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# PERSPECTIVAS MACROEVOLUTIVAS E MACROECOLÓGICAS DA COLORAÇÃO DAS FLORES DE ANGIOSPERMAS

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Co-orientador: Prof. Dr. Pedro Joaquim Bergamo

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*Os membros da Comissão Examinadora acima assinaram a Ata de defesa, que se encontra no processo de vida acadêmica do aluno.*

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**RESUMO**

A quantidade de UV refletido no espectro total de cores de uma flor, chamada de croma UV, está relacionado à força das pressões seletivas exercidas por polinizadores e antagonistas florais, que agem por meio de mecanismos de atração e exclusão sensorial. Ademais, fatores abióticos e geográficos também desempenham um papel importante na expressão do espectro UV nas flores. Para preencher as lacunas na compreensão desses fatores em escalas mais amplas, este estudo reuniu um conjunto abrangente de dados, incluindo informações sobre refletâncias espectrais, distribuição geográfica, visitantes florais, sistemas de polinização, variáveis climáticas e filogenia de diferentes espécies de angiospermas com o objetivo de explorar a diversidade de cores nas flores de angiospermas, com foco no croma ultravioleta (UV) e compreender a relação das características espectrais florais com fatores bióticos e abióticos (capítulo 1).

Analisamos a influência de polinização por abelhas vs. aves nas características espectrais das flores (capítulo 2). A análise verificou como o croma UV das flores varia para atender às preferências visuais específicas desses polinizadores, dentro do contexto da hipótese de exclusão sensorial. Analisamos a distribuição espacial do croma UV floral em diferentes regiões geográficas e investigamos como variáveis como altitude, temperatura, radiação UV-B, precipitação, tipo de polinizador e categoria de cor afetam a quantidade de croma UV nas flores (capítulo 3). Os resultados desses capítulos revelam informações essenciais sobre a diversidade e a evolução das características espectrais florais das diferentes espécies estudadas.

O capítulo 1 resultou em um conjunto de dados para 463 espécies com diferentes categorias de cores florais UV absorventes e reflexivas, com destaque para branco, vermelho e amarelo como as mais prevalentes. Abelhas, outros insetos e aves também se destacam como principais visitantes florais. Foi possível verificar a associação de categorias de cores específicas a diferentes sistemas de polinização, bem como padrões distintos na diversidade de cores florais entre áreas neotropicais e extra-neotropicais. Ainda, variações altitudinais e climáticas enfatizam a adaptabilidade das angiospermas a condições ambientais diversas.

No capítulo 2, a análise de 292 espécies evidencia uma ampla variação do croma UV de flores vermelhas, brancas e amarelas. A reconstrução do estado ancestral revela uma trajetória evolutiva dinâmica, com diferentes taxas de transição entre estes estados de cor floral. A evolução de um maior croma UV foi associada a flores vermelhas e brancas polinizadas por abelhas e flores amarelas polinizadas por aves. Esses resultados indicam que pressões de atração e exclusão contribuem para a diversidade das cores florais, especialmente em flores vermelhas polinizadas por abelhas e aves.

No capítulo 3 identificamos uma autocorrelação espacial positiva no croma UV entre as angiospermas analisadas, indicando uma tendência para espécies com croma UV semelhante se agruparem geograficamente. Regiões neotropicais mostraram aglomerados com maior croma UV. Vimos que variação espacial do croma UV nas espécies estudadas é influenciada pela precipitação anual, temperatura média anual (em menor medida), categoria de cor e tipos de sistema de polinização. Flores verdes e azuis, bem como sistemas de polinização de abelhas, morcegos e vertebrados+insetos foram associados a um maior croma UV.

## ABSTRACT

The amount of UV reflected in the total color spectrum of a flower, known as UV chroma, is related to the strength of the selective pressures exerted by pollinators and floral antagonists, acting through mechanisms of sensory attraction and exclusion. Additionally, abiotic and geographic factors also play an important role in the expression of the UV spectrum in flowers. To fill the gaps in understanding these factors on larger scales, this study gathered a comprehensive set of data, including information on spectral reflectance, geographical distribution, floral visitors, pollination systems, climatic variables, and phylogeny of different angiosperm species to explore the diversity of colors in angiosperm flowers, focusing on ultraviolet (UV) chroma and understanding the relationship of floral spectral characteristics with biotic and abiotic factors (chapter 1).

We analyzed the influence of bee vs. bird pollination on the spectral characteristics of flowers (chapter 2). The analysis examined how the UV chroma of flowers varies to meet the specific visual preferences of these pollinators within the context of the sensory exclusion hypothesis. We analyzed the spatial distribution of floral UV chroma in different geographic regions and investigated how variables such as altitude, temperature, UV-B radiation, precipitation, type of pollinator, and color category affect the amount of UV chroma in flowers (chapter 3). The results from these chapters reveal essential information about the diversity and evolution of the floral spectral characteristics of the different species studied.

Chapter 1 yielded a dataset for 463 species with different categories of UV-absorbing and reflective floral colors, with white, red, and yellow being the most prevalent. Bees, other insects, and birds also stood out as the main floral visitors. It was possible to observe the association of specific color categories with different pollination systems, as well as distinct patterns in floral color diversity between Neotropical and non-Neotropical areas. Altitudinal and climatic variations emphasize the adaptability of angiosperms to diverse environmental conditions.

In chapter 2, the analysis of 292 species revealed a wide variation in UV chroma of red, white, and yellow flowers. The reconstruction of ancestral states showed a dynamic evolutionary trajectory, with different transition rates between these states of floral color. The evolution of a higher UV chroma was associated with red and white flowers pollinated by bees and yellow flowers pollinated by birds. These results indicate that both attraction and exclusion pressures contribute to the diversity of floral colors, particularly in red flowers pollinated by bees and birds.

In chapter 3, we identified a positive spatial autocorrelation in UV chroma among the angiosperms analyzed, indicating a tendency for species with similar UV chroma to cluster geographically. Neotropical regions showed clusters with higher UV chroma. We found that the spatial variation of UV

chroma in the studied species is influenced by annual precipitation, average annual temperature (to a lesser extent), color category, and types of pollination systems. Green and blue flowers, as well as pollination systems involving bees, bats, and vertebrates with insects, were associated with a higher UV chroma.

# Sumário

**INTRODUÇÃO GERAL**

O sucesso reprodutivo da maioria das plantas com flores depende da interação com animais polinizadores (Ollerton et al. 2011; Rodger et al. 2021). As plantas possuem diversas estratégias para atrair os polinizadores enquanto se mantêm discretas para possíveis antagonistas como florívoros e pilhadores. Esses organismos usam e esgotar recursos das flores, como o néctar e o pólen, sem contribuir com a polinização da planta, afetando assim seu sucesso reprodutivo. A interação eficaz com polinizadores é estabelecida por meio de atrativos florais que sinalizam a disponibilidade de recursos, como alimento, abrigo e oportunidades reprodutivas, motivando sua visita (Willmer 2011). As flores utilizam uma gama variada de sinais, principalmente ligados às características florais, como tamanho, simetria, cores e perfumes para atrair os visitantes (Goulson 2000; Chittka & Raine 2006; Willmer 2011). Dentre estes sinais, a cor desempenha papel fundamental para a estabelecimento dessas interações, pois a maioria dos visitantes depende, em certa medida, da visão para localizar as flores (Chittka & Raine 2006; Schiestl & Johnson 2013; Narbona et al. 2021; Trunschke et al. 2021).

Os pigmentos mais prevalentes entre as plantas, os flavonoides e os carotenoides, são responsáveis pela ampla variedade de cores presentes nas flores (Thompson et al. 1972; Kevan et al. 1996; Grotewold 2006). Enquanto os carotenoides abrangem tonalidades que vão do amarelo ao laranja, os flavonoides incluem cores como branco (flavonas, flavonóis e flavanonas), amarelo (chalconas e auronas) e tons como laranja, vermelho, violeta e azul (antocianinas) (Grotewold 2006; Saigo et al. 2020). A extensa diversidade de cores nas flores das angiospermas tem sido um mistério para os cientistas ao longo dos anos. Essas cores são influenciadas por vários fatores inerentes às plantas (Vignolini et al. 2013; Moyroud & Glover 2017; Airoldi et al. 2019; van der Kooi et al. 2019; Wong et al. 2023) e pelas interações das plantas com fatores bióticos e abióticos ( Schremske & Bierzychudek 2001;Warren & Mackenzie 2001; Coberly & Rausher 2003; Jaakola & Hotola 2010; Arista et al. 2013; Koski & Ashman 2015b, 2016; Dalrymple et al. 2020; Koski et al. 2020; Koski e Galloway 2020; Martins et al 2021;). Entre estes fatores, a interação com os polinizadores tem recebido maior atenção (van der Kooi et al. 2019; Koski 2020).

A percepção e a aquisição dos sinais florais e suas cores no ambiente variam de acordo com cada animal. Mesmo em linhagens aparentadas, a diversidade intra e intertaxonômica revela diferenças significativas nas capacidades visuais dos animais (Weiss 2001). Insetos, aves e mamíferos percebem as cores florais de maneiras distintas devido às variações em seus tipos e números de células fotorreceptoras (Fein & Szuts 1982; Peitsch et al. 1992). As diferentes capacidades visuais desses animais implicam em pressões seletivas distintas nas cores florais, o que influencia a expressão e evolução deste atributo nas plantas (Briscoe & Chittka 2001; Rausher 2008; Trunschke et al. 2021). As diferenças nas capacidades visuais destacam também a importância de considerar a sensibilidade visual dos polinizadores e os fatores que a afetam ao interpretar as diversas interações entre polinizadores e flores, bem como o papel das interações planta-polinizador no sucesso reprodutivo das plantas (Chittka & Thomson 2001). Fatores como disponibilidade de recursos, energia gasta na busca por alimento e a presença de padrões visuais que facilitam a associação entre a flor e os recursos, por exemplo, influenciam a preferência e até mesmo a constância dos polinizadores por flores com determinadas cores (Goulson 1999, 2000; Gegear & Laverty 2001).

Muitas flores refletem comprimentos de onda correspondentes ao espectro visível de grupos importantes de visitantes florais, incluindo o ultravioleta (UV), frequentemente observado em padrões nas flores (Chittka & Thomson, 2001). Esses padrões resultam do acúmulo de pigmentos que podem absorver (flavonoides) e refletir (carotenoides) UV em diferentes partes da flor, criando áreas contrastantes que desempenham um papel crucial na distinção entre flores, na orientação e na localização de recursos dentro delas pelos polinizadores (Koski 2020). A quantidade de luz ultravioleta refletida pelas flores em relação ao espectro total, conhecida como croma UV, desempenha um papel significativo na forma como os polinizadores percebem e diferenciam as flores (Knuth 1891; Chittka et al. 1994; Kevan et al. 2001). Porém, o conhecimento sobre a evolução do espectro de UV em flores ainda é pouco estudado. Embora haja evidências de que a diversidade das cores florais, incluindo aquelas relacionadas ao UV, varie ao longo da evolução em diferentes linhagens (Muchhala et al. 2014; Gómez et al. 2015; Koski & Ashman 2016), alguns estudos indicam restrições filogenéticas nos padrões florais de UV (Koski & Ashman 2013; Camargo et al. 2019; Koski 2020; Tunes et al. 2021), enquanto outros apontam para uma evolução independente do parentesco filogenético desse atributo nas plantas (Koski & Ashman 2016). A quantidade de UV croma presente nas flores e seus padrões específicos desempenham um papel significativo na interação planta-polinizador, influenciando as preferências visuais dos animais em relação às cores florais (Tunes et al. 2020). Há uma associação clara entre o tipo de característica floral de UV e grupos de polinizadores (Lunau et al. 2011, Dyer et al. 2016; Reverté et al. 2016; Lunau, 2014; Dunn et al. 2020). Diferentes polinizadores têm preferências específicas por certas cores e padrões de UV, tornando-se potenciais agentes de seleção para esse traço floral. Assim, a interação dinâmica entre as habilidades de discriminação de cores e preferências visuais dos polinizadores e as cores das flores desempenham um papel importante na seleção das tonalidades florais mais adequadas para diferentes guildas de polinizadores (Garcia et al. 2020; Dyer et al. 2021; Price et al. 2019, Dyer et al. 2012). Essa relação pode ser a força motriz por trás das variações observadas na quantidade de UV croma das flores em diferentes espécies e locais.Por outro lado, muitas vezes, o papel dos polinizadores neste processo é superestimado e as pressões exercidas por outros visitantes florais, incluindo aqueles menos eficazes, acaba sendo negligenciada. Considerar uma variedade de visitantes florais, pode ajudar a revelar diferentes padrões de sinalização floral, bem como importantes implicações para a compreensão da evolução deste atributo floral. O croma UV está também provavelmente relacionado à evolução e às pressões seletivas exercidas por antagonistas florais, além dos polinizadores, através de mecanismos de exclusão sensorial. A associação entre este atributo e diferentes tipos de visitantes, como abelhas e aves, tem sido objeto de estudo em pesquisa sobre cores florais e seus processos moduladores. Nesse sentido, a evolução de certas cores de flores, principalmente polinizadas por aves, é resultado das pressões de exclusão sensorial exercidas por antagonistas florais como abelhas, em vez de uma pressão específica de atração desses animais (Raven 1972; Lunau et al. 2011; Bergamo et al. 2016; Papiorek et al. 2016). Nestas flores, em geral adaptadas morfologicamente à polinização eficaz por aves, as abelhas acabam atuando como pilhadores, o que consequentemente pode resultar em uma redução do sucesso reprodutivo destas plantas. Flores vermelhas, brancas e amarelas polinizadas por beija-flores, por exemplo, podem ser pouco atrativas às abelhas, dado o contraste estabelecido com o plano de fundo e padrões de refletância e absorção de UV (Lunau et al. 2011, Bergamo et al. 2016, Papiorek et al. 2016). Flores vermelhas e brancas UV-refletantes são acromáticas para abelhas e, por estimularem igualmente os três canais fotoreceptivos destes insetos, são também pouco conspícuas (Lunau et al. 2011, Bergamo et al. 2016). A presença de um padrão UV-absorvente no centro das pétalas e UV-refletante na periferia determina a atratividade das abelhas em flores amarelas. Se presente, o estímulo visual será percebido através do canal cromático, já que esta via necessita da informação de mais de um tipo de fotorreceptor, mas na ausência do guia UV, frequente em flores polinizadas por beija-flores, esta cor seria percebida de forma acromática pelas abelhas (Papiorek et al. 2016, Camargo et al. 2019). Dada a dificuldade em detectar sinais puramente acromáticos as abelhas concentram o forrageamento em flores mais conspícuas e isso cria um nicho exclusivo para polinizadores eficazes, como as aves, explorarem flores com cores diferentes, como vermelho, branco e amarelo, que exibem padrões únicos de croma UV e que são pouco atrativos para antagonistas florais. Essas interações entre cores florais, UV croma e polinizadores/visitantes desempenham um papel crucial na evolução e diversidade das plantas com flores. Compreender esses mecanismos contribui para uma visão mais abrangente das estratégias adaptativas das plantas em diferentes ambientes e na promoção de seu sucesso reprodutivo.

Apesar das interações entre plantas e polinizadores serem consideradas o principal fator na explicação da variação do espectro ultravioleta nas flores, fatores abióticos também podem atuar como pressões seletivas, levando a padrões de variação geográfica e ambiental desse atributo ( Schremske & Bierzychudek 2001;Warren & Mackenzie 2001; Coberly & Rausher 2003; Jaakola & Hotola 2010; Arista et al. 2013; Koski & Ashman 2015b, 2016; Dalrymple et al. 2020; Koski et al. 2020; Koski e Galloway 2020; Martins et al 2021;Koski 2020). Isso pois, além da sinalização e atração, os pigmentos responsáveis pelas cores das flores desempenham um papel na resistência a fatores abióticos, como altas temperaturas, baixa precipitação e alta radiação ultravioleta, que variam no espaço ( Warren & Mackenzie 2001; Arista et al. 2013; Koski & Ashman 2015). Por exemplo, o aumento da produção de antocianinas tem sido atribuído a maiores áreas de absorção de UV em flores em resposta a condições de alta radiação UV e baixos níveis de precipitação. Além disso, a composição desse pigmento pode variar entre as altitudes, latitudes e as condições ambientais relacionadas, como a quantidade de horas de luz, temperatura e os níveis de precipitação (Arista et al. 2013; Koski & Ashman 2015b, c; Lawson & Rands 2019; Dalrymple et al. 2020; Koski 2020). Portanto, da mesma forma que os polinizadores, os fatores abióticos desempenham um papel crucial na determinação da diversidade de cores florais e na variação notada no croma UV das flores (Schemske & Bierzychudek 2001; Arista et al. 2013; Koski & Ashman 2015b, 2016; Dalrymple et al. 2020; Koski 2020).

A reflexão ultravioleta é tão relevante quanto outras cores como vermelho, verde ou azul para a visão dos animais (Kevan et al 2001). Embora a reflexão UV não seja o fator mais determinante nos processos visuais, suas peculiaridades merecem atenção. Nossa limitação humana em perceber comprimentos de onda UV significa que podemos não alcançar certos processos sem realizar medidas apropriadas, como aquelas envolvendo a espectrofotometria ou fotografias em UV, por exemplo. Além disso, o UV pode causar danos às plantas. Como uma onda eletromagnética mais curta, o UV carrega uma quantidade de energia mais elevada, em comparação com outros comprimentos, o que pode comprometer o DNA e tecidos das plantas e suas flores. Embora estudos prévios tenham abordado a importância dos fatores bióticos e abióticos na determinação das cores das flores em escalas locais e nível de família, ainda não se conhece a influência desses fatores em escalas e níveis mais abrangentes. Entender como o croma UV se caracteriza em uma escala macroevolutiva ou macroecológica, pode contribuir significativamente para nossa compreensão acerca da diversidade e distribuição das características espectrais florais em diferentes regiões geográficas e escalas filogenéticas e temporais, abrindo caminhos para novos insights e hipóteses acerca de como as interações entre plantas, polinizadores e fatores abióticos moldam a evolução das cores florais. Como objetivo geral, visamos contribuir com esta perspectiva, bem como com futuras pesquisas no campo da biologia cognitiva e da polinização. Para isto compilamos um conjunto abrangente de dados, incluindo informações sobre refletâncias espectrais, distribuição geográfica, visitantes florais, sistemas de polinização, variáveis climáticas e filogenia para diferentes espécies de angiospermas (capítulo 1). Vale ressaltar que a seleção das espécies amostradas foi realizada considerando um recorte taxonômico e espacial específico. Dentre as inúmeras espécies para as quais tínhamos informações sobre refletâncias espectrais, incluímos apenas aquelas cuja as informações sobre polinizadores e visitantes foram levantadas. A coleta de refletâncias de todas as espécies iniciais presentes no banco de dados brutos, não seguiu um critério específico ou julgamento de valor, mas foi resultado de anos de esforços de coleta in situ, objetivando o trabalho com cores florais e ecologia cognitiva. Além disso, destacamos que este trabalho foca nas características espectrais florais das espécies. Embora estimemos e citemos categorias de cor para as espécies, neste trabalho não acessamos o atributo cor propriamente dado que estas categorias partem de curvas de refletâncias e não de modelos de visão em cores de animais. Este conjunto de dados tem como objetivos específicos explorar a diversidade de características espectrais nas flores de angiospermas, com foco no croma ultravioleta (UV) e aprofundar nossa compreensão sobre a relação desse atributo floral com fatores bióticos e abióticos em uma perspectiva evolutiva e ecológica global. Para investigar essas relações, conduzimos análises em duas perspectivas: uma macroevolutiva considerando fatores bióticos (capítulo 2) e uma macroecológica que inclui tanto fatores bióticos quanto abióticos (capítulo 3). No capítulo 2, dentro do contexto dos fatores bióticos, objetivamos examinar a influência de abelhas e aves, na variação do croma UV das flores que visitam. Nossa análise leva em conta a variação do croma UV das flores em relação às preferências visuais específicas desses polinizadores, contextualizando a hipótese de exclusão sensorial. Adicionalmente, no capítulo 3, investigamos a influência dos fatores abióticos e geográficos na quantidade de croma UV presente nas flores. Mais especificamente, nossos objetivos eram analisar a distribuição espacial da cromaticidade UV em flores de regiões geográficas distintas e investigar como elementos como altitude, temperatura, radiação UV-B, precipitação, tipo de polinizador e categorias de cores afetam esse atributo das cores florais. Nossos resultados, alinhados com estudos anteriores, oferecem insights valiosos sobre os processos evolutivos e ecológicos que influenciam as cores florais e a cromaticidade UV em flores de angiospermas.

