric, flower tip upper side | UV-blue | purple | | Menzel | |
| 2517 | HTMLfile | Eschscholzia | californica | Unknown | | radially symmetric, whole flower lower side | green | orange | | Rosen | |
| 2525 | HTMLfile | Papaver | rhoeas | Unknown | | radially symmetric, whole flower upper side | UV | red | | Rosen | |

**Figure 4 | Search results.** When a user runs a basic or advanced search, the interface returns a table of hits, with information on each of the samples matching the search criteria.


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