CAPÍTULO 1

*Manuscrito a ser submetido como Data paper*

# A global dataset on flower colors for macroevolutive and macroecological perspectives


## ABSTRACT

Floral color in angiosperms is a functional trait influenced by various factors, including pigments, pollinators, and environmental conditions. This study introduces a curated and comprehensive dataset comprising spectral reflectances, floral color categories, geographic distribution, floral visitors, pollination systems, related altitudinal and climatic variables and phylogeny of 464 angiosperm species, with 367 species presenting previously unpublished data, significantly expanding our understanding of floral color diversity. The dataset categorizes floral colors into UV-absorbing and UV-reflecting categories, encompassing a wide range of color hues. UV+ and UV- white, red, and yellow are the most common categories in the dataset. The analysis of floral visitors and pollination systems highlights the central role of bees, insects, and birds as primary floral visitors of the species in the dataset. Specific color categories were more associated with different pollination systems, emphasizing the coevolution between plants and their pollinators. Geographical distribution reveals intriguing patterns in floral color diversity, with neotropical areas exhibiting distinct prevalence of color categories. Altitudinal and climatic variations further emphasize the adaptability of angiosperms to diverse environmental conditions. The inclusion of phylogenetic information provides insights into convergent evolution within distinct lineages. This dataset consolidates existing knowledge and provides new pathways to floral color research. It offers a wealth of previously uncompiled and unpublished data, contributing to our understanding of the factors shaping floral colors. An invaluable resource for scientists studying floral colors' ecology and evolution, it provides a global perspective on reflectances, pollinators, and environmental change.



## KEYWORDS

color ecology, climate and flowers, geographical distribution of floral colors, spectral reflectances of flowers, pollination, UV

**INTRODUCTION**

There is a remarkable diversity of floral colors in the angiosperm. Floral colors are produced by the accumulation, manifestation and combination of different classes of pigments such as flavonoids, anthocyanins and carotenoids(Grotewold 2006; van der Kooi et al. 2016; Wong et al. 2023). Flowers coloration is also influenced by the shape of the cells that retain these pigments and by physical factors such as brightness, polarization, iridescence and fluorescence (Vignolini et al. 2013; Moyroud and Glover 2017; Airoldi et al. 2019; Van Der Kooi et al. 2019). Floral color is a trait that covers a wide visual spectrum and varies at different temporal and spatial scales, within individuals, within and between populations, within and between plant communities and at the global scale(; Arista et al. 2013; Shrestha et al. 2014; Brito et al. 2015; Bergamo et al. 2018; Koski 2020; Tai et al. 2020). Many studies have pointed out the evolutionary labile nature of floral color and, in addition to the evolutionary history of plants, biotic and abiotic factors can shape how floral colors are structured at different scales (Rausher 2008; Trunschke et al. 2021).

The current diversity of floral colors has often been associated with its attractive role to floral visitors that frequently act as selection agents (Rausher 2008; Schiestl and Johnson 2013; Trunschke et al. 2021, Koski 2023).This is because floral colors are not just an intrinsic plant trait, but a product of the perception and processing of the chemical and physical properties the photoreceptors and the cognitive system of floral visitors (Chittka and Thomson 2001; Willmer 2011; Bukovac et al. 2017; Garcia et al. 2020). Photoreceptors can vary both in diversity and in number of pigments between and within different taxa, such as insects, birds and mammals that visit flowers (Briscoe and Chittka 2001; Weiss 2001). These characteristics affect the visual perception capacity of each group and, therefore, can determine the interaction of floral visitors with the flowers.

Abiotic factors related to patterns of geographic variation can also influence the diversity of floral colors at different scales. Solar radiation, precipitation, temperature and soil conditions have a major impact under colors and their patterns on flowers (Weiss 1995; Arista et al. 2013; Koski and Ashman 2016; Dalrymple et al. 2020; Koski et al. 2020) and can also influence the perception and visual processing of flowers by floral visitors. Besides signaling resources to visitors, floral pigments are also associated with plant tolerance under abiotic stress conditions such as water scarcity, high temperatures and ultraviolet radiation (Arista et al. 2013; Koski and Ashman 2016; Dalrymple et al. 2020; Koski et al. 2020). For example, increased anthocyanin production has been attributed to larger areas of UV absorption in flowers in response to conditions of high UV radiation and low levels of precipitation(Arista et al. 2013; Koski and Ashman 2016). Furthermore, the composition of this pigment can vary across latitudes and may be related to environmental conditions, such as the number of hours of light and precipitation levels.

Most studies focused on understanding the diversity and color patterns in flowers were conducted at microevolutionary and local scales (Arista et al. 2013; Shrestha et al. 2014; Bergamo et al. 2018; Koski 2020). These previous studies have highlighted the importance of biotic and abiotic factors determining this floral trait. However, there is still a notable gap in the understanding of how these factors and their structuring processes extend on a global scale, from the perspective of macroevolutionary and macroecological approaches. While some studies, have explored macroevolutionary and macroecological patterns, respectively, they do not cover all angiosperms globally, often focusing on specific clades or regions (Koski and Ashman 2016; Moré et al. 2020; Dalrymple et al. 2020). Understanding how and which ecological aspects influence the diversity of floral colors in plants from such perspectives is an important step toward improving the knowledge of floral color on a larger scale.

Here, we present a comprehensive global dataset on spectral reflectances, floral color categories, geographic distribution, floral visitors, pollination systems, related climatic variables, and phylogeny of 464 angiosperm species. These large-scale ecological data provide important records about floral colors globally. This dataset serves as a powerful tool, allowing researchers to explore the interplay between biogeographic and evolutionary history, as well as biotic and abiotic factors, in influencing the diversity and patterns of colors in flowers on a global scale. This dataset not only fills a critical gap in the current knowledge but also surpasses the scope of previous research by providing more extensive and in-depth data accessible to the scientific community. It enables researchers to conduct studies that were previously not possible due to a lack of comprehensive data on a global scale.

## DATA DESCRIPTION

### Identifier

ERDP-20XX-XX

### Contributor

*Dataset owner*

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**Geographical coverage**

The study covers a latitude range from 66.31ºN to 43.64ºS, covering the Tropical and Temperate zones of the globe.

**Temporal coverage**

The climate data gather historical monthly weather information for 1970-2000 with 10 minutes (~340 km2) of spatial resolutions

**Taxonomic coverage**

Dataset cover angiosperm species (0.15% of global angiosperm diversity) distributed across 93 botanical families (30% of angiosperms), with a notable representation of Asteraceae and Fabaceae, as well as, and functional groups of floral visitors (invertebrates and vertebrates) related to such species.

**METHODS**

This dataset was based on a compilation of spectral reflectances of 920 species concerning 130 families of angiosperms, hereafter known as Papiorek- SP and KL dataset (previously collected by dataset owners and co-authors Drs. Klaus Lunau and Sarah Papiorek- - resulting from years of in situ collection efforts at different sites for flower color and cognitive ecology studies) and from Coimbra et al. (2020) dataset, which counts 389 species from 65 botanical families. Starting from these raw data (covering more than 1000 species), we proceeded with the collection of data on floral visitors, records of geographic occurrences, climatic data and as well as with the processing and cleaning of the datasets. Therefore, the selection of sampled species was based on a specific taxonomic and spatial scope, including only those for which information on pollinators and visitors was collected. Taxonomic nomenclatures were verified manually and automatically (Taxonstand package, Cayuela et al. 2012) following The Plant List and World Flora Online basis (http://www.theplantlist.org/; www.worldfloraonline.org).

*Spectral reflectance*

Reflectances are limited to wavelengths between 300 nm and 700 nm (UV to red) values corresponding to the visible spectrum of pollinator species studied so far. Reflectances of one specimen per species were originally measured by spectrophotometer (USB 2000, USB 4000; Ocean Optics) at 45°, calibrated with white barium sulfate (BaSo4) standard and no light as a black standard (Lunau *et al.* 2011; Papiorek *et al.* 2016; Coimbra *et al.* 2020). We considered the measurements collected for what we judged be the predominant attractive structures of the species at long distances, thereby serving as the first long-distance communication channel between flowers and animals(Menzel *et al.* 1997; Spaethe *et al.* 2001). This included petals, sepals, stamens as well as bracts, that we were collectively referred to as "flowers" for standardization. Species with floral polymorphisms regarding color were not included. To ensure that the measurements were comparable, reflectances were normalized and corrected for negative values(pavo package, Maia et al. 2013).

*Categorical and continuous variables*

Once we had an initial list of species with information on attractive structures and standardized and corrected reflectance, we proceeded to survey the floral visitors associated with them and categorize visitors and pollination systems, encompassing 11 categories. With this information, the initial list of species was narrowed down, and only those for which we found data on visitors and pollinators up to December 2021 were included in the final version of this dataset. For these species, we continued categorizing color categories based on their reflectance curves, encompassing 16 categories. We estimated and defined these color categories to standardize terms, but it's important to highlight that we did not directly access the actual color attributes. We recognize that this is an arbitrary measure with limitations, but we understand and emphasize its utility for large datasets like this. Its use can simplify and facilitate the approach and comparison across different environments where species occur, as well as their various pollination systems, for which there are still limitations in the availability of visual models. Finally, we georeferenced these species and extracted climatic data that included annual averages of temperature, precipitation, and UV-B radiation (continuous variables) and classified the species according to their area of occurrence across three categories. See below for more details on the collection of these categorical and continuous variables.

*Floral visitors and pollination systems*

Data on floral visitors associated with the species was retrieved from literature searches using keywords such as “plant species” * “pollination” or “pollinator” on datasets such as Web of Science and Google Scholar. We included in our dataset floral visitor groups for which literature cited as frequent visitor as well as pollinators. The survey was comprehensive to increase the reach of our search and we considered different types of methodologies, including research papers, theses, dissertations and reviews. Visitors were categorized into large taxonomic functional groups based on their specific behavior, size, and function during flower visits (Ollerton et al. 2007). We then classified the species in pollination systems considering such functional groups (Ollerton et al. 2007). This classification involved categorizing the pollination systems that plants use based on the functional groups of floral visitors that are present in those systems. Thus, the plants were grouped into: 1-bee flowers (species with records of visits/pollination only by bees or wasps), 2- beetle flowers (species visited/pollinated only by beetles), 3- fly flowers (species visited/pollinated only by flies), 4- butterfly flowers (species visited/pollinated only by butterflies), 5- moth flowers (species visited/pollinated only by moths), 6- bat flowers (species visited/pollinated only by bats), 7- bird flowers (species visited/pollinated only by birds), 8- bee+insect flowers (species visited/pollinated by bees and others insects), 9- insect flowers (species visited/pollinated by more than one group of insects rather than bees), 10- vertebrate+insect flowers (species visited/pollinated by birds, bats and insects including bees) and 11- vertebrate flowers (species visited/pollinated by birds, bats, marsupials and lizards).

*Color categories*

We classified the colors of the species' attractive structures into categories considering their absorbance (-) or reflectance(+) within each UV (u), blue (b), green (g) and red (r) spectral bands (300-700 nm) using thresholds such as 0.1 (10%) for UV, 0.3 (30%) for blue, 0.4 (40%) for green, 0.5 (50%) for differentiating green flowers from blue and red ones and 0.6 (60%) for red (adapted from Camargo et al. 2019 and Coimbra et al. 2020). Considering these thresholds and the combination of the presence or absence of reflection in each band, different color categories could be classified as follows: 1- UV-Black (u-b-g-r-); 2- UV-Blue (u-b+g-r-); 3-UV-Cyan (u-b+g+r-); 4- UV-Green(u-b-g+r-); 5- UV-Pink (u-b+g-r+); 6- UV-Red (u-b-g-r+); 7- UV-White (u-b+g+r+); 8- UV-Yellow (u-b-g+r+); 9 – UV+Black (u+b-g-r-); 10- UV+Blue (u+b+g-r-); 11-UV-Cyan (u+b+g+r-); 12- UV+Green(u+b-g+r-); 13- UV+Pink (u+b+g-r+); 14- UV+Red (u+b-g-r+); 15- UV+White (u+b+g+r+); 16- UV+Yellow (u+b-g+r+).

*Geographical distribution of species and climate data*

We retrieved each species records of geographic occurrences, latitude and longitude, from the GBIF dataset (Global Biodiversity Information Facility - https://www.gbif.org/ - spocc package, Chamberlain et al. 2018). The data was filtered to present only spatially valid records. Missing, duplicated and erroneously processed coordinates outside the natural range of species such as on non-vegetative areas, herbariums, botanical gardens and the sea were removed (CoordinateCleaner package, Zizka et al. 2019).

Geographic coordinates were verified using the QGis 3.16.0 program to generate species distribution maps and classify the species according to their area of occurrence as Neotropical, Extra-Neotropical, or Global (when the species were distributed in both areas). The selection of these regions considered one of the forthcoming research focuses, which aims to analyze the ecological and evolutionary roles of pollinators on floral colors of species concentrated mainly in the Neotropics. Therefore, it made sense to include Extra-Neotropical as another classification for comparison purposes, encompassing both the Paleotropics and North America as contrasting areas to the Neotropics. Thus, this classification of areas of occurrence considered both one of our studies focuses and the differences in the biogeographical histories of these regions, which lead to variations in biodiversity, including the diversity of floral colors

For each georeferenced plant we also extracted information on altitude and climate. Altitude, mean annual temperature and annual precipitation data were retrieved from the WorldClim dataset (https://www.worldclim.org/data/, Hijmans et al., 2005) while mean annual UV-B irradiance was retrieved from Beckmann et al. (2014) respectively. These variables were chosen because they have been previously tested for their role in influencing variations in plant pigmentation. Additionally, using mean values allows for easier comparisons considering different temporal and spatial scales where species occurs. The final dataset includes the mean of these continuous variables extracted for each georeferenced point of each species.

*Phylogeny*

Inferences about the phylogenetic relationships of the species in the dataset were done based on the ALLMB dated phylogeny by Smith and Brown (2018) which contains 356,305 terminal taxa and combines genetic data from GenBank and phylogenetics from Open Tree of Life (ape package, Paradis and Schliep 2019). This was the backbone tree that included the largest number of species from our dataset. We assumed that distances within the same genus or between sister genera are smaller than those at other hierarchical levels, and we corrected for missing species in the phylogeny by substituting them with species from the same genus if present in the tree, or with species from sister genera if absent, which creates polytomies by adding absent genera or species to their closest taxa. Polytomies were then automatically solved. The resulting tree was used as the basis for the analyses performed subsequently.

For understand the influence of phylogenetic relatedness on the diversity of floral colors among dataset species, we assessed the phylogenetic signal for the average reflectance in each of the four-color bands (UV - 300 to 400nm, blue - 401 to 500nm, green - 501 to 600nm, red - 601 to 700nm). The phylogenetic signal was quantified by Blomberg's K statistic (Blomberg et al. 2003; phylosignal package; Keck et al. 2016), and its statistical significance was tested contrasting results against a null distribution generated from 1000 random phylogenies. This method is based on a Brownian motion evolution model of the trait (BM), where K >1 for a given variable indicates that phylogenetically related species resemble each other more than expected under the model, while K <1 indicates that phylogenetically close species are less similar than expected by the model.

*Code and Validation*

All the code used for the compiled data, analyzes and figures is provided in R language. The validation of the data entries followed the review of the codes as mentioned above, in addition to visual inspections by the authors.

## DATA STRUCTURE

*Data files*

The database has four files as described in Table 1.

*File format*

Data files are presented in newick (.tree) and comma-separated value (.csv) format with UTF-8 encoding.

*Variable definitions*

Variable names and definitions of each database file are found in Table 1.

*Unit definitions*

Temperature values are given in °C * 10, precipitation in mm (millimeter), altitude in m (meter) and UV-B radiation in J $m^{-2}$ $d^{-1}$.

## RESULTS

*Floral Color Diversity*

The species in the dataset exhibit a wide array of floral color categories, including black (2), blue (32), cyan (2), green (4), pink (74), red (127), white (128), and yellow (96), grouped into UV-absorbing (UV-, 197 species) and UV-reflecting (UV+, 268 species) categories. The most common categories encompass UV+ and UV- white (74 and 54), UV+ and UV- red (62 and 65), and UV+ and UV- yellow (53 and 43), representing 75.6% of the dataset (Fig. 1; Table S1).

*Floral visitors and pollination systems*

Various functional groups of floral visitors have been recorded among plant species, such as isolated records of non-marsupial mammals (1), marsupials (1), and lizards (1), wasps (7), bats (12), moths (24), beetles (45), butterflies (63), flies (97), birds (158), and bees (258) (Fig 2; Table S2). Approximately 81% of the categorized pollination systems for these plants are represented by bee+insect (89), bird (131) and bee (155). Among species categorized within these pollination systems, the majority fall into pink (74), yellow (96), white (128) and red (127) floral color categories (Table S3).

*Geographical Distribution and Climate Data*

The dataset covers 10.504 species occurrence records with validated distribution ranging from 66.31º N to 43.64º S, encompassing both tropical and temperate zones worldwide (Fig. 3; See Table S1 for the list of species). A total of 287 species occurs in Extra-Neotropical areas, 113 in neotropical and 65 are found in both areas. In neotropical areas, most plants exhibit flowers with UV+ yellow (12), UV+ pink (16), UV+ white (18) and UV+ and UV- red (19 and 23), representing 77.8% of the neotropical species occurrences (Table S4). Conversely, extra-neotropical areas predominantly feature plants with UV+ pink (31), UV+ and UV- red (32 and 29), UV+ and UV- yellow (37 and 35) and UV+ and UV- white (41 and 42), comprising 86% of species occurrences outside the neotropics (Table S4). Additionally, 14% of species occurrences span both neotropical and extra-neotropical regions, primarily categorized as UV+ and UV- red (11 and 13) and UV+ white (15) (Fig.4, Table S4).

The altitudinal range varies from -407 meters (for *Aaronsohnia factorovskyi* Warb. & Eig and *Anthemis melampodina* Delile records in Palestine) to 4,747 meters (for *Cobaea scandens* Cav. records in Bolivia). The annual mean temperature ranges from -2.1 degrees Celsius (for *Heliconia metallica* Planch. & Linden ex Hook. record in Colombia) to 29.7°C (for *Lycium shawii* Roem. & Schult. record in Sudan). The minimum annual precipitation (3 mm) was recorded in Egypt for *Pulicaria incisa* (Lam.) DC occurrences, and the maximum (7,324 mm) in Colombia for *Monolena primuliflora* Hook. f. occurrences. The annual average UV-B irradiation varies from 3,019 (for *Desfontainia spinosa* Ruiz & Pav. records in Argentina) to 9,979 × $10^9$J $m^{-2}$ $d^{-1}$ (for *Cleome gynandra* L. and *Sesamum indicum* L. records in Finland).

*Phylogeny*

Phylogenetic inference covered 463 taxa out of 464 in the dataset, distributed among 324 genera and 93 botanical families (Fig. 5, See Table S1). Among them, Asteraceae, Bromeliaceae and Fabaceae represent the most representative families in the dataset. The phylogenetic signal was low for all color bands, suggesting that in phylogenetically related species, floral colors are less similar than expected under a Brownian motion model of evolution (Table 2). Only the blue band exhibited a weak phylogenetic signal, indicating a tendency for closely related species to have similar reflectance within this reflectance range.

## DISCUSSION

The dataset presented in this study represents a significant tool to advance our understanding of floral color diversity and its ecological and evolutionary drivers. Although its representativeness relative to the global diversity of angiosperms is small, this data still surpasses the scope of previous research, providing more information to the scientific community that can help fill gaps in current knowledge about the diversity of floral colors. What sets this dataset apart from previously published floral color datasets is its coverage of biological and ecological information for 464 angiosperm species, with a notable 367 of these species contributing previously uncompiled and unpublished data. While existing datasets, such as those used in this study—Floral Reflectance Dataset (FReD) and those resulting from Coimbra et al. (2020)—have made valuable contributions to the field, the inclusion of these new species may signify a substantial expansion of available knowledge. Therefore, this extensive dataset not only helps consolidate existing knowledge but also pushes the boundaries of floral color research by introducing a wealth of previously unpublished information. It is a significant resource for scientists studying the ecology and evolution of floral coloration, not just aiding in current understanding but also paving the way for further exploration and discoveries in this field.

The floral coloration, modulated by pigments such as flavonoids, anthocyanins, and carotenoids, presents an extensive spectrum across various species. This dataset highlights a wide range of color categories, including black (natural dark-red or brown flowers), blue, cyan, green, pink, red, white, and yellow. The presence of diverse color categories suggests an intricate interaction between pigments and external factors in forming these hues (Grotewold 2006; van der Kooi et al. 2016, 2019; Wong et al. 2023). The distinction between UV- and UV+ within these categories indicates significant variation in reflectance patterns among species regarding the UV spectrum. Many pollinators, including insects and birds, can perceive ultraviolet light, guiding them towards flowers and their rewards (Knuth 1891; Chittka et al. 1994; Briscoe and Chittka 2001; Müller et al. 2009), underscoring the importance of UV in attracting floral visitors (Lunau et al. 2011; Papiorek et al. 2016; Camargo et al. 2019; Coimbra et al. 2020; Tunes et al. 2021).

There is a notable difference in the prevalence of specific colors between neotropical and extra-neotropical areas, suggesting potential adaptations to regional environmental conditions. For instance, the prevalence of UV+ white, pink, yellow, and red flowers in neotropical areas may be linked to specific pollinator preferences or a response to abiotic stressors (Arista et al. 2013; Koski and Ashman 2015b; Koski et al. 2020; Agati et al. 2021; Trunschke et al. 2021). Altitudinal and climatic variations further highlight the adaptability of angiosperms in response to environmental gradients (Arista et al. 2013; Koski and Ashman 2015; Koski et al. 2020). Therefore, floral pigments, besides attracting visitors, also assist plants in adapting to environmental stressors like high UV radiation and low precipitation. Significantly, the datasets coverage across a wide range of latitudes, altitudes, and climatic conditions provides a basis for exploring how biogeographic factors influence floral color.

Similarly, the inclusion of phylogenetic information in the dataset enhances our understanding of the evolutionary relationships among angiosperm species. The low phylogenetic signal observed for all color ranges indicates that closely related species may not necessarily share similar floral colors. This suggests an evolutionary lability in floral colors probably influenced by biotic and abiotic factors at different spatial and temporal scales. Moreover, it highlights the intriguing phenomenon of convergent evolution in floral colors among plant species, as indicated by the representation of these colors in different genera and botanical families within distinct lineages (Table 1; Rausher 2008; Mcewen et al. 2010; Trunschke et al. 2021).

Our dataset showed that plants primarily pollinated by bees exhibit a broad spectrum of colors and have a widespread global distribution. This converges with the literature findings that has pointed out that bees demonstrate preferences for a wide spectrum of colors, ranging from yellow to blue-violet, for pure colors that reflect UV, and for floral patterns (Lehrer et al. 1995; Lunau et al. 1996; Gumbert 2000; Raine and Chittka 2007; Maharaj et al. 2019; Aguiar et al. 2023). Meanwhile, birds, especially in tropical regions, are more commonly associated with white and vibrant colors such as red, orange, and yellow(Lunau and Maier 1995; Buzato et al. 2000; Dziedzioch et al. 2003; Cronk and Ojeda 2008; Handelman and Kohn 2014). Preference tests conducted with hummingbirds have revealed that they do not inherently prefer the colors they are typically linked to, such as white and red (Lunau et al. 2011). Generally, these colors vary in their reflective properties for ultraviolet light, with red flowers being UV absorbent and white flowers being UV reflective, for example. Our findings indicate that plants pollinated by birds predominate in specific regions like the Neotropics, southern Africa, Asia, and Australia, showcasing predominantly red and yellow colors that both absorb and reflect UV light. In the case of bats, flowers pollinated by them tend to display colors such as green, white, brown, or reddish-brown, and in some cases, bright (Winter and von Helversen 2001; Machado and Lopes 2004). Our results indicate preliminary association of these animals with flowers of white, yellow, and pink colors, primarily UV-reflective. Vision plays a relevant role for these animals, especially at night, where the contrast between the whitish color of flowers, particularly provided by the reflection of ultraviolet light, and the environment facilitates their detection (Winter and von Helversen 2001; Winter et al. 2003; Müller et al. 2009).

The relationship between floral colors and non-flying vertebrate pollinators is less studied. What is known pertains to anthesis and organization of flowers in inflorescences (Lumer and Schoer 1986; Kress et al. 1994; Hackett and Goldingay 2001; Godínez-Álvarez 2004). Flowers adapted for lizard pollination, for example, are known to be generally shared with other pollinators like birds or bees, displaying variable characteristics (Nyhagen et al. 2001; Godínez-Álvarez 2004; Sazima et al. 2010). In our dataset, the interaction of these animals occurs in generalist plants, also recorded for the visitation of other vertebrates and insects, presenting red UV-absorbing and reflective flowers.

Flies use visual signals over long distances but rely more on olfactory cues when close to flowers (Weiss 2001; Willmer 2011). Different groups of flies show preferences for specific colors, such as the innate preference for yellow in Syrphidae and for pink-blue in Bombyliidae (Goldblatt et al. 2001). This contrasts with our dataset, where we observed common interactions between flies and flowers of different colors in various regions. In the Neotropics, flies tend to interact with red and white flowers, reflecting UV, while they engage more with yellow and blue-toned flowers that absorb UV light in temperate regions of the Northern Hemisphere. However, fly pollination systems are more common in tropical and temperate regions of the southern hemisphere than in the northern hemisphere. Additionally, this system becomes more important at higher altitudes, which may influence the distribution of color categories within this pollination system (Weiss 2001; Devoto et al. 2005).

Our dataset included few cases of interaction with beetles, and among these, the plants are mainly red and white UV-absorbing. For these animals, the scent and temperature of flowers seem to be the main attractants, although in some specific situations, they are attracted by visual stimuli at short distances(Seymour and Schultze-Motel 1997; Weiss 2001). Despite reports of scarab beetles being associated with a wide range of color preferences ranging from white to red UV-absorbent, flowers pollinated by beetles exhibit few visual attractants, generally featuring pale, whitish, and greenish colors(Dafni et al. 1990; Van Kleunen et al. 2007; Streinzer et al. 2019).

Flowers attractive to butterflies and diurnal moths vary from yellow, blue, red to orange, often with mechanical or visual guides to nectar (Weiss 1997, 2001; Blackiston et al. 2011; Nuzhnova and Vasilevskaya 2013; Van Der Kooi et al. 2021). Our results show interactions of butterflies with flowers in the red and UV-absorbing and reflective pink spectrum, while interactions with moths predominantly involve UV-reflective white colors. For these visitors, usually nocturnal, floral scent is the main attractant, resulting in flowers typically being white or pale without nectar guides (Weiss 2001).

We highlight the dataset's limitations, including gaps in the representation of certain lineages and regions, which should be considered for a more holistic understanding. One potential area of improvement involves data coverage, particularly with respect to under-sampled pollination systems and the absence of some angiosperm lineages, such as basal angiosperms. Its poses a challenge when attempting to depict a general pattern of floral color evolution across the evolutionary history of all flowering plants. Another point of consideration concerns the arbitrary measure we used to classify color categories. While this measure can be quite useful and valid for global comparisons, as proposed in this work, we recommend using appropriate tools that account for different vision models and backgrounds if the focus is to delve into the knowledges of colors and the visual perception of animals. By acknowledging these limitations, we believe that appropriately use of the dataset presented in this study can significantly contribute as tool to our knowledge of floral color diversity and its ecological and evolutionary drivers. These data emphasize the intricate interplay between reflectance, pollinators, and environmental factors in shaping floral colors. Additionally, the dataset's global scope and phylogenetic information provide opportunities for further research into the macroevolutionary and macroecological patterns of floral color. Ultimately, understanding the factors influencing floral color diversity at multiple scales is crucial for elucidating the coevolutionary dynamics between plants and their pollinators, as well as advancing our understanding of the ecology and evolution of this floral trait.

## ACCESSIBILITY

*Location of storage and License*

This database will be made available through a selected data paper storage repository at a later stage, under an appropriate CC BY license.

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## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

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## TABLES

Table 1 - Description of database files with variable names and their definitions

| **Data file name** | **Description** | **Variable** | **Variable definition** |
|---|---|---|---|
| ReflectanceSpecies.csv | Spectral reflectance of predominant attractive structure of species | wl | wavelengths values in nanometers (nm) |
| | | Genus_specifcepithet_ attractivestructure_note | Species and attractive structures names. In note it is possible to find detailed information about which part of the attractive structure the spectral reflectance value refers |
| SpeciesInfo.csv | General species information, including taxonomy, attractive structure, classification of occurrence areas, general observations, visitor groups, categorized pollination systems, color category, average reflectances per color band | Sp | Species name |
| | | Sp_authority | Species name with authority |
| | | Genus | Genus name |
| | | Family | Family name |
| | | Attract_structure | Type of attractive structure |
| | | Area | Species area of occurrence |
| | | Note | Detailed information about attractive structures |
| | | Visitor_groups | Functional group of floral visitors |
| | | Poll_system | Pollination system |
| | | Col_categ | Color categories |
| | | UV | Average reflectance for UV band |
| | | Blue | Average reflectance for blue band |
| | | Green | Average reflectance for green band |

| | | | |
|---|---|---|---|
| | | Red | Average reflectance for red band |
| | | NA | Not available values |
| | | Ref_index | Reference index for visitor and pollinator groups |
| SpeciesCoordinatesClima.csv | Latitude, longitude, altitude, annual mean temperature, annual mean precipitation and annual mean UV-B irradiance data extracted for each species | Sp | Species name |
| | | Genus | Genus name |
| | | Family | Family name |
| | | Id | Point identity |
| | | Long | Longitude |
| | | Lat | Latitude |
| | | Alt | Altitude |
| | | tmean | Mean annual temperature |
| | | pmean | Annual precipitation |
| | | rad | Mean annual UV-B radiation |
| | | NA | Not available values |
| SpeciesPhylogeny.tree | A Newick phylogenetic tree describing the evolutionary relationships between the species in the database. | edge | An array where each row represents a branch of the tree and the first column shows the index of the branch's ancestor node and the second column shows the descendant node of that branch |
| | | edge.length | Tree branch lengths sizes |
| | | Nnode | Number of nodes |
| | | node.label | Node names |
| | | tip.label | Species names present in the phylogeny |

Table 2 - Phylogenetic signal (Blomberg's K) of the average reflectance intensity in color bands. p-values are based on 1000 simulations of Brownian motion evolution of variables along the phylogenetic tree. An asterisk (*) indicates significant p-values.

| **Color bands** | **K** | **P** |
|---|---|---|
| Green | 0.023884 | 0.9511 |
| Blue | 0.181656 | 0.0436* |
| Red | 0.034778 | 0.9089 |
| UV | 0.1377 | 0.351 |

**FIGURES**

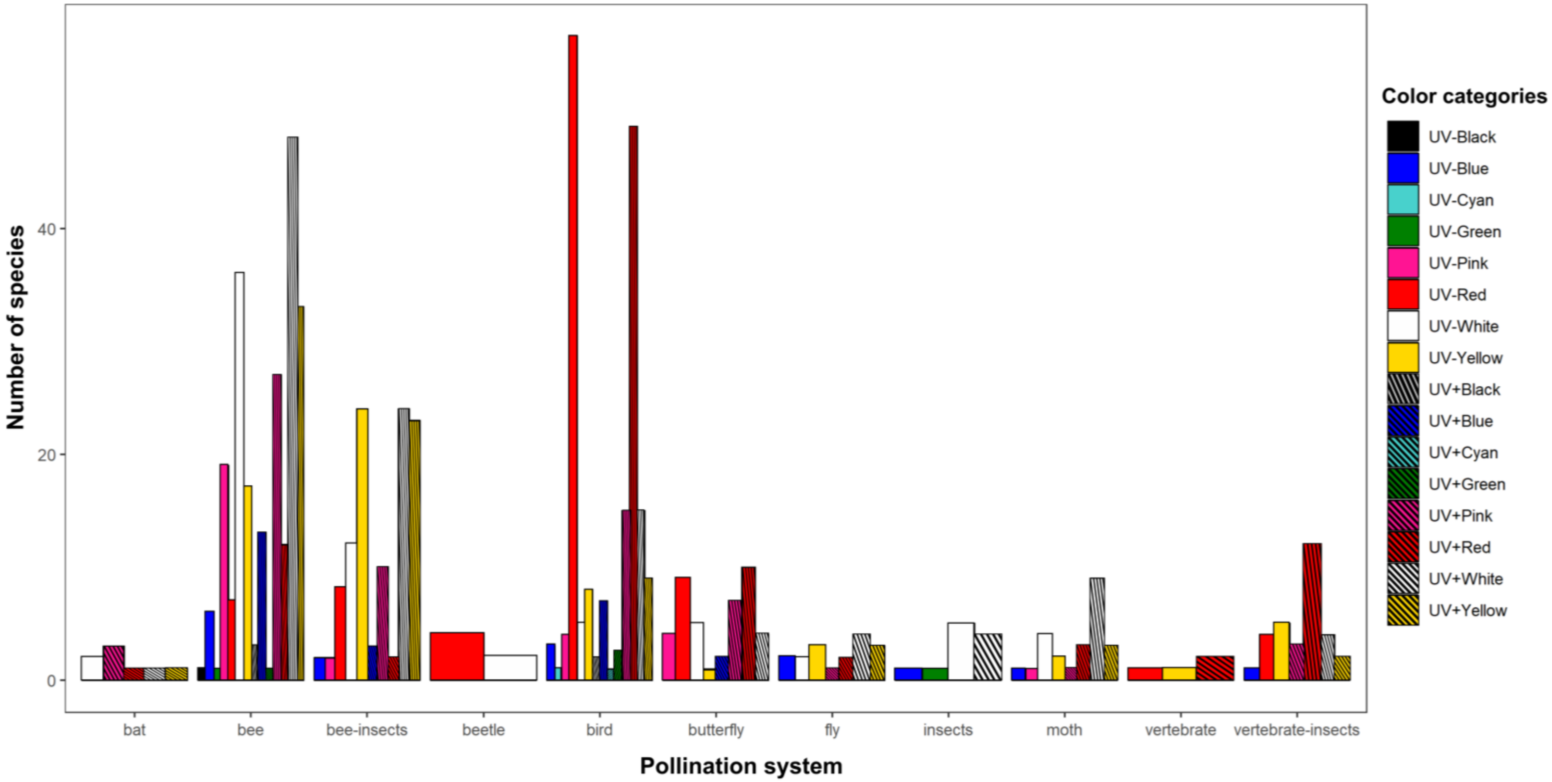


Figure 1. The relationship between floral color categories grouped as UV-absorbing (UV-) and UV-reflective (UV+) and the various pollination systems observed in the compiled dataset. The colors of the species' attractive structures were categorized based on their absorbance or reflectance within the UV, blue, green, and red spectral bands (300-700 nm), using specific thresholds: 0.1 (10%) for UV, 0.3 (30%) for blue, 0.4 (40%) for green, 0.5 (50%) to differentiate green flowers from blue and red ones, and 0.6 (60%) for red. UV-absorbing categories (UV-) are depicted with darker shading and dashed lines, while UV-reflective categories (UV+) are depicted with lighter shading.

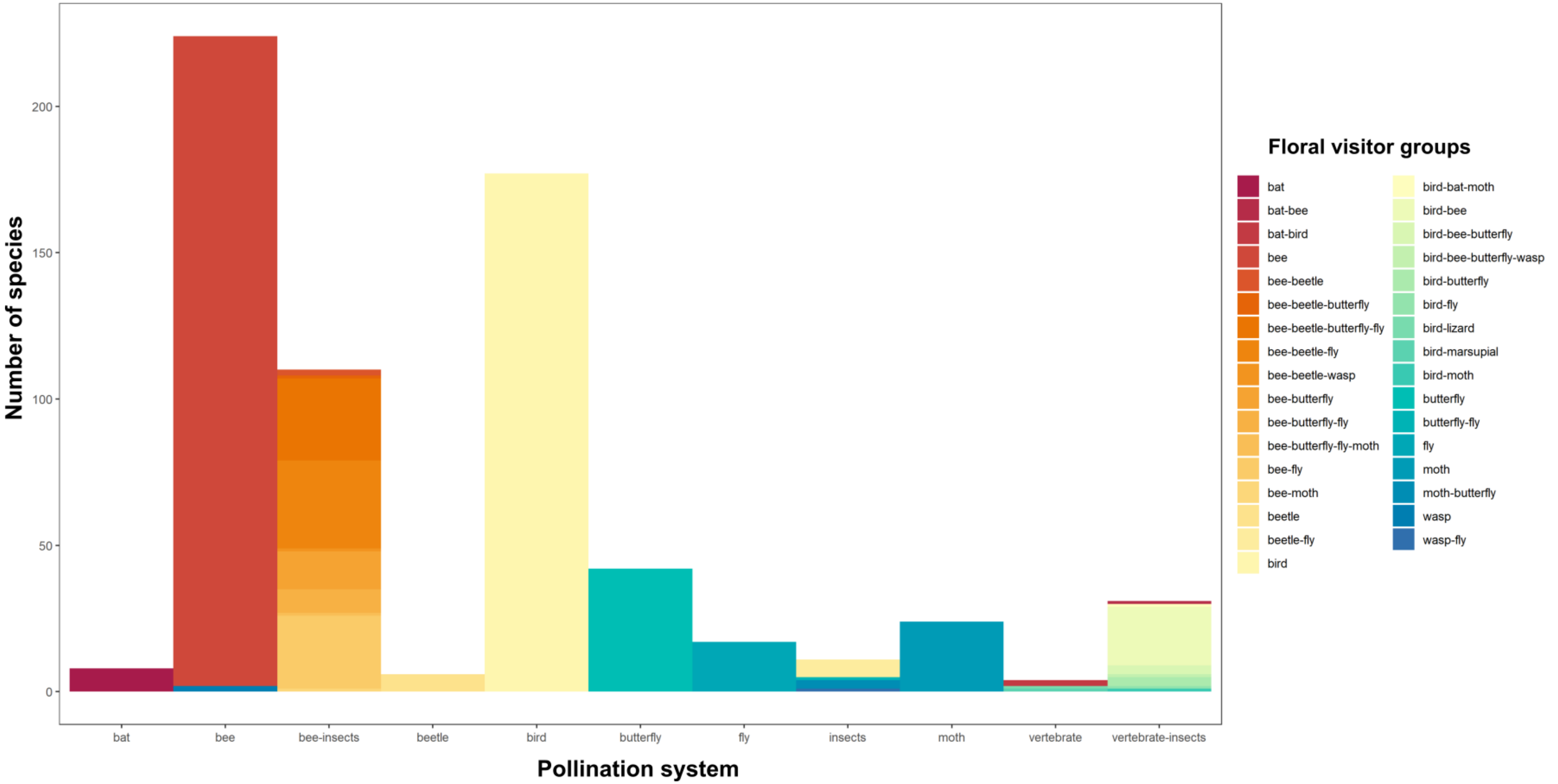


Figure 2. Functional groups of floral visitors representative of each pollination system, categorized for species observed within the compiled dataset. Visitors were grouped based on their specific behavior, size, and function during flower visits. We classified the species into pollination systems by considering the functional groups of pollinators, which involved categorizing the pollination systems plants use based on the functional groups of floral visitors present in those systems.

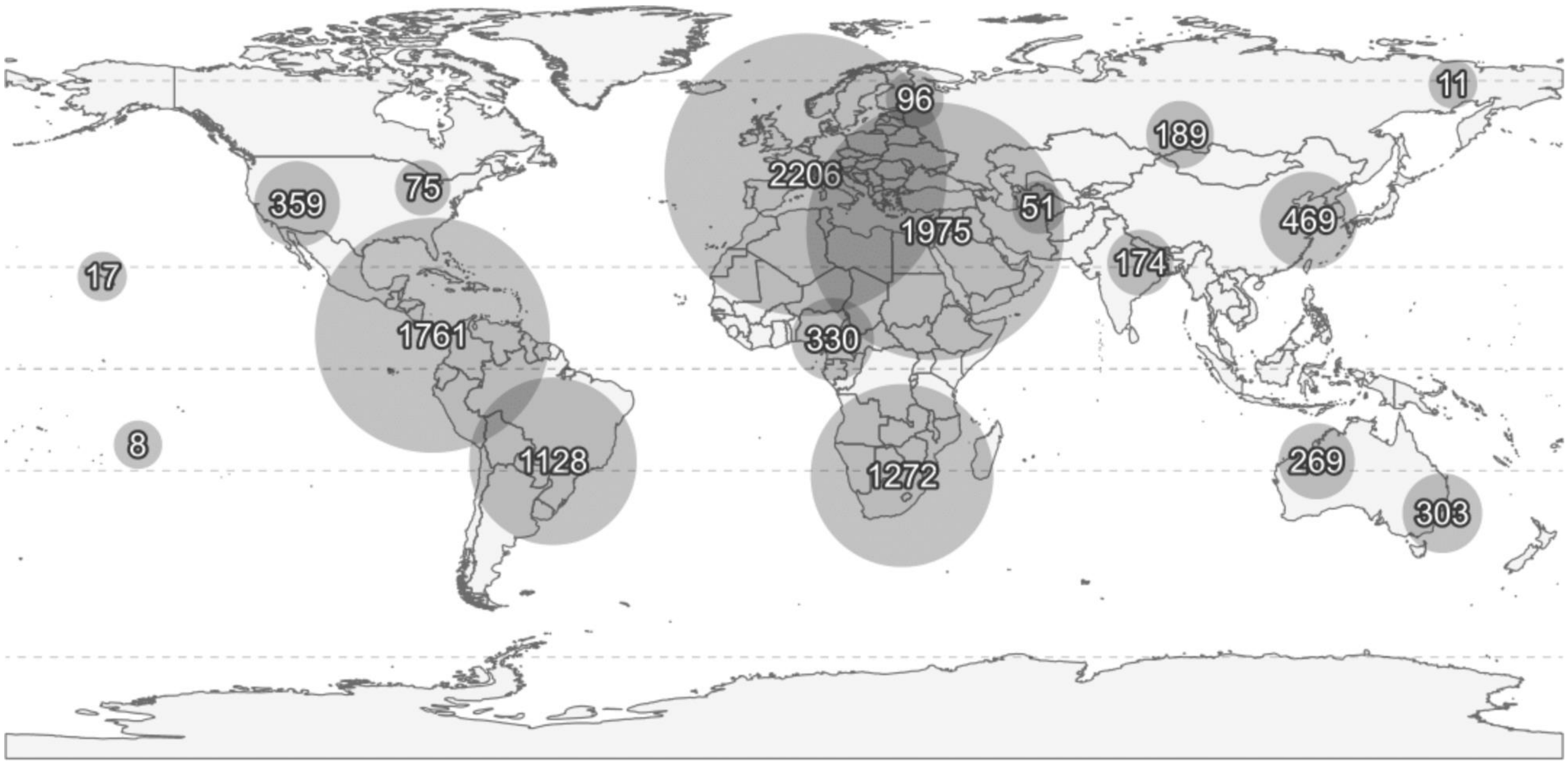


Figure 3. Occurrence records of plant species within the compiled dataset with validated global distribution. The grey circle sizes represent the number of records. Each species' records of geographic occurrences, latitude, and longitude were retrieved from the GBIF dataset. The data were filtered to present only spatially valid records.

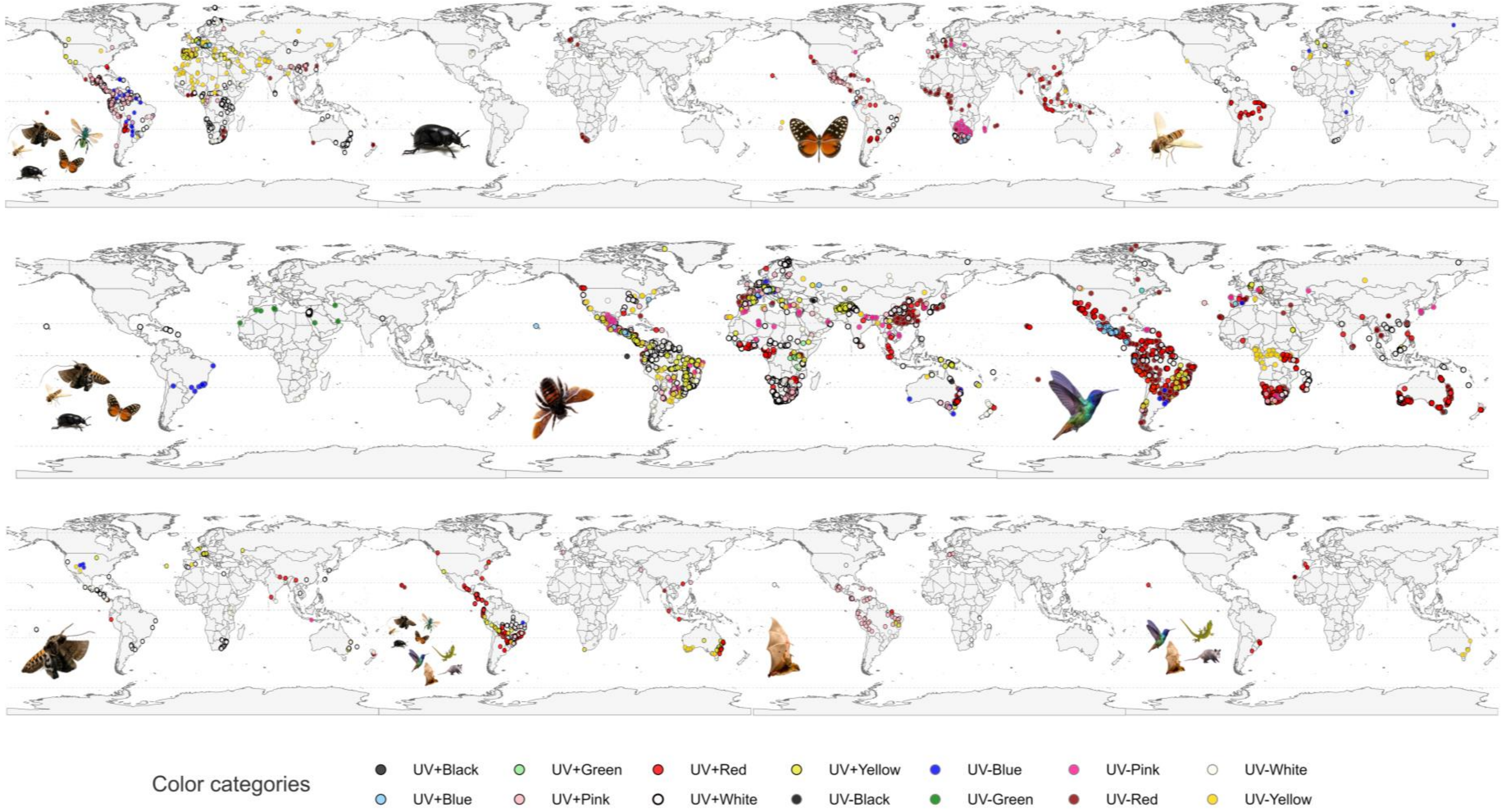


Figure 4. Global distribution of plant species within the compiled dataset across color categories (represented by colored dots) and pollination systems (represented by animal images). . Pollinators vector sources: Freepik Company S.L. Version: 15th April 2024. freepik.com

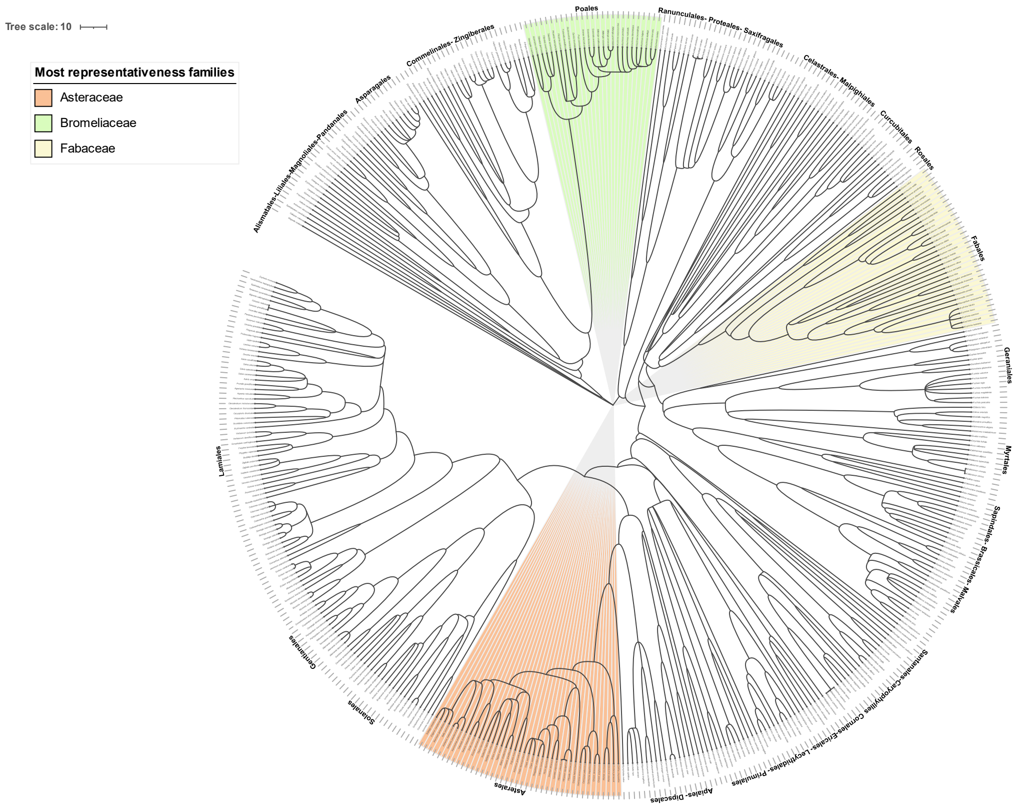


Figure 5. Phylogeny inferred from the species within the compiled dataset, based on the ALLMB dated phylogeny by Smith and Brown (2018). Phylogenetic inference covered 463 taxa out of 464 in the dataset, distributed among 324 genera and 93 botanical families. Angiosperm orders are highlighted in bold, while the top three most representative families in the dataset are colored in orange (Asteraceae), green (Bromeliaceae) and yellow (Fabaceae).

**MATERAIL SUPLEMENTAR**

**Supplementary Table S1.** List of 464 plant species selected for a detailed analysis of their floral reflectance properties. Botanical classification of the plant species (complete binomial, genus and family), their attractant structures (S), geographical occurrence areas (N- neotropical, EM -extra-neotropical, G- global), functional visitor group classifications (VG), pollination system categorizations (PS), color categories (color), reference index (RI), and the data sources from which reflectance information was gathered (database). Attractant structures (S) are categorized as P-petal, SP-sepal, L-leaf, B-bract, and ST-stamen. VG refers to categorizing visitors into groups based on their specific behavior, size, and function during flower visits. PS involves categorizing the pollination systems that plants use based on the functional groups of floral visitors that are present in those systems. The color categories features 16 subdivisions of colors including the UV absorbent (UV-) and UV reflectant (UV+) ones (following Camargo et al. 2019 and Coimbra et al. 2020). The data sources for this information come from two main databases: one is a comprehensive database (referred to here as "SP and KL dataset") previously compiled by coauthors Drs. Klaus Lunau and Sarah Papiorek , and the other dataset was collected from Coimbra et al. 2020. The species are arranged according to their botanical families, spanning across 379 genera and 102 distinct botanical families.

| *Species* | Genus | Family | S | Area | VG | PS | Color | RI | Database |
|---|---|---|---|---|---|---|---|---|---|
| *Aaronsohnia factorovskyi Warb. & Eig* | Aaronsohnia | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Acacia podalyriifolia G.Don* | Acacia | Fabaceae | ST | G | Bee | bee | UV-Yellow | 283 | SP and KL dataset |
| *Acalypha hispida Burm.f.* | Acalypha | Euphorbiaceae | ST | G | bee-beetle-butterfly-fly | bee-insects | UV-Red | 2 | SP and KL dataset |
| *Acca sellowiana (O.Berg) Burret* | Acca | Myrtaceae | ST | G | bee-bat-bird-mammal | vertebrate-insects | UV+Red | 3; 336 | SP and KL dataset |
| *Acnistus arborescens (L.) Schltdl.* | Acnistus | Solanaceae | P | N | bee-butterfly-fly | bee-insects | UV+White | 4 | SP and KL dataset |
| *Aconitum anthora L.* | Aconitum | Ranunculaceae | P | EN | Bee | bee | UV+Yellow | 5 | SP and KL dataset |
| *Aconitum napellus L.* | Aconitum | Ranunculaceae | P | EN | Bee | bee | UV+Blue | 6 | SP and KL dataset |
| *Aechmea aquilega (Salisb.) Griseb.* | Aechmea | Bromeliaceae | P | G | Bird | bird | UV-Red | 3 | Coimbra et al. 2020 |
| *Aechmea blanchetiana (Baker) L.B.Sm.* | Aechmea | Bromeliaceae | B | N | Bird | bird | UV-Red | 9 | SP and KL dataset |
| *Aechmea bromeliifolia (Rudge) Baker* | Aechmea | Bromeliaceae | P | G | Bird | bird | UV-Red | 10; 7 | Coimbra et al. 2020 |
| *Aechmea caudata Lindm.* | Aechmea | Bromeliaceae | P | G | bird-bee-butterfly | vertebrate-insects | UV+Red | 12 | SP and KL dataset |
| *Aechmea eurycorymbus Harms* | Aechmea | Bromeliaceae | P | N | Bird | bird | UV-Yellow | 7; 12 | Coimbra et al. 2020 |
| *Aechmea fulgens Brongn.* | Aechmea | Bromeliaceae | P | N | Bird | bird | UV+Pink | 13 | SP and KL dataset |
| *Aechmea nudicaulis (L.) Griseb.* | Aechmea | Bromeliaceae | B | N | bird-bee | vertebrate-insects | UV-Red | 14; 255 | SP and KL dataset |
| *Aechmea pectinata Baker* | Aechmea | Bromeliaceae | P | N | Bird | bird | UV+White | 15; 7 | Coimbra et al. 2020 |
| *Aechmea recurvata (Klotzsch) L.B.Sm.* | Aechmea | Bromeliaceae | P | N | Bird | bird | UV+Pink | 16 | SP and KL dataset |
| *Agapetes hosseana Diels* | Agapetes | Ericaceae | P | EN | Bird | bird | UV-Red | 17 | SP and KL dataset |
| *Agapetes serpens (Wight) Sleumer* | Agapetes | Ericaceae | P | EN | Bird | bird | UV+Red | 17 | SP and KL dataset |
| *Agastache mexicana (Kunth) Lint & Epling* | Agastache | Lamiaceae | P | G | Bird | bird | UV+Pink | 284 | SP and KL dataset |
| *Ainsworthia trachycarpa Boiss.* | Ainsworthia | Apiaceae | P | EN | Beetle | beetle | UV-White | 387 | Coimbra et al. 2020 |
| *Vriesea extensa L.B.Sm.* | Alcantarea | Bromeliaceae | P | N | Bat | bat | UV+Yellow | 18 | SP and KL dataset |
| *Alcea rosea L.* | Alcea | Malvaceae | P | EN | Bee | bee | UV+Pink | 7 | SP and KL dataset |
| *Alkanna strigosa Boiss. & Hohen.* | Alkanna | Boraginaceae | P | G | Bee | bee | UV+Blue | 1 | Coimbra et al. 2020 |
| *Allamanda blanchetii A.DC.* | Allamanda | Apocynaceae | P | G | Bee | bee | UV-Pink | 19 | SP and KL dataset |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Allamanda cathartica L.* | Allamanda | Apocynaceae | P | N | bee-beetle | bee-insects | UV+Yellow | 20; 367 | SP and KL dataset |
| *Allamanda schottii Pohl* | Allamanda | Apocynaceae | P | G | Bee | bee | UV-Yellow | 21 | SP and KL dataset |
| *Aloe africana Mill.* | Aloe | Asphodelaceae | P | EN | Bird | bird | UV-Yellow | 22 | SP and KL dataset |
| *Aloe bakeri Scott-Elliot* | Aloe | Asphodelaceae | P | EN | Bird | bird | UV+Yellow | 16 | SP and KL dataset |
| *Aloe bellatula Reynolds* | Aloe | Asphodelaceae | P | EN | Bird | bird | UV+Red | 16 | SP and KL dataset |
| *Aloe ciliaris Haw.* | Aloe | Asphodelaceae | P | EN | Bird | bird | UV-Red | 16 | SP and KL dataset |
| *Aloe descoingsii Reynolds* | Aloe | Asphodelaceae | P | EN | Bird | bird | UV+Red | 16 | SP and KL dataset |
| *Aloe plicatilis (L.) Mill.* | Aloe | Asphodelaceae | P | EN | Bird | bird | UV+Red | 16 | SP and KL dataset |
| *Aloe viguieri H.Perrier* | Aloe | Asphodelaceae | P | EN | Bird | bird | UV+Red | 16 | SP and KL dataset |
| *Aloe vogtsii Reynolds* | Aloe | Asphodelaceae | P | EN | Bird | bird | UV-Yellow | 23 | SP and KL dataset |
| *Alpinia purpurata (Vieill.) K.Schum.* | Alpinia | Zingiberaceae | B | G | Bird | bird | UV-Red | 24 | SP and KL dataset |
| *Alpinia zerumbet (Pers.) B.L.Burtt & R.M.Sm.* | Alpinia | Zingiberaceae | P | EN | Bee | bee | UV+Yellow | 25 | SP and KL dataset |
| *Amherstia nobilis Wall.* | Amherstia | Fabaceae | P | EN | Bird | bird | UV-Red | 47 | SP and KL dataset |
| *Anagyris foetida L.* | Anagyris | Fabaceae | P | EN | Bee | bee | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Ananas bracteatus (Lindl.) Schult. & Schult.f.* | Ananas | Bromeliaceae | B | N | Bird | bird | UV-Red | 27; 302 | Coimbra et al. 2020 |
| *Anchusa strigosa Banks & Sol.* | Anchusa | Boraginaceae | P | EN | Bee | bee | UV+Blue | 1 | Coimbra et al. 2020 |
| *Androsace chamaejasme Wulfen* | Androsace | Primulaceae | P | EN | bee-fly | bee-insects | UV+White | 28 | SP and KL dataset |
| *Anemone coronaria L.* | Anemone | Ranunculaceae | P | EN | Beetle | beetle | UV-Red | 1 | Coimbra et al. 2020 |
| *Anemone nemorosa L.* | Anemone | Ranunculaceae | P | EN | Bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Anigozanthos flavidus DC.* | Anigozanthos | Haemodoraceae | P | EN | Bird | bird | UV-Cyan | 2; 297 | SP and KL dataset |
| *Anthemis melampodina Delile* | Anthemis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Anthemis pseudocotula Boiss.* | Anthemis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Anthurium obtusum (Engl.) Grayum* | Anthurium | Araceae | P | G | bee-beetle-butterfly-fly | bee-insects | UV+White | 16 | SP and KL dataset |
| *Apeiba tibourbou Aubl.* | Apeiba | Malvaceae | P | N | Bee | bee | UV+Yellow | 29; 379 | SP and KL dataset |
| *Aquilegia caerulea E.James* | Aquilegia | Ranunculaceae | P | EN | bee-moth | bee-insects | UV-Blue | 367; 338 | SP and KL dataset |
| *Aquilegia chrysantha A.Gray* | Aquilegia | Ranunculaceae | P | EN | bee-moth | bee-insects | UV-Yellow | 31 | SP and KL dataset |
| *Aquilegia einseleana F.W.Schultz* | Aquilegia | Ranunculaceae | P | EN | Bee | bee | UV-Blue | 31; 7 | SP and KL dataset |
| *Arabidopsis arenosa (L.) LawalrÃ©e* | Arabidopsis | Brassicaceae | P | EN | bee-fly | bee-insects | UV-White | 1 | Coimbra et al. 2020 |
| *Arctostaphylos uva-ursi (L.) Spreng.* | Arctostaphylos | Ericaceae | P | EN | Bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Arenaria serpyllifolia L.* | Arenaria | Caryophyllaceae | P | EN | Fly | fly | UV-White | 1 | Coimbra et al. 2020 |
| *Arnica montana L.* | Arnica | Asteraceae | P | G | Fly | fly | UV+Yellow | 32 | SP and KL dataset |
| *Asclepias incarnata L.* | Asclepias | Apocynaceae | P | EN | bee-moth | bee-insects | UV+Pink | 33 | SP and KL dataset |
| *Asphodeline liburnica (Scop.) Rchb.* | Asphodeline | Asphodelaceae | P | EN | bee | bee | UV+Yellow | 34 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Asphodelus aestivus Brot.* | Asphodelus | Asphodelaceae | P | EN | bee | bee | UV+White | 34; 1 | SP and KL dataset |
| *Asteriscus graveolens (Forssk.) Less.* | Asteriscus | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Astragalus amalecitanus Boiss.* | Astragalus | Fabaceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Baccharis trimera (Less.) DC.* | Baccharis | Asteraceae | P | N | bee | bee | UV-Yellow | 12 | SP and KL dataset |
| *Banksia prionotes Lindl.* | Banksia | Proteaceae | ST | EN | bird | bird | UV+Red | 35 | SP and KL dataset |
| *Banksia serrata L.f.* | Banksia | Proteaceae | ST | EN | bird-marsupial | vertebrate | UV-Yellow | 36; 322 | SP and KL dataset |
| *Barringtonia racemosa (L.) Spreng.* | Barringtonia | Lecythidaceae | ST | EN | bat-moth | vertebrate-insects | UV+White | 37; 288 | SP and KL dataset |
| *Bauhinia variegata L.* | Bauhinia | Fabaceae | P | EN | bird-moth | vertebrate-insects | UV+Pink | 38; 353 | SP and KL dataset |
| *Begonia boliviensis A.DC.* | Begonia | Begoniaceae | P | G | bee-wasp | bee | UV+Red | 39 | SP and KL dataset |
| *Begonia coccinea Hook.* | Begonia | Begoniaceae | P | G | bee | bee | UV+White | 40;344 | SP and KL dataset |
| *Begonia microsperma Warb.* | Begonia | Begoniaceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 17 | SP and KL dataset |
| *Begonia minor Jacq.* | Begonia | Begoniaceae | P | EN | bee-beetle-fly | bee-insects | UV-Red | 17 | SP and KL dataset |
| *Begonia sericoneura Liebm.* | Begonia | Begoniaceae | P | N | bee-beetle-fly | bee-insects | UV+White | 17 | SP and KL dataset |
| *Bellis perennis L.* | Bellis | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV+White | 41 | SP and KL dataset |
| *Berberis darwinii Hook.* | Berberis | Berberidaceae | P | EN | bee | bee | UV+Yellow | 42; 303 | SP and KL dataset |
| *Bidens ferulifolia (Jacq.) Sweet* | Bidens | Asteraceae | P | EN | bee | bee | UV+Yellow | 43; 316 | SP and KL dataset |
| *Billbergia amoena (Lodd.) Lindl.* | Billbergia | Bromeliaceae | P | N | bird | bird | UV+Green | 44; 301 | SP and KL dataset |
| *Billbergia nutans H.Wendl. ex Regel* | Billbergia | Bromeliaceae | B | G | bird | bird | UV-Red | 16 | SP and KL dataset |
| *Billbergia pyramidalis (Sims) Lindl.* | Billbergia | Bromeliaceae | B | G | bird | bird | UV-Red | 45; 1 | Coimbra et al. 2020 |
| *Billbergia viridiflora H.Wendl.* | Billbergia | Bromeliaceae | B | N | bird | bird | UV+Red | 16 | SP and KL dataset |
| *Persicaria amplexicaulis (D.Don) Ronse Decr.* | Bistorta | Polygonaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+Pink | 2 | SP and KL dataset |
| *Brownea grandiceps Jacq.* | Brownea | Fabaceae | P | G | bird | bird | UV+Red | 46 | SP and KL dataset |
| *Brugmansia arborea (L.) Steud.* | Brugmansia | Solanaceae | P | G | moth | moth | UV-White | 47; 285 | SP and KL dataset |
| *Brunfelsia americana L.* | Brunfelsia | Solanaceae | P | G | moth-butterfly | insects | UV+White | 48 | SP and KL dataset |
| *Brunfelsia uniflora (Pohl) D.Don* | Brunfelsia | Solanaceae | P | N | moth-butterfly | insects | UV-Blue | 49; 348 | SP and KL dataset |
| *Buddleja davidii Franch.* | Buddleja | Scrophulariaceae | P | EN | butterfly | butterfly | UV+Pink | 50;306;307;308;309 | SP and KL dataset |
| *Byrsonima verbascifolia (L.) DC.* | Byrsonima | Malpighiaceae | P | N | bee | bee | UV+Yellow | 51 | SP and KL dataset |
| *Calanthe vestita Wall. ex Lindl.* | Calanthe | Orchidaceae | P | EN | bee | bee | UV-White | 16 | SP and KL dataset |
| *Calendula arvensis M.Bieb.* | Calendula | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Calicotome villosa (Poir.) Link* | Calicotome | Fabaceae | P | EN | bee | bee | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Calliandra haematocephala Hassk.* | Calliandra | Fabaceae | ST | G | bird-bee | vertebrate-insects | UV+Red | 17 | SP and KL dataset |
| *Calliandra brevipes Benth.* | Calliandra | Fabaceae | ST | N | bird-bee | vertebrate-insects | UV+Pink | 12 | SP and KL dataset |
| *Calliandra tweedii Benth.* | Calliandra | Fabaceae | ST | N | bird-bee | vertebrate-insects | UV+Red | 12 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Callianthe megapotamica (A.Spreng.) Dorr* | Callianthe | Malvaceae | P | G | bird | bird | UV-Yellow | 52 | SP and KL dataset |
| *Callianthe picta (Gillies ex Hook. & Arn.) Donnell* | Callianthe | Malvaceae | P | G | bird | bird | UV-Red | 53 | SP and KL dataset |
| *Callistemon citrinus (Curtis) Skeels* | Callistemon | Myrtaceae | ST | EN | bird-bee-butterfly-wasp | vertebrate-insects | UV+Red | 54 | SP and KL dataset |
| *Callistemon viminalis (Sol. ex Gaertn.) G.Don* | Callistemon | Myrtaceae | ST | EN | bird | bird | UV+Red | 2 | SP and KL dataset |
| *Callopsis volkensii Engl.* | Callopsis | Araceae | P | EN | beetle-fly | insects | UV-White | 16 | SP and KL dataset |
| *Calluna vulgaris (L.) Hull* | Calluna | Ericaceae | P | EN | bee-beetle-fly | bee-insects | UV+Pink | 1 | Coimbra et al. 2020 |
| *Calvoa orientalis Taub.* | Calvoa | Melastomataceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+Pink | 2 | SP and KL dataset |
| *Camellia japonica L.* | Camellia | Theaceae | P | EN | bird | bird | UV+Pink | 55 | SP and KL dataset |
| *Camellia sasanqua Thunb.* | Camellia | Theaceae | P | EN | bird | bird | UV-Pink | 56; 17 | SP and KL dataset |
| *Camellia sinensis (L.) Kuntze* | Camellia | Theaceae | P | G | bee | bee | UV+White | 17 | SP and KL dataset |
| *Campanula cochleariifolia Lam.* | Campanula | Campanulaceae | P | EN | bee | bee | UV+Blue | 57; 325 | SP and KL dataset |
| *Campanula poscharskyana Degen* | Campanula | Campanulaceae | P | EN | bee | bee | UV+Blue | 58 | SP and KL dataset |
| *Campsis grandiflora (Thunb.) K.Schum.* | Campsis | Bignoniaceae | P | EN | bee | bee | UV+Red | 59 | SP and KL dataset |
| *Campsis radicans (L.) Seem.* | Campsis | Bignoniaceae | P | EN | bird | bird | UV-Red | 17 | SP and KL dataset |
| *Canarina canariensis (L.) Vatke* | Canarina | Campanulaceae | P | EN | bird | bird | UV+Red | 60 | SP and KL dataset |
| *Cantua buxifolia Juss. ex Lam.* | Cantua | Polemoniaceae | P | G | bird | bird | UV+Pink | 61; 17 | SP and KL dataset |
| *Capsella bursa-pastoris (L.) Medik.* | Capsella | Brassicaceae | P | EN | bee-fly | bee-insects | UV+White | 1 | Coimbra et al. 2020 |
| *Cardamine pratensis L.* | Cardamine | Brassicaceae | P | EN | bee-butterfly | bee-insects | UV-White | 62 | SP and KL dataset |
| *Caryocar brasiliense A.St.-Hil.* | Caryocar | Caryocaraceae | P | N | bird-bat-moth | vertebrate-insects | UV+White | 63 | SP and KL dataset |
| *Ceiba erianthos (Cav.) K.Schum.* | Ceiba | Malvaceae | P | N | bat | bat | UV-White | 64; 386 | SP and KL dataset |
| *Centaurea aegyptiaca L.* | Centaurea | Asteraceae | P | EN | bee | bee | UV+White | 1 | Coimbra et al. 2020 |
| *Centaurea ammocyanus Boiss.* | Centaurea | Asteraceae | P | EN | bee | bee | UV+Pink | 1 | Coimbra et al. 2020 |
| *Centaurea pallescens Delile* | Centaurea | Asteraceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Centranthus ruber (L.) DC.* | Centranthus | Caprifoliaceae | P | EN | butterfly | butterfly | UV+Red | 65; 52 | SP and KL dataset |
| *Centropogon cornutus (L.) Druce* | Centropogon | Campanulaceae | P | G | bird | bird | UV-Red | 66 | SP and KL dataset |
| *Centropogon valerii Standl.* | Centropogon | Campanulaceae | P | N | bird | bird | UV-Red | 66 | SP and KL dataset |
| *Cercis siliquastrum L.* | Cercis | Fabaceae | P | EN | bee | bee | UV-Pink | 1 | Coimbra et al. 2020 |
| *Ceropegia dichotoma Haw.* | Ceropegia | Apocynaceae | P | EN | fly | fly | UV+Yellow | 67 | SP and KL dataset |
| *Cestrum elegans (Brongn. ex Neumann) Schltdl.* | Cestrum | Solanaceae | P | G | bird-butterfly-moth | vetebrate-insects | UV+Red | 68; 319 | SP and KL dataset |
| *Cestrum parqui (Lam.) L'HÃ©r.* | Cestrum | Solanaceae | P | EN | bird-butterfly-moth | vetebrate-insects | UV-Yellow | 68; 319 | SP and KL dataset |
| *Chaenomeles japonica (Thunb.) Lindl. ex Spach* | Chaenomeles | Rosaceae | P | EN | bee | bee | UV-Red | 69 | SP and KL dataset |
| *Chasmanthe aethiopica (L.) N.E.Br.* | Chasmanthe | Iridaceae | P | EN | bird | bird | UV+Red | 70; 321 | SP and KL dataset |
| *Chelone lyonii Pursh* | Chelone | Plantaginaceae | P | EN | bee | bee | UV+Pink | 71 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Cirsium eriophorum (L.) Scop.* | Cirsium | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV+Pink | 72; 380 | SP and KL dataset |
| *Cirsium oleraceum (L.) Scop.* | Cirsium | Asteraceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Cistus creticus (Viv.) Greuter & Burdet* | Cistus | Cistaceae | P | EN | bee | bee | UV-Pink | 73; 375 | SP and KL dataset |
| *Cistus inflatus Pourr. ex J.-P.Demoly* | Cistus | Cistaceae | P | EN | bee | bee | UV-White | 74 | SP and KL dataset |
| *Citrus aurantium L.* | Citrus | Rutaceae | P | G | bird | bird | UV-White | 75; 292 | SP and KL dataset |
| *Cleome spinosa Jacq.* | Cleome | Cleomaceae | P | G | bat | bat | UV+Pink | 76; 332 | SP and KL dataset |
| *Clerodendrum thomsoniae Balf.f.* | Clerodendrum | Lamiaceae | P | G | butterfly | butterfly | UV+Red | 12 | SP and KL dataset |
| *Clerodendrum trichotomum Thunb.* | Clerodendrum | Lamiaceae | P | EN | butterfly | butterfly | UV+White | 12 | SP and KL dataset |
| *Clidemia hirta (L.) D. Don* | Clidemia | Melastomataceae | P | EN | bee | bee | UV-White | 12; 300 | SP and KL dataset |
| *Clusia lanceolata Cambess.* | Clusia | Clusiaceae | P | N | bee | bee | UV+White | 77 | SP and KL dataset |
| *Clytostoma callistegioides (Cham.) Baill.* | Clytostoma | Bignoniaceae | P | G | bee | bee | UV-Pink | 78 | SP and KL dataset |
| *Cobaea scandens Cav.* | Cobaea | Polemoniaceae | P | N | bat | bat | UV+Pink | 79; 289; 290 | SP and KL dataset |
| *Cochlospermum vitifolium (Willd.) Spreng.* | Cochlospermum | Bixaceae | P | N | bee | bee | UV+Yellow | 80; 368; 369 | SP and KL dataset |
| *Codiaeum variegatum (L.) Rumph. ex A.Juss.* | Codiaeum | Euphorbiaceae | ST | EN | bee-beetle-butterfly-fly | bee-insects | UV-White | 81 | SP and KL dataset |
| *Codonanthe gracilis (Mart.) Hanst.* | Codonanthe | Gesneriaceae | P | N | bee | bee | UV+White | 17 | SP and KL dataset |
| *Codonanthopsis crassifolia* | Codonanthe | Gesneriaceae | P | N | moth | moth | UV+White | 82 | SP and KL dataset |
| *Coelogyne cristata Lindl.* | Coelogyne | Orchidaceae | P | EN | moth | moth | UV+White | 83 | SP and KL dataset |
| *Coleonema album (Thunb.) Bartl. & H.L.Wendl.* | Coleonema | Rutaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+White | 84 | SP and KL dataset |
| *Collaea argentina Griseb.* | Collaea | Fabaceae | P | N | bee | bee | UV+Pink | 85 | SP and KL dataset |
| *Columnea magnifica Klotzsch ex Oerst.* | Columnea | Gesneriaceae | P | N | bird | bird | UV+Red | 86;10 | SP and KL dataset |
| *Columnea microcalyx Hanst.* | Columnea | Gesneriaceae | P | N | bird | bird | UV-Red | 86 | SP and KL dataset |
| *Columnea scandens L.* | Columnea | Gesneriaceae | P | G | bird | bird | UV-Red | 87 | SP and KL dataset |
| *Convolvulus arvensis L.* | Convolvulus | Convolvulaceae | P | EN | bee-fly | bee-insects | UV-White | 88 | SP and KL dataset |
| *Coreopsis grandiflora Hogg ex Sweet* | Coreopsis | Asteraceae | P | EN | bee | bee | UV-Yellow | 89 | SP and KL dataset |
| *Corylus avellana L.* | Corylus | Bertulaceae | P | EN | bee | bee | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Corymbia ficifolia (F.Muell.) K.D.Hill & L.A.S.Johnson* | Corymbia | Myrtaceae | ST | EN | bird | bird | UV-Red | 90 | SP and KL dataset |
| *Costus afer Ker Gawl.* | Costus | Costaceae | P | EN | bee | bee | UV+White | 42;91 | SP and KL dataset |
| *Costus erythrophyllus Loes.* | Costus | Costaceae | P | N | bee | bee | UV+White | 92 | SP and KL dataset |
| *Costus lucanusianus J.Braun & K.Schum.* | Costus | Costaceae | P | EN | bird-bee | vertebrate-insects | UV+Red | 93 | SP and KL dataset |
| *Costus malortieanus H.Wendl.* | Costus | Costaceae | P | G | bee | bee | UV+Yellow | 94 | SP and KL dataset |
| *Costus pulverulentus C.Presl* | Costus | Costaceae | P | N | bee | bee | UV+Red | 94 | SP and KL dataset |
| *Costus spicatus (Jacq.) Sw.* | Costus | Costaceae | P | N | bird | bird | UV-Pink | 94 | SP and KL dataset |
| *Crataegus azarolus L.* | Crataegus | Rosaceae | P | EN | bee-beetle-fly | bee-insects | UV-White | 1 | Coimbra et al. 2020 |

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|---|---|---|---|---|---|---|---|---|---|
| *Crepis aspera L.* | Crepis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Crepis hierosolymitana Boiss.* | Crepis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Crepis sancta (L.) Bornm.* | Crepis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Crinodendron patagua Molina* | Crinodendron | Elaeocarpaceae | P | N | bee | bee | UV-White | 95 | SP and KL dataset |
| *Crocus angustifolius Weston* | Crocus | Iridaceae | P | EN | bee-fly | bee-insects | UV-Yellow | 96 | SP and KL dataset |
| *Crocus flavus Weston* | Crocus | Iridaceae | P | EN | bee-fly | bee-insects | UV-Yellow | 44;96 | SP and KL dataset |
| *Crotalaria agatiflora Schweinf.* | Crotalaria | Fabaceae | P | EN | bird | bird | UV+Green | 97; 187 | SP and KL dataset |
| *Cuphea ignea A.DC.* | Cuphea | Lythraceae | P | G | bird-butterfly | vertebrate-insects | UV-Red | 98 | SP and KL dataset |
| *Cuphea lanceolata W.T.Aiton* | Cuphea | Lythraceae | P | G | bee-butterfly-fly | bee-insects | UV+Pink | 99 | SP and KL dataset |
| *Curcuma longa L.* | Curcuma | Zingiberaceae | P | G | bee | bee | UV+White | 100 | SP and KL dataset |
| *Cyclamen hederifolium Aiton* | Cyclamen | Primulaceae | P | EN | bee-fly | bee-insects | UV-White | 101 | SP and KL dataset |
| *Cyclamen persicum Mill.* | Cyclamen | Primulaceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Dahlstedtia pinnata (Benth.) Malme* | Dahlstedtia | Fabaceae | P | N | bird | bird | UV+Pink | 45 | Coimbra et al. 2020 |
| *Dalechampia spathulata (Scheidw.) Baill.* | Dalechampia | Euphorbiaceae | L | N | bee | bee | UV+Pink | 104; 2 | SP and KL dataset |
| *Deherainia smaragdina (Planch. ex Linden) Decne.* | Deherainia | Primulaceae | P | N | fly | fly | UV+Green | 105; 327 | SP and KL dataset |
| *Dendrobium nobile Lindl.* | Dendrobium | Orchidaceae | P | EN | bee | bee | UV-Pink | 16 | SP and KL dataset |
| *Desfontainia spinosa Ruiz & Pav.* | Desfontainia | Columelliaceae | P | N | bird | bird | UV-Red | 107; 327 | SP and KL dataset |
| *Deuterocohnia meziana Kuntze ex Mez* | Deuterocohnia | Bromeliaceae | P | N | bird-bee | vertebrate-insects | UV-Red | 108 | SP and KL dataset |
| *Dianthus carthusianorum L.* | Dianthus | Caryophyllaceae | P | EN | bee-butterfly | bee-insects | UV-Pink | 1 | Coimbra et al. 2020 |
| *Dianthus superbus L.* | Dianthus | Caryophyllaceae | P | EN | bee | bee | UV+White | 109 | SP and KL dataset |
| *Dianthus sylvestris Wulfen* | Dianthus | Caryophyllaceae | P | EN | butterfly- moth | insects | UV+Pink | 110;304 | SP and KL dataset |
| *Dichorisandra thyrsiflora J.C.Mikan* | Dichorisandra | Commelinaceae | P | EN | bee | bee | UV+Blue | 255; 370; 371 | SP and KL dataset |
| *Isoplexis canariensis (L.) Loudon* | Digitalis | Plantaginaceae | P | EN | bird-lizard | vertebrate | UV-Red | 210 | SP and KL dataset |
| *Digitalis parviflora Jacq.* | Digitalis | Plantaginaceae | P | EN | bee | bee | UV-Red | 210 | SP and KL dataset |
| *Digitalis purpurea L.* | Digitalis | Plantaginaceae | P | EN | bee | bee | UV+Pink | 210 | SP and KL dataset |
| *Duranta erecta L.* | Duranta | Verbenaceae | P | EN | bee | bee | UV-Blue | 237; 351 | SP and KL dataset |
| *Dyckia brevifolia Baker* | Dyckia | Bromeliaceae | P | N | bird-bee | vertebrate-insects | UV-Yellow | 239 | SP and KL dataset |
| *Echium angustifolium Mill.* | Echium | Boraginaceae | P | EN | bee | bee | UV-Pink | 1 | Coimbra et al. 2020 |
| *Echium candicans L.f.* | Echium | Boraginaceae | P | EN | bee | bee | UV-Blue | 271 | SP and KL dataset |
| *Echium hierrense Webb ex Bolle* | Echium | Boraginaceae | P | EN | bee | bee | UV+Pink | 140 | SP and KL dataset |
| *Echium rauwolfii Delile* | Echium | Boraginaceae | P | EN | bee | bee | UV+Pink | 1 | Coimbra et al. 2020 |
| *Echium vulgare L.* | Echium | Boraginaceae | P | EN | bee | bee | UV+Blue | 47;30 | SP and KL dataset |
| *Eichhornia azurea (Sw.) Kunth* | Eichhornia | Pontederiaceae | P | N | bee | bee | UV-Blue | 117; 291 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Emilia coccinea (Sims) G.Don* | Emilia | Asteraceae | P | EN | bee | bee | UV+White | 186 | SP and KL dataset |
| *Entelea arborescens R.Br.* | Entelea | Malvaceae | P | EN | bee | bee | UV-White | 125 | SP and KL dataset |
| *Epimedium versicolor E.Morren* | Epimedium | Berberidaceae | P | EN | bee | bee | UV+Yellow | 260 | SP and KL dataset |
| *Eremurus stenophyllus (Boiss. & Buhse) Baker* | Eremurus | Asphodelaceae | P | EN | bee | bee | UV+Yellow | 16 | SP and KL dataset |
| *Erica caffra L.* | Erica | Ericaceae | P | EN | bee | bee | UV+White | 17; 299 | SP and KL dataset |
| *Erica mammosa L.* | Erica | Ericaceae | P | EN | bird | bird | UV+White | 236 | SP and KL dataset |
| *Erica versicolor Andrews* | Erica | Ericaceae | P | EN | bird | bird | UV-Red | 236 | SP and KL dataset |
| *Erigeron canadensis L.* | Erigeron | Asteraceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Eriobotrya japonica (Thunb.) Lindl.* | Eriobotrya | Rosaceae | P | EN | bird | bird | UV-White | 207 | SP and KL dataset |
| *Erysimum cheiranthoides L.* | Erysimum | Brassicaceae | P | EN | bee-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Erythrina crista-galli L.* | Erythrina | Fabaceae | P | EN | bird-bee | vertebrate-insects | UV+Red | 152; 68 | SP and KL dataset |
| *Erythrina falcata Benth.* | Erythrina | Fabaceae | P | N | bird | bird | UV-Red | 143; 310 | Coimbra et al. 2020 |
| *Erythrina fusca Lour.* | Erythrina | Fabaceae | P | G | bird | bird | UV+White | 209; 339 | Coimbra et al. 2020 |
| *Erythrina humeana Spreng.* | Erythrina | Fabaceae | P | G | bird | bird | UV-Red | 17 | SP and KL dataset |
| *Erythrina speciosa Andrews* | Erythrina | Fabaceae | P | N | bird | bird | UV+Red | 45 | Coimbra et al. 2020 |
| *Erythrochiton brasiliensis Nees & Mart.* | Erythrochiton | Rutaceae | P | N | bird | bird | UV+White | 192 | SP and KL dataset |
| *Erythronium oregonum Applegate* | Erythronium | Liliaceae | P | EN | bee | bee | UV+White | 217 | SP and KL dataset |
| *Eschscholzia californica Cham.* | Eschscholzia | Papaveraceae | P | EN | bee | bee | UV-Yellow | 280 | SP and KL dataset |
| *Etlingera elatior (Jack) R.M.Sm.* | Etlingera | Zingiberaceae | P | EN | bird-bee | vertebrate-insects | UV-Red | 242; 352 | SP and KL dataset |
| *Eucomis comosa (Houtt.) Wehrh.* | Eucomis | Asparagaceae | P | EN | bee-beetle-fly-wasp | bee-insects | UV-White | 251; 362 | SP and KL dataset |
| *Euphorbia atropurpurea Brouss. ex Willd.* | Euphorbia | Euphorbiaceae | P | EN | fly | fly | UV+Pink | 2 | SP and KL dataset |
| *Euphorbia hierosolymitana Boiss.* | Euphorbia | Euphorbiaceae | P | EN | fly | fly | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Euphorbia pulcherrima Willd. ex Klotzsch* | Euphorbia | Euphorbiaceae | B | N | bird | bird | UV-Red | 207; 7 | SP and KL dataset |
| *Euryops pectinatus (L.) Cass.* | Euryops | Asteraceae | P | EN | bee-fly | bee-insects | UV+Yellow | 130;305 | SP and KL dataset |
| *Fosterella penduliflora (C.H.Wright) L.B.Sm.* | Fosterella | Bromeliaceae | P | N | bee | bee | UV-White | 16 | SP and KL dataset |
| *Freycinetia cumingiana Gaudich.* | Freycinetia | Pandanaceae | B | EN | bird | bird | UV+Red | 135 | SP and KL dataset |
| *Freylinia lanceolata (L.) G.Don* | Freylinia | Scrophulariaceae | P | EN | bee | bee | UV-Yellow | 214;268 | SP and KL dataset |
| *Fuchsia boliviana CarriÃ¨re* | Fuchsia | Onagraceae | P | N | bird | bird | UV+Red | 52; 2 | SP and KL dataset |
| *Fuchsia loxensis Kunth* | Fuchsia | Onagraceae | SP | N | bird | bird | UV+Pink | 2 | SP and KL dataset |
| *Fuchsia magdalenae Munz* | Fuchsia | Onagraceae | P | N | bird | bird | UV+Red | 2 | SP and KL dataset |
| *Fuchsia microphylla Kunth* | Fuchsia | Onagraceae | P | G | bird | bird | UV+Pink | 114 | SP and KL dataset |
| *Fuchsia paniculata Lindl.* | Fuchsia | Onagraceae | P | G | bird | bird | UV+Pink | 2 | SP and KL dataset |
| *Fuchsia regia (Vand. ex Vell.) Munz* | Fuchsia | Onagraceae | P | N | bird | bird | UV-Red | 253 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Fuchsia vulcanica AndrÃ©* | Fuchsia | Onagraceae | P | N | bird | bird | UV-Red | 2 | SP and KL dataset |
| *Galium verum L.* | Galium | Rubiaceae | P | EN | bee | bee | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Gardenia jasminoides J.Ellis* | Gardenia | Rubiaceae | P | G | moth | moth | UV+White | 266; 381; 382 | SP and KL dataset |
| *Gasteria pulchra (Aiton) Haw.* | Gasteria | Asphodelaceae | P | EN | bird | bird | UV-Red | 170 | Coimbra et al. 2020 |
| *Gazania heterochaeta DC.* | Gazania | Asteraceae | P | EN | beetle | beetle | UV-Red | 1 | Coimbra et al. 2020 |
| *Gentiana acaulis L.* | Gentiana | Gentianaceae | P | EN | bee | bee | UV+Blue | 112 | SP and KL dataset |
| *Gentiana asclepiadea L.* | Gentiana | Gentianaceae | P | EN | bee | bee | UV+Blue | 218 | SP and KL dataset |
| *Gerbera jamesonii Bolus ex Hook.f.* | Gerbera | Asteraceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV-Red | 134 | SP and KL dataset |
| *Gesneria ventricosa Sw.* | Gesneria | Gesneriaceae | P | N | bird | bird | UV-Red | 17 | SP and KL dataset |
| *Gloriosa superba L.* | Gloriosa | Colchicaceae | P | EN | bird-bee | vertebrate-insects | UV+Red | 234; 350 | SP and KL dataset |
| *Gomphocarpus physocarpus E.Mey.* | Gomphocarpus | Apocynaceae | P | G | wasp | bee | UV+White | 149; 314;315 | SP and KL dataset |
| *Gossypium herbaceum L.* | Gossypium | Malvaceae | P | G | bee | bee | UV+White | 208 | SP and KL dataset |
| *Grevillea banksii R.Br.* | Grevillea | Proteaceae | P | G | bird | bird | UV-Red | 148; 2 | SP and KL dataset |
| *Grevillea rosmarinifolia A.Cunn.* | Grevillea | Proteaceae | P | EN | bird | bird | UV+Pink | 148; 2 | SP and KL dataset |
| *Greyia sutherlandii Hook. & Harv.* | Greyia | Francoaceae | P | EN | bird | bird | UV+Red | 211; 341 | SP and KL dataset |
| *Cleome gynandra L.* | Gynandropsis | Cleomaceae | P | G | bee-butterfly-fly | bee-insects | UV+White | 111 | SP and KL dataset |
| *Gypsophila arabica Barkoudak* | Gypsophila | Caryophyllaceae | P | EN | beetle-fly | insects | UV+White | 1 | Coimbra et al. 2020 |
| *Gypsophila repens L.* | Gypsophila | Caryophyllaceae | P | EN | bee-fly | bee-insects | UV-White | 193 | SP and KL dataset |
| *Hamelia patens Jacq.* | Hamelia | Rubiaceae | P | EN | bird-butterfly | vertebrate-insects | UV+Red | 40; 221; 345 | SP and KL dataset |
| *Handroanthus heptaphyllus (Vell.) Mattos* | Handroanthus | Bignoniaceae | P | G | bee | bee | UV-Pink | 199 | SP and KL dataset |
| *Hedychium coccineum Buch.-Ham. ex Sm.* | Hedychium | Zingiberaceae | P | G | butterfly | butterfly | UV+Red | 153 | SP and KL dataset |
| *Hedychium coronarium J.Koenig* | Hedychium | Zingiberaceae | P | EN | moth | moth | UV+White | 177 | SP and KL dataset |
| *Hedychium gardnerianum Sheppard ex Ker Gawl.* | Hedychium | Zingiberaceae | P | EN | moth | moth | UV+Yellow | 178 | SP and KL dataset |
| *Heliconia angusta Vell.* | Heliconia | Heliconiaceae | B | G | bird | bird | UV+Red | 45 | SP and KL dataset |
| *Heliconia bihai (L.) L.* | Heliconia | Heliconiaceae | B | N | bird | bird | UV+Red | 158 | SP and KL dataset |
| *Heliconia farinosa Raddi* | Heliconia | Heliconiaceae | B | N | bird | bird | UV-Red | 258 | SP and KL dataset |
| *Heliconia metallica Planch. & Linden ex Hook.* | Heliconia | Heliconiaceae | P | G | bird | bird | UV-Red | 246 | Coimbra et al. 2020 |
| *Heliconia rostrata Ruiz & Pav.* | Heliconia | Heliconiaceae | P | G | bird | bird | UV+Red | 45 | SP and KL dataset |
| *Hellenia speciosa (J.Koenig) S.R.Dutta* | Hellenia | Costaceae | P | G | bee | bee | UV+White | 242 | SP and KL dataset |
| *Hesperis pendula DC.* | Hesperis | Brassicaceae | P | EN | bee | bee | UV-Green | 1 | Coimbra et al. 2020 |
| *Heterocentron elegans (Schltdl.) Kuntze* | Heterocentron | Melastomataceae | P | N | bee | bee | UV+Pink | 238 | SP and KL dataset |
| *Hibiscus pedunculatus L. f.* | Hibiscus | Malvaceae | P | EN | butterfly | butterfly | UV-Pink | 273 | SP and KL dataset |
| *Hibiscus sabdariffa L.* | Hibiscus | Malvaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV-White | 216 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Hibiscus schizopetalus (Dyer) Hook.f.* | Hibiscus | Malvaceae | P | G | bird | bird | UV+Red | 51 | SP and KL dataset |
| *Hieracium laevigatum Froel.* | Hieracium | Asteraceae | P | EN | bee-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Hieracium sabaudum L.* | Hieracium | Asteraceae | P | EN | bee-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Hippobroma longiflora (L.) G.Don* | Hippobroma | Campanulaceae | P | N | fly | fly | UV+White | 240 | SP and KL dataset |
| *Hoffmannia refulgens (Hook.) Hemsl.* | Hoffmannia | Rubiaceae | P | N | bee | bee | UV+Red | 17 | SP and KL dataset |
| *Hypenia reticulata (Mart. ex Benth.) Harley* | Hypenia | Lamiaceae | P | N | bird-bee | vertebrate-insects | UV+Red | 115 | SP and KL dataset |
| *Hypericum balearicum L.* | Hypericum | Hypericaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+Yellow | 262 | SP and KL dataset |
| *Hypericum maculatum Crantz* | Hypericum | Hypericaceae | P | EN | bee | bee | UV+Yellow | 165 | SP and KL dataset |
| *Impatiens burtonii Hook.f.* | Impatiens | Balsamiaceae | P | EN | bee-fly | bee-insects | UV+White | 160; 156 | SP and KL dataset |
| *Impatiens niamniamensis Gilg* | Impatiens | Balsamiaceae | P | EN | bird | bird | UV-Yellow | 52; 2 | SP and KL dataset |
| *Impatiens noli-tangere L.* | Impatiens | Balsamiaceae | P | EN | bird | bird | UV+Yellow | 229; 2 | SP and KL dataset |
| *Impatiens scabrida DC.* | Impatiens | Balsamiaceae | P | EN | bee | bee | UV-Yellow | 229; 2 | SP and KL dataset |
| *Incarvillea delavayi Bureau & Franch.* | Incarvillea | Bignoniaceae | P | EN | bee | bee | UV+Pink | 137 | SP and KL dataset |
| *Inga sessilis (Vell.) Mart.* | Inga | Fabaceae | ST | N | bat | bat | UV-White | 142 | SP and KL dataset |
| *Inga vera Willd.* | Inga | Fabaceae | ST | G | bat-bird-moth | vertebrate-insects | UV+White | 282 | SP and KL dataset |
| *Ipomoea squamosa Choisy* | Ipomoea | Convolvulaceae | P | G | bee-beetle | bee-insects | UV+Pink | 1 | Coimbra et al. 2020 |
| *Iris domestica (L.) Goldblatt & Mabb.* | Iris | Iridaceae | P | EN | bee | bee | UV-Red | 190 | SP and KL dataset |
| *Isatis lusitanica L.* | Isatis | Brassicaceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Jasminum polyanthum Franch.* | Jasminum | Oleaceae | P | EN | moth | moth | UV+White | 127 | SP and KL dataset |
| *Jatropha podagrica Hook.* | Jatropha | Euphorbiaceae | P | EN | bird | bird | UV-Red | 2 | SP and KL dataset |
| *Kennedia coccinea Vent.* | Kennedia | Fabaceae | P | EN | bird | bird | UV-Red | 194 | SP and KL dataset |
| *Knautia arvensis (L.) Coult.* | Knautia | Caprifoliaceae | P | EN | bee-butterfly | bee-insects | UV-Pink | 1 | Coimbra et al. 2020 |
| *Knautia dipsacifolia Kreutzer* | Knautia | Caprifoliaceae | P | EN | butterfly | butterfly | UV-Pink | 1 | Coimbra et al. 2020 |
| *Kniphofia uvaria (L.) Oken* | Kniphofia | Asphodelaceae | P | EN | bird | bird | UV-Red | 274; 2 | SP and KL dataset |
| *Kohleria spicata (Kunth) Oerst.* | Kohleria | Gesneriaceae | P | N | bird | bird | UV+Red | 201 | SP and KL dataset |
| *Lamprocapnos spectabilis (L.) Fukuhara* | Lamprocapnos | Papaveraceae | P | EN | bee | bee | UV+Pink | 257; 376; 377 | SP and KL dataset |
| *Lantana camara L.* | Lantana | Verbenaceae | P | N | butterfly | butterfly | UV-Red | 255; 386 | SP and KL dataset |
| *Lapageria rosea Ruiz & Pav.* | Lapageria | Philesiaceae | P | N | bird | bird | UV+Pink | 116 | SP and KL dataset |
| *Lapsana communis L.* | Lapsana | Asteraceae | P | EN | bee-butterfly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Launaea angustifolia (Desf.) Kuntze* | Launaea | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Leopoldia longipes (Boiss.) Losinsk.* | Leopoldia | Asparagaceae | P | EN | bee | bee | UV-Blue | 1 | Coimbra et al. 2020 |
| *Lessertia frutescens (L.) Goldblatt & J.C. Manning* | Lessertia | Fabaceae | P | EN | bird | bird | UV+Red | 249; 361 | SP and KL dataset |
| *Leucospermum glabrum E. Phillips* | Leucospermum | Proteaceae | ST | EN | bird | bird | UV+Yellow | 205 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Leycesteria formosa Wall.* | Leycesteria | Caprifoliaceae | P | EN | bee | bee | UV-White | 17 | SP and KL dataset |
| *Libertia ixioides (G.Forst.) Spreng.* | Libertia | Iridaceae | P | EN | bee | bee | UV-White | 118 | SP and KL dataset |
| *Linum grandiflorum Desf.* | Linum | Linaceae | P | EN | bee | bee | UV+Red | 2 | SP and KL dataset |
| *Lippia lupulina Cham.* | Lippia | Verbenaceae | P | N | butterfly | butterfly | UV+Pink | 267 | SP and KL dataset |
| *Lobelia anceps L.f.* | Lobelia | Campanulaceae | P | EN | bee | bee | UV-Blue | 17 | Coimbra et al. 2020 |
| *Lobelia siphilitica L.* | Lobelia | Campanulaceae | P | EN | bee | bee | UV+Blue | 172 | SP and KL dataset |
| *Lobelia tupa L.* | Lobelia | Campanulaceae | P | N | bird | bird | UV+Red | 206; 17 | SP and KL dataset |
| *Lonicera fragrantissima Lindl. & J. Paxton* | Lonicera | Caprifoliaceae | P | EN | bee | bee | UV+White | 256 | SP and KL dataset |
| *Lotus berthelotii Masf.* | Lotus | Fabaceae | P | EN | bird | bird | UV-Red | 60 | SP and KL dataset |
| *Lycium shawii Roem. & Schult.* | Lycium | Solanaceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Macroptilium atropurpureum (DC.) Urb.* | Macroptilium | Fabaceae | P | G | bee | bee | UV+Black | 272 | SP and KL dataset |
| *Magnolia stellata (Siebold & Zucc.) Maxim.* | Magnolia | Magnoliaceae | P | EN | beetle | beetle | UV-White | 166; 323; 324 | SP and KL dataset |
| *Malouetia arborea (Vell.) Miers* | Malouetia | Apocynaceae | P | N | bee | bee | UV-White | 166; 323; 324 | SP and KL dataset |
| *Malva alcea L.* | Malva | Malvaceae | P | EN | bee | bee | UV+Pink | 181 | SP and KL dataset |
| *Mammillaria sheldonii (Britton & Rose) Boed.* | Mammillaria | Cactaceae | P | N | bee | bee | UV+Pink | 2 | SP and KL dataset |
| *Manettia cordifolia Mart.* | Manettia | Rubiaceae | P | N | bird | bird | UV+Red | 132 | SP and KL dataset |
| *Medinilla magnifica Lindl.* | Medinilla | Melastomataceae | P | EN | bee | bee | UV+Pink | 264 | SP and KL dataset |
| *Melaleuca elliptica Labill.* | Melaleuca | Myrtaceae | ST | EN | bird | bird | UV-Red | 2 | SP and KL dataset |
| *Melaleuca hypericifolia Sm.* | Melaleuca | Myrtaceae | P | EN | bird | bird | UV+Red | 226; 2 | SP and KL dataset |
| *Melaleuca pallida (Bonpl.) Craven* | Melaleuca | Myrtaceae | ST | EN | bee-beetle-wasp | bee-insects | UV+White | 54 | SP and KL dataset |
| *Melaleuca quadrifida (R.Br.) Craven & R.D.Edwards* | Melaleuca | Myrtaceae | ST | EN | bird | bird | UV+Red | 129 | SP and KL dataset |
| *Melastoma malabathricum L.* | Melastoma | Melastomataceae | P | EN | bee | bee | UV-White | 195; 333 | SP and KL dataset |
| *Mesembryanthemum nodiflorum L.* | Mesembryanthemum | Azioaceae | P | EN | beetle-fly | insects | UV-White | 1 | Coimbra et al. 2020 |
| *Mimosa polycarpa Kunth* | Mimosa | Fabaceae | ST | N | bee | bee | UV+Pink | 188 | SP and KL dataset |
| *Mimulus cardinalis Douglas ex Benth.* | Mimulus | Phrymaceae | P | EN | bird | bird | UV+Red | 245; 357; 358; 359 | SP and KL dataset |
| *Mirabilis jalapa L.* | Mirabilis | Nyctaginaceae | P | N | moth | moth | UV+Red | 138 | SP and KL dataset |
| *Moehringia trinervia (L.) Clairv.* | Moehringia | Caryophyllaceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Monolena primuliflora Hook. f.* | Monolena | Melastomataceae | P | N | bee-beetle-butterfly-fly | bee-insects | UV+Pink | 2 | SP and KL dataset |
| *Moricandia nitens (Viv.) E.A.Durand & Barratte* | Moricandia | Brassicaceae | P | EN | bee | bee | UV+Pink | 1 | Coimbra et al. 2020 |
| *Musa paradisiaca L.* | Musa | Musaceae | B | N | bat | bat | UV+Red | 219; 343 | SP and KL dataset |
| *Ensete lasiocarpum (Franch.) Cheesman* | Musella | Musaceae | B | EN | bee | bee | UV+Yellow | 189 | SP and KL dataset |
| *Mussaenda frondosa L.* | Mussaenda | Rubiaceae | B | EN | bee-bird-butterfly | vertebrate-insects | UV-Red | 123 | SP and KL dataset |
| *Mutisia acuminata Ruiz & Pav.* | Mutisia | Asteraceae | P | N | bird | bird | UV+Yellow | 204 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Mutisia acuminata Ruiz & Pav.* | Mutisia | Asteraceae | P | N | bird | bird | UV+Red | 203 | SP and KL dataset |
| *Mutisia coccinea A.St.-Hil.* | Mutisia | Asteraceae | P | N | bird | bird | UV-Red | 244; 356 | SP and KL dataset |
| *Myosotis decumbens Host* | Myosotis | Boraginaceae | P | EN | fly | fly | UV-Blue | 1 | Coimbra et al. 2020 |
| *Myosotis stricta Link ex Roem. & Schult.* | Myosotis | Boraginaceae | P | EN | bee-fly | bee-insects | UV+Blue | 1 | Coimbra et al. 2020 |
| *Myosotis vestergrenii Stroh* | Myosotis | Boraginaceae | P | EN | fly | fly | UV-Blue | 1 | Coimbra et al. 2020 |
| *Nanorrhinum scoparium* | Nanorrhinum | Plantaginaceae | P | EN | bee | bee | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Napaea dioica L.* | Napaea | Malvaceae | P | EN | bee | bee | UV+White | 169 | SP and KL dataset |
| *Neoregelia cruenta (Graham) L.B.Sm.* | Neoregelia | Bromeliaceae | P | N | bird | bird | UV-Blue | 146 | Coimbra et al. 2020 |
| *Nerine sarniensis (L.) Herb.* | Nerine | Amaryllidaceae | P | EN | bee | bee | UV-Red | 16 | SP and KL dataset |
| *Nicotiana rustica L.* | Nicotiana | Solanaceae | P | G | bee | bee | UV+Yellow | 17 | SP and KL dataset |
| *Nymphoides indica (L.) Kuntze* | Nymphoides | Menyanthaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+White | 250 | SP and KL dataset |
| *Oenothera glazioviana Micheli* | Oenothera | Onagraceae | P | EN | moth | moth | UV+Yellow | 176 | SP and KL dataset |
| *Oenothera lindheimeri Engelm. & A.Gray* | Oenothera | Onagraceae | P | EN | bee | bee | UV+Red | 126 | SP and KL dataset |
| *Oncidium ornithorhynchum Kunth* | Oncidium | Orchidaceae | P | N | bee | bee | UV-Pink | 231; 233 | SP and KL dataset |
| *Opuntia fragilis (Nutt.) Haw.* | Opuntia | Cactaceae | P | EN | bird | bird | UV+Pink | 197 | SP and KL dataset |
| *Ornithogalum candicans (Baker) J.C.Manning & Goldblatt* | Ornithogalum | Asparagaceae | P | EN | bee-bird-fly | vertebrate-insects | UV+White | 133 | SP and KL dataset |
| *Osmanthus delavayi Franch.* | Osmanthus | Oleaceae | P | EN | bee-butterfly-fly-moth | bee-insects | UV+White | 139 | SP and KL dataset |
| *Oxypetalum coccineum Â Griseb* | Oxypetalum | Apocynaceae | P | N | butterfly | butterfly | UV+Red | 26;68 | SP and KL dataset |
| *Pachypodium bispinosum (L.f.) A.DC.* | Pachypodium | Apocynaceae | P | EN | bee | bee | UV+White | 17 | SP and KL dataset |
| *Pachypodium succulentum (L.f.) Sweet* | Pachypodium | Apocynaceae | P | EN | butterfly | butterfly | UV+Pink | 17 | SP and KL dataset |
| *Pandorea jasminoides (Lindl.) K.Schum.* | Pandorea | Bignoniaceae | P | EN | bee | bee | UV+White | 222 | SP and KL dataset |
| *Papaver nudicaule L.* | Papaver | Papaveraceae | P | EN | beetle | beetle | UV-Red | 119 | SP and KL dataset |
| *Papaver orientale L.* | Papaver | Papaveraceae | P | EN | beetle | beetle | UV-Red | 119 | SP and KL dataset |
| *Papaver rhoeas L.* | Papaver | Papaveraceae | P | EN | bee | bee | UV-Red | 1 | Coimbra et al. 2020 |
| *Parnassia palustris L.* | Parnassia | Parnassiaceae | P | EN | butterfly-fly | insects | UV-White | 1 | Coimbra et al. 2020 |
| *Passiflora citrina J.M.MacDougal* | Passiflora | Passifloraceae | P | N | bee | bee | UV+Yellow | 196 | SP and KL dataset |
| *Passiflora edulis Sims* | Passiflora | Passifloraceae | P | N | bee | bee | UV-White | 255; 373 | SP and KL dataset |
| *Paullinia cupana Kunth* | Paullinia | Sapindaceae | P | G | bee | bee | UV-White | 248; 360 | SP and KL dataset |
| *Pavonia multiflora A. St.-Hil.* | Pavonia | Malvaceae | SP | N | bird | bird | UV-Red | 17 | SP and KL dataset |
| *Pelargonium crithmifolium Sm.* | Pelargonium | Geraniaceae | P | EN | bee | bee | UV+White | 259; 2 | SP and KL dataset |
| *Pelargonium echinatum Curtis* | Pelargonium | Geraniaceae | P | EN | bee-moth | bee-insects | UV+White | 213 | SP and KL dataset |
| *Pelargonium oblongatum E. Mey. ex Harv.* | Pelargonium | Geraniaceae | P | EN | bee-butterfly-fly | bee-insects | UV+White | 199 | SP and KL dataset |
| *Pelargonium tetragonum L'HÃ©r.* | Pelargonium | Geraniaceae | P | EN | fly | fly | UV+White | 259; 2 | SP and KL dataset |

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| *Penstemon pinifolius Greene* | Penstemon | Plantaginaceae | P | EN | bird | bird | UV+Red | 184 | SP and KL dataset |
| *Pentas lanceolata (Forssk.) Deflers* | Pentas | Rubiaceae | P | EN | bee | bee | UV-Red | 255 | SP and KL dataset |
| *Petunia axillaris (Lam.) Britton, Sterns & Poggenb.* | Petunia | Solanaceae | P | G | moth | moth | UV+White | 167 | SP and KL dataset |
| *Philadelphus coronarius L.* | Philadelphus | Hydrangeaceae | P | EN | bee | bee | UV+White | 231; 233 | SP and KL dataset |
| *Phlomoides tuberosa (L.) Moench* | Phlomoides | Lamiaceae | P | EN | bee | bee | UV+White | 215 | SP and KL dataset |
| *Phlox paniculata L.* | Phlox | Polemoniaceae | P | EN | butterfly-moth | insects | UV-Pink | 159 | SP and KL dataset |
| *Phragmanthera usuiensis (Oliv.) M.G.Gilbert* | Phragmanthera | Loranthaceae | P | EN | bird | bird | UV+Red | 183; 179 | SP and KL dataset |
| *Phygelius capensis E. Mey. ex Benth.* | Phygelius | Scrophulariaceae | P | EN | bird | bird | UV-Pink | 136; 17 | SP and KL dataset |
| *Picris longirostris Sch.Bip.* | Picris | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Pieris japonica (Thunb.) D. Don ex G. Don* | Pieris | Ericaceae | P | EN | bee | bee | UV-White | 261; 229; 287 | SP and KL dataset |
| *Pilosella officinarum Vaill.* | Pilosella | Asteraceae | P | EN | fly | fly | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Pinguicula alpina L.* | Pinguicula | Lentibulariaceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Pitcairnia heterophylla (Lindl.) Beer* | Pitcairnia | Bromeliaceae | P | N | bird | bird | UV+Red | 16 | SP and KL dataset |
| *Pitcairnia punicea Scheidw.* | Pitcairnia | Bromeliaceae | P | N | bird | bird | UV-Red | 180 | SP and KL dataset |
| *Plectranthus saccatus Benth.* | Plectranthus | Lamiaceae | P | EN | fly | fly | UV+Pink | 43;230; 349 | SP and KL dataset |
| *Plumbago zeylanica L.* | Plumbago | Plumbaginaceae | P | EN | fly | fly | UV+White | 175 | SP and KL dataset |
| *Polygala myrtifolia L.* | Polygala | Polygalaceae | P | EN | bee | bee | UV+Pink | 2 | SP and KL dataset |
| *Potentilla heptaphylla L.* | Potentilla | Rosaceae | P | EN | bee | bee | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Primula vialii Delavay ex Franch.* | Primula | Primulaceae | P | EN | butterfly | butterfly | UV+White | 188 | SP and KL dataset |
| *Proboscidea fragrans (Lindl.) Decne.* | Proboscidea | Martyniaceae | P | G | bee | bee | UV-Pink | 113 | SP and KL dataset |
| *Protea comptonii Beard* | Protea | Proteaceae | ST | EN | bird | bird | UV+White | 124; 296 | SP and KL dataset |
| *Protea nubigena Rourke* | Protea | Proteaceae | P | EN | bird | bird | UV+White | 124 | SP and KL dataset |
| *Prunella grandiflora (L.) Scholler* | Prunella | Lamiaceae | P | EN | bee-butterflu-fly | bee-insects | UV+White | 131 | SP and KL dataset |
| *Prunus laurocerasus L.* | Prunus | Rosaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+White | 2 | SP and KL dataset |
| *Prunus padus L.* | Prunus | Rosaceae | P | EN | bee-butterfly-fly | bee-insects | UV-White | 106;128;185 | SP and KL dataset |
| *Pseudobombax grandiflorum (Cav.) A.Robyns* | Pseudobombax | Malvaceae | P | N | bat | bat | UV+White | 79;145;311;312 | SP and KL dataset |
| *Psychotria nuda (Cham. & Schltdl.) Wawra* | Psychotria | Rubiaceae | P | N | bird | bird | UV-Yellow | 103; 244 | SP and KL dataset |
| *Pulicaria incisa (Lam.) DC.* | Pulicaria | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 2 | Coimbra et al. 2020 |
| *Puya santosii Cuatrec.* | Puya | Bromeliaceae | P | EN | bird | bird | UV+Cyan | 16 | SP and KL dataset |
| *Qualea multiflora Mart.* | Qualea | Vochysiaceae | P | N | bee | bee | UV+White | 212;342 | SP and KL dataset |
| *Quesnelia arvensis (Vell.) Mez* | Quesnelia | Bromeliaceae | B | N | bird | bird | UV-Pink | 45 | Coimbra et al. 2020 |
| *Quesnelia liboniana (De Jonghe) Mez* | Quesnelia | Bromeliaceae | P | N | bird | bird | UV+Blue | 202 | Coimbra et al. 2020 |
| *Ranunculus acris L.* | Ranunculus | Ranunculaceae | P | EN | bee-fly | bee-insects | UV-Yellow | 1 | Coimbra et al. 2020 |

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|---|---|---|---|---|---|---|---|---|---|
| *Ranunculus alpestris L.* | Ranunculus | Ranunculaceae | P | EN | bee-fly | bee-insects | UV-White | 247 | SP and KL dataset |
| *Ranunculus marginatus d'Urv.* | Ranunculus | Ranunculaceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Ranunculus millefolius Banks & Sol.* | Ranunculus | Ranunculaceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Ratibida columnifera (Nutt.) Wooton & Standl.* | Ratibida | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV-Yellow | 204 | SP and KL dataset |
| *Ravenala madagascariensis Sonn.* | Ravenala | Strelitziaceae | P | EN | bat-bird-mammals | vertebrate | UV+White | 120; 293; 294 | SP and KL dataset |
| *Renealmia petasites Gagnep.* | Renealmia | Zingiberaceae | P | N | bird | bird | UV+White | 142 | SP and KL dataset |
| *Rhagadiolus stellatus (L.) Gaertn.* | Rhagadiolus | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Rhipsalis baccifera (J.S.Muell.) Stearn* | Rhipsalis | Cactaceae | P | G | bird | bird | UV+White | 162 | SP and KL dataset |
| *Rhipsalis elliptica G.Lindb. ex K.Schum.* | Rhipsalis | Cactaceae | P | N | bee | bee | UV+White | 122; 295 | SP and KL dataset |
| *Rhododendron lochae F.Muell.* | Rhododendron | Ericaceae | P | EN | bird | bird | UV+Red | 279 | SP and KL dataset |
| *Rivina humilis L.* | Rivina | Phytolaccaceae | P | EN | bee | bee | UV-White | 174; 331 | Coimbra et al. 2020 |
| *Rosa canina L.* | Rosa | Rosaceae | P | EN | bee-fly | bee-insects | UV+Pink | 163 | SP and KL dataset |
| *Rudbeckia fulgida Aiton* | Rudbeckia | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV+Yellow | 281 | SP and KL dataset |
| *Russelia equisetiformis Schltdl. & Cham.* | Russelia | Plantaginaceae | P | EN | bird | bird | UV-Red | 182 | SP and KL dataset |
| *Ruta chalepensis L.* | Ruta | Rutaceae | P | EN | fly | fly | UV-Yellow | 1 | Coimbra et al. 2020 |
| *Salvia cacaliifolia Benth.* | Salvia | Lamiaceae | P | N | bird | bird | UV+Blue | 276 | SP and KL dataset |
| *Salvia canariensis L.* | Salvia | Lamiaceae | P | EN | bee | bee | UV+Pink | 277 | SP and KL dataset |
| *Salvia patens Cav.* | Salvia | Lamiaceae | P | G | bird | bird | UV+Blue | 275 | SP and KL dataset |
| *Salvia splendens Sellow ex Schult.* | Salvia | Lamiaceae | P | EN | bird | bird | UV+Red | 255; 374 | SP and KL dataset |
| *Salvia urica Epling* | Salvia | Lamiaceae | P | N | bee | bee | UV+Blue | 241 | SP and KL dataset |
| *Saraca indica L.* | Saraca | Fabaceae | P | EN | bee-butterfly-fly | bee-insects | UV+Red | 252; 363 | SP and KL dataset |
| *Saxifraga aizoides L.* | Saxifraga | Saxifragaceae | P | EN | fly | fly | UV+Yellow | 141 | SP and KL dataset |
| *Scabiosa columbaria L.* | Scabiosa | Caprifoliaceae | P | EN | bee-butterfly-fly | bee-insects | UV+Blue | 171; 328; 329 | SP and KL dataset |
| *Schizanthus pinnatus Ruiz & Pav.* | Schizanthus | Solanaceae | P | N | bee | bee | UV-White | 4; 17 | SP and KL dataset |
| *Scrophularia xanthoglossa Boiss.* | Scrophularia | Scrophulariaceae | P | EN | bee | bee | UV-Black | 1 | Coimbra et al. 2020 |
| *Scutellaria costaricana H.Wendl.* | Scutellaria | Lamiaceae | P | N | bird | bird | UV-Red | 17 | SP and KL dataset |
| *Seemannia sylvatica (Kunth) Baill.* | Seemannia | Gesneriaceae | P | N | bird-butterfly | vertebrate-insects | UV+Yellow | 201 | SP and KL dataset |
| *Senecio inaequidens DC.* | Senecio | Asteraceae | P | EN | bee | bee | UV+Yellow | 16 | SP and KL dataset |
| *Senna artemisioides Isely* | Senna | Fabaceae | P | EN | bee | bee | UV-Yellow | 200 | SP and KL dataset |
| *Senna bicapsularis (L.) Roxb.* | Senna | Fabaceae | P | G | bee | bee | UV+Yellow | 200; 334; 335 | SP and KL dataset |
| *Sesamum indicum L.* | Sesamum | Pedaliaceae | P | G | bee | bee | UV+White | 164 | SP and KL dataset |
| *Silene aegyptiaca (L.) L.f.* | Silene | Caryophyllaceae | P | EN | bee | bee | UV+Pink | 1 | Coimbra et al. 2020 |
| *Silene flos-cuculi (L.) Greuter & Burdet* | Silene | Caryophyllaceae | P | EN | bee-butterfly | bee-insects | UV+Pink | 269; 383;384 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Silene vulgaris (Moench) Garcke* | Silene | Caryophyllaceae | P | EN | bee-fly-moth | bee-insects | UV-White | 225; 346 | SP and KL dataset |
| *Sinapis arvensis L.* | Sinapis | Brassicaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Sinningia aggregata (Ker Gawl.) Wiehler* | Sinningia | Gesneriaceae | P | N | bird | bird | UV+Red | 223; 224 | SP and KL dataset |
| *Sinningia eumorpha H.E. Moore* | Sinningia | Gesneriaceae | P | N | bee | bee | UV+White | 223; 224 | SP and KL dataset |
| *Sinningia macropoda (Sprague) H.E. Moore* | Sinningia | Gesneriaceae | P | N | bird | bird | UV-Red | 223; 224 | SP and KL dataset |
| *Sinningia sellovii (Mart.) Wiehler* | Sinningia | Gesneriaceae | P | N | bird | bird | UV-Red | 223; 224 | SP and KL dataset |
| *Solanum betaceum Cav.* | Solanum | Solanaceae | P | N | bee | bee | UV-White | 102 | SP and KL dataset |
| *Solidago canadensis L.* | Solidago | Asteraceae | P | EN | bee-fly | bee-insects | UV+Yellow | 161; 1 | SP and KL dataset |
| *Sonchus oleraceus (L.) L.* | Sonchus | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Sophora macrocarpa Sm.* | Sophora | Fabaceae | P | N | bird | bird | UV+Yellow | 144 | SP and KL dataset |
| *Spathiphyllum cannifolium (Dryand. ex Sims) Schott* | Spathiphyllum | Araceae | B | N | bee | bee | UV+White | 278; 385 | SP and KL dataset |
| *Spathodea campanulata P.Beauv.* | Spathodea | Bignoniaceae | P | EN | bird | bird | UV-Red | 265; 207 | SP and KL dataset |
| *Stifftia chrysantha J.C.Mikan* | Stifftia | Asteraceae | P | N | bird | bird | UV-Yellow | 207; 337 | SP and KL dataset |
| *Strelitzia reginae Banks* | Strelitzia | Strelitziaceae | B | EN | bird | bird | UV+Red | 168 | SP and KL dataset |
| *Streptosolen jamesonii (Benth.) Miers* | Streptosolen | Solanaceae | P | N | bird | bird | UV-Red | 116 | SP and KL dataset |
| *Styrax camporum Pohl* | Styrax | Styracaceae | P | N | bee-fly | bee-insects | UV+White | 243; 354; 355; 386 | SP and KL dataset |
| *Swartzia oblata Cowan* | Swartzia | Fabaceae | P | EN | bee | bee | UV-White | 227 | SP and KL dataset |
| *Swartzia simplex (Sw.) Spreng.* | Swartzia | Fabaceae | P | N | bee | bee | UV+Yellow | 228 | Coimbra et al. 2020 |
| *Symphytum brachycalyx Boiss.* | Symphytum | Boraginaceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Tacinga palmadora (Britton & Rose) N.P.Taylor & Stuppy* | Tacinga | Cactaceae | P | N | bird | bird | UV-Red | 191 | SP and KL dataset |
| *Tagetes erecta L.* | Tagetes | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV-Yellow | 173; 330 | SP and KL dataset |
| *Tanaecium pyramidatum (Rich.) L.G.Lohmann* | Tanaecium | Bignoniaceae | P | EN | bee-wasp | bee | UV-Pink | 155 | SP and KL dataset |
| *Telopea speciosissima (Sm.) R. Br.* | Telopea | Proteaceae | B | EN | bird | bird | UV+Red | 232 | SP and KL dataset |
| *Temnadenia violacea (Vell.) Miers* | Temnadenia | Apocynaceae | P | N | bee-fly | bee-insects | UV+Pink | 157 | SP and KL dataset |
| *Theobroma cacao L.* | Theobroma | Malvaceae | P | N | fly | fly | UV+White | 254 | SP and KL dataset |
| *Theobroma speciosum Willd. ex Spreng.* | Theobroma | Malvaceae | P | EN | fly | fly | UV+Red | 254 | SP and KL dataset |
| *Tilesia baccata (L.) Pruski* | Tilesia | Asteraceae | P | N | bee-butterfly-wasp | bee-insects | UV+Yellow | 147;313 | SP and KL dataset |
| *Tillandsia aeranthos (Loisel.) L.B.Sm.* | Tillandsia | Bromeliaceae | P | G | bird | bird | UV-Blue | 253 | SP and KL dataset |
| *Tillandsia ionantha Planch.* | Tillandsia | Bromeliaceae | B | G | bird | bird | UV+Blue | 154 | SP and KL dataset |
| *Trichostigma peruvianum (Moq.) H. Walter* | Trichostigma | Phytolaccaceae | P | N | bee-beetle-butterfly-fly | bee-insects | UV+Pink | 2 | SP and KL dataset |
| *Tripora divaricata (Maxim.) P.D.Cantino* | Tripora | Lamiaceae | P | EN | bee | bee | UV+Blue | 263 | SP and KL dataset |
| *Trollius chinensis Bunge* | Trollius | Ranunculaceae | P | EN | fly | fly | UV-Yellow | 220 | SP and KL dataset |
| *Uncarina grandidieri (Baill.) Stapf* | Uncarina | Pedaliaceae | P | EN | bee-butterfly-wasp | bee-insects | UV-Yellow | 235 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|
| *Vaccinium vitis-idaea L.* | Vaccinium | Ericaceae | P | EN | bee | bee | UV-White | 1 | Coimbra et al. 2020 |
| *Vellozia candida J.C.Mikan* | Vellozia | Velloziaceae | P | N | bee | bee | UV-White | 270 | SP and KL dataset |
| *Verbascum densiflorum Bertol.* | Verbascum | Scrophulariaceae | P | EN | bee-butterfly-fly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Verbascum lychnitis L.* | Verbascum | Scrophulariaceae | P | EN | bee-butterfly | bee-insects | UV+Yellow | 1 | Coimbra et al. 2020 |
| *Verbena bonariensis L.* | Verbena | Verbenaceae | P | EN | bee | bee | UV+Pink | 255 | SP and KL dataset |
| *Veronica chamaedrys L.* | Veronica | Plantaginaceae | P | EN | bee-fly | bee-insects | UV+Blue | 1 | Coimbra et al. 2020 |
| *Veronica prostrata L.* | Veronica | Plantaginaceae | P | EN | bee-butterfly-fly | bee-insects | UV+Blue | 1 | Coimbra et al. 2020 |
| *Vicia faba L.* | Vicia | Fabaceae | P | EN | bee | bee | UV+White | 150; 317; 318 | SP and KL dataset |
| *Vriesea neoglutinosa Mez* | Vriesea | Bromeliaceae | B | N | bird | bird | UV-Red | 146; 286 | SP and KL dataset |
| *Zephyranthes candida (Lindl.) Herb.* | Zephyranthes | Amaryllidaceae | P | EN | bee | bee | UV-White | 16 | SP and KL dataset |
| *Zeyheria montana Mart.* | Zeyheria | Bignoniaceae | P | N | bird | bird | UV+Yellow | 121; 386 | SP and KL dataset |
| *Zilla spinosa (L.) Prantl* | Zilla | Brassicaceae | P | EN | bee | bee | UV-Pink | 1 | Coimbra et al. 2020 |

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**Supplementary Material Table S2**. Count of species within each category of pollination systems and visitor groups recorded for the 464 species in the dataset.

| Pollination system | Visitor group | Species count |
|---|---|---|
| Bat | Bat | 7 |
| Bee | Bee | 153 |
| | Wasp | 2 |
| Bird | Bird | 131 |
| Beetle | Beetle | 6 |
| Butterfly | Butterfly | 12 |
| Moth | Moth | 10 |
| Fly | Fly | 18 |
| Bee-insects | bee-beetle | 2 |
| | bee-beetle-butterfly-fly | 14 |
| | bee-beetle-fly | 21 |
| | bee-beetle-fly-wasp | 1 |
| | bee-beetle-wasp | 1 |
| | bee-butterflu-fly | 1 |
| | bee-butterfly | 6 |
| | bee-butterfly-fly | 14 |
| | bee-butterfly-fly-moth | 1 |
| | bee-butterfly-wasp | 2 |
| | bee-fly | 21 |
| | bee-fly-moth | 1 |
| | bee-moth | 4 |
| Vertebrates | bat-bird-mammals | 1 |
| | bird-lizard | 1 |
| | bird-marsupial | 1 |
| Vertebrate-insects | bat-bird-moth | 1 |
| | bat-moth | 1 |
| | bee-bat-bird-mammal | 1 |
| | bee-bird-butterfly | 1 |
| | bee-bird-fly | 1 |
| | bird-bat-moth | 1 |
| | bird-bee | 11 |
| | bird-bee-butterfly | 1 |
| | bird-bee-butterfly-wasp | 1 |
| | bird-butterfly | 3 |
| | bird-moth | 1 |
| | bird-butterfly-moth | 2 |
| Insects | beetle-fly | 3 |
| | butterfly- moth | 1 |
| | butterfly-fly | 1 |
| | butterfly-moth | 1 |
| | moth-butterfly | 2 |

**Supplementary Material Table S3**. Species count by color categories and their corresponding pollination systems among the 464 plant species in the dataset. Color categories include subdivisions such as UV absorbent (UV-) and UV reflectant (UV+), which differ in their absorbance and reflection within the UV spectrum (following Camargo et al. 2019 and Coimbra et al. 2020). The Black category encompasses flowers exhibiting dark red/brown hues in the natural world.

| Color category | | Pollination System | Species count |
|---|---|---|---|
| Black (2) | UV+ (1) | Bee | 1 |
| | UV- (1) | Bee | 1 |
| Blue (32) | UV+ (20) | Bee | 12 |
| | | bee-insects | 4 |
| | | Bird | 4 |
| | UV- (12) | Bee | 6 |
| | | bee-insects | 1 |
| | | Bird | 2 |
| | | Fly | 2 |
| | | Insects | 1 |
| Cyan (2) | UV+ (1) | Bird | 1 |
| | UV- (1) | Bird | 1 |
| Green (4) | UV+ (1) | Bee | 1 |
| | UV- (3) | Bird | 2 |
| | | Fly | 1 |
| Pink (74) | UV+ (54) | Bat | 2 |
| | | Bee | 20 |
| | | bee-insects | 12 |
| | | Bird | 12 |
| | | Butterfly | 3 |
| | | Fly | 2 |
| | | Insects | 1 |
| | | vertebrate-insects | 2 |
| | UV- (20) | Bee | 11 |
| | | bee-insects | 2 |
| | | Bird | 4 |
| | | Butterfly | 2 |
| | | Insects | 1 |
| Yellow (96) | UV+ (53) | Bat | 1 |
| | | Bee | 20 |
| | | bee-insects | 19 |
| | | Bird | 6 |
| | | Fly | 4 |
| | | Moth | 2 |
| | | vertebrate-insects | 1 |
| | UV- (43) | Bee | 12 |
| | | bee-insects | 18 |
| | | Bird | 7 |
| | | Fly | 3 |
| | | Vertebrate | 1 |
| | | vertebrate-insects | 1 |
| | UV+ (74) | Bat | 1 |
| | | Bee | 29 |
| | | bee-insects | 17 |
| | | Bird | 8 |
| | | Butterfly | 2 |
| | | Fly | 4 |
| | | Insects | 2 |
| | | Moth | 6 |
| | | Vertebrate | 1 |
| | | vertebrate-insects | 4 |
| | | Bat | 2 |
| | | Bee | 31 |
| | | bee-insects | 12 |
| | | Beetle | 2 |

| | | | |
|---|---|---|---|
| White (128) | UV- (54) | Bird | 2 |
| | | Fly | 1 |
| | | Insects | 3 |
| | | Moth | 1 |
| Red (127) | UV+ (62) | Bat | 1 |
| | | Bee | 6 |
| | | bee-insects | 1 |
| | | Bird | 37 |
| | | Butterfly | 4 |
| | | Fly | 1 |
| | | Moth | 1 |
| | | vertebrate-insects | 10 |
| | UV- (65) | Bee | 6 |
| | | bee-insects | 3 |
| | | Beetle | 4 |
| | | Bird | 45 |
| | | Butterfly | 1 |
| | | vertebrate | 1 |
| | | vertebrate-insects | 5 |

**Supplementary Material Table S4**. Count of the 464 plant species in the dataset based on their geographic distribution and color categories. The data is divided into three distinct geographic regions: Extra-neotropical, Neotropical, and Global. The Global category includes species found in both extra-neotropical and neotropical areas. Within each region, the table offers a comprehensive summary of color categories, presenting a detailed breakdown of species counts for color subdivisions like UV absorbent (UV-) and UV reflectant (UV+).

| Geographic area | Color category | | Species count |
|---|---|---|---|
| Extra-neotropical (287) | UV+ (157) | Blue | 14 |
| | | Cyan | 1 |
| | | Green | 1 |
| | | Pink | 31 |
| | | Red | 32 |
| | | White | 41 |
| | | Yellow | 37 |
| | UV- (130) | Black | 1 |
| | | Blue | 8 |
| | | Cyan | 1 |
| | | Green | 1 |
| | | Pink | 13 |
| | | Red | 29 |
| | | White | 42 |
| | | Yellow | 35 |
| Global (65) | UV+ (41) | Black | 1 |
| | | Blue | 3 |
| | | Pink | 7 |
| | | Red | 11 |
| | | White | 15 |
| | | Yellow | 4 |
| | UV- (24) | Blue | 1 |
| | | Pink | 4 |
| | | Red | 13 |
| | | White | 3 |
| | | Yellow | 3 |
| Neotropical (113) | UV+ (70) | Blue | 3 |
| | | Green | 2 |
| | | Pink | 16 |
| | | Red | 19 |
| | | White | 18 |
| | | Yellow | 12 |
| | UV- (43) | Blue | 3 |
| | | Pink | 3 |
| | | Red | 23 |
| | | White | 9 |
| | | Yellow | 5 |

**Supplementary Material Table S5**. Count of the 464 plant species in the dataset based on their geographic distribution and pollination systems. The data is categorized into three distinct geographic regions: Extra-neotropical, Neotropical, and Global, the latter including species found in both extra-neotropical and neotropical areas. Within each region, the table offers a comprehensive summary of the existing pollination systems, presenting a detailed breakdown of species counts for various visitor groups like birds, bats, bees, butterflies, flies, beetles, moths, and other insects.

| Geographic area | Pollination system | Species count |
|---|---|---|
| Extra-neotropical (287) | Bee | 106 |
| | bee-insects | 76 |
| | Beetle | 6 |
| | Bird | 53 |
| | Butterfly | 7 |
| | Fly | 14 |
| | Insects | 6 |
| | Moth | 5 |
| | Vertebrate | 3 |
| | vertebrate-insects | 11 |
| Global (65) | Bat | 1 |
| | Bee | 20 |
| | bee-insects | 5 |
| | Bird | 26 |
| | Butterfly | 2 |
| | Fly | 1 |
| | Insects | 1 |
| | Moth | 3 |
| | vertebrate-insects | 6 |
| Neotropical (113) | Bat | 6 |
| | Bee | 30 |
| | bee-insects | 8 |
| | Bird | 52 |
| | Butterfly | 3 |
| | Fly | 3 |
| | Insects | 1 |
| | Moth | 2 |
| | vertebrate-insects | 8 |

CAPÍTULO 2

*Manuscrito a ser submetido como Research paper*

# Evolution of UV reflectance in bee- and bird-pollinated flowers


## ABSTRACT

Floral color is one of the most important traits mediating plant-pollinator interactions. Certain flower colors are responses to pollinator preferences while others act as filters against floral antagonists and less effective pollinators. Such sensory exclusion creates a distinct niche that effective pollinators can exploit. However, it is still unclear if attraction and exclusion processes have influenced the evolution of floral colors. Here, we investigated a wide array of plant species across the angiosperms, using ancestral state reconstruction and evolutionary models to understand the evolution of UV chroma, a key color trait mediating attraction and exclusion of floral visitors in bee- and bird-pollinated species. Based on the sensory exclusion hypothesis, we expected evolution of higher UV chroma in white bird-pollinated flowers and lower UV chroma in red and yellow ones, while the opposite patterns for bee-pollinated ones of the same colors. The 292 studied species exhibited a wide variation in UV chroma, with a focus on red, white, and yellow flowers. Ancestral state reconstructions unveiled a highly-changing evolutionary trajectory characterized by varying rates of transition between different states (UV+ and UV- red; UV+ and UV – white; UV+ and UV- yellow). The evolution of higher UV chroma was associated with bee-pollinated red and white flowers and bird-pollinated yellow flowers. Furthermore, there were a notable variance and high evolutionary rate in UV chroma throughout the evolutionary history of white and yellow bee flowers. Collectively, our results demonstrate that both attraction and exclusion pressures contributed to the remarkable floral color diversity in red bee- and bird-pollinated flowers, while such influence was less pronounced in white and yellow flowers. Thus, our results support that the evolution of floral color is influenced by relationships with pollinators and floral antagonists at a macroevolutionary level.



## KEYWORDS

sensory exclusion, color evolution, ancestral state reconstruction, evolutionary models, flower diversity, color classifications, Brownian motion, Ornstein –Uhlenbeck, private channel

**INTRODUCTION**

Flower color plays a critical role in plant reproduction, because it is the main signals that floral visitors use to locate floral resources in nature (Chittka & Raine 2006; Willmer 2011). Flower color is not solely determined by intrinsic plant processes but is also influenced by environmental factors and the visual systems of floral visitors (Chittka & Thomson 2001; Arista *et al.* 2013; van der Kooi *et al.* 2019; Dalrymple *et al.* 2020; Garcia *et al.* 2020; Trunschke *et al.* 2021). Collectively, the visual systems of floral visitors span different types of color-sensitive cells called photoreceptors, which enable them to perceive colors across the ultraviolet to the red spectrum (Fein & Szuts 1982; Briscoe & Chittka 2001; Chittka & Thomson 2001b; Weiss 2001). The specific type and number of photoreceptors vary significantly among and within different taxonomic groups, such as insects, birds, and mammals, (Peitsch *et al.* 1992; Briscoe & Chittka 2001; Weiss 2001; Osorio & Vorobyev 2008; van der Kooi *et al.* 2019). For instance, most bees bear three photoreceptors types sensitive to UV, blue, and green lights, which are responsible for the perception of a wide range of floral colors (Briscoe & Chittka 2001). In contrast, birds generally have four photoreceptor types and perceive UV, blue, green, and red lights (Ödeen & Håstad 2010; Kelber 2019). However, we still know little about how these different color visual systems have driven the evolution of floral color.

Different properties of flower colors, including spectral purity (hue intensity and amount of gray), chromatic and achromatic contrasts (detectability of an object in the chromatic and achromatic channel), can be quantified based on the excitation peaks they elicit in the different visual systems of floral visitors. These components have been shown to be relevant in how flowers attract and are discriminated by pollinators (Lunau *et al.* 1996; Spaethe *et al.* 2001; Chittka & Raine 2006; Van Der Kooi *et al.* 2019). Likewise, the amount of ultraviolet (UV) light in the total spectrum reflected by flowers, known as UV chroma, is a property of the reflectance curve that also plays a significant role in how pollinators perceive and differentiate them in their natural environment ( Chittka *et al.* 1994; Kevan *et al.* 2001). Furthermore, the amount of UV light will also determine floral purity and contrasts, ultimately influencing plant-pollinator interactions and plant reproduction (Lunau 1992; Chen *et al.* 2020a). It is also important to note that besides pollinators, environmental factors such as exposure to UV radiation also influences the evolution of UV chroma because pigments that absorb UV light protect the reproductive parts against this factor and the larger the area of UV absorption in the flower, the lower its UV chroma will be (Koski & Ashman 2015, 2016; Koski *et al.* 2020).

The amount and distribution of UV chroma can vary between plant pollination systems. Among bee pollinated flowers, some exhibit UV patterns organized into apical areas that reflect UV light and central areas that absorb UV light, serving as visual guides to floral resources, namely “floral guides” (Lunau 1993; Lehrer *et al.* 1995; Lunau *et al.* 1996). Bird-pollinated species typically exhibit more specific colors with less chromatic variation, often consisting of different shades of red (Cronk & Ojeda 2008; Kelber 2019, Coimbra *et al.* 2020). However, although birds are sensitive to UV light, there is no strong association between UV chroma and bird attraction (Stoddard *et al.* 2020). Therefore, the spectral sensitivity of birds to red wavelengths has been used as evidence to explain the association between birds and purely red flowers and their evolution (Shrestha *et al.* 2013). Interestingly, despite the association between birds and red flowers, they do not inherently prefer red colors (Stiles 1976; Lunau & Maier 1995; Lunau *et al.* 2011). An alternative hypothesis suggests that the evolution of specific colors in flowers primarily pollinated by birds is a result of sensory exclusion pressures from floral antagonists, which are typically bees that act as nectar robbers, pollen consumers and/or less efficient pollinators (Raven 1972; Lunau & Maier 1995; Cronk & Ojeda 2008; Lunau *et al.* 2011). In some plant species, less conspicuous floral colors for certain animals may reduce their interference as antagonists in the pollination process (Rodríguez-Gironés & Santamaría 2004; Bergamo *et al.* 2016). In general, bees perceive purely red flowers pollinated by birds as achromatic signals, such as the contrast produced in a single photoreceptor (green) or the combined excitation of all photoreceptors (Chittka & Waser 1997). Consequently, due to the challenge in detecting purely achromatic signals like red flowers that do not reflect other wavelengths such as UV, bees tend to concentrate their foraging efforts on more conspicuous flowers. This opens up a private niche for birds to exploit, supporting the hypothesis of sensory exclusion (Lunau *et al.* 2011).

The sensory exclusion hypothesis has been investigated in various field and experimental studies (Lunau *et al.* 2011; Bergamo *et al.* 2016; de Camargo *et al.* 2019; Chen *et al.* 2020b; Rodríguez-Sambruno *et al.* 2024). Although it has primarily been examined in the context of red flowers, niche segregation between flowers primarily pollinated by bees (referred to as bee-flowers) and birds (referred to as bird-flowers) can also occur in other parts of the color spectrum (Papiorek *et al.* 2016; Camargo *et al.* 2019; Coimbra *et al.* 2020), particularly due to their UV properties. White and yellow bird-flowers may also be unattractive to bees due to the contrasting background and patterns of UV reflectance and absorption (Lunau *et al.* 2011; Bergamo *et al.* 2016; Papiorek *et al.* 2016). White bird-flowers uniformly reflect UV light, appearing achromatic and less noticeable to bees, while white bee-flowers uniformly absorb UV light (Lunau *et al.* 2011; Bergamo *et al.* 2016). In the case of yellow flowers, bee attractiveness is determined by the presence of UV patterns, in which petal apex reflects UV while petal center absorbs UV light (Papiorek *et al.* 2016). However, when UV light is completely absorbed, as is common in yellow bird-flowers, this color becomes less attractive to bees (Papiorek *et al.* 2016; Camargo *et al.* 2019).

Effective pollinators and floral antagonists can act as selective agents for floral color (Rodríguez-Gironés & Santamaría 2004; Rausher 2008). However, it is still unclear how pollinator attraction and sensory exclusion processes underlie the well-documented diversity of floral colors over extensive evolutionary timescales. The amount of UV reflectance in flowers is likely to be evolutionarily linked to the strength of selective pressures exerted by floral antagonists and pollinators through sensory exclusion and attraction mechanisms. Bee- and bird-pollinated flowers serve as excellent models for studying this phenomenon at macroevolutionary scales, as the sensory exclusion hypothesis predicts differences in UV-reflectance properties between these two groups (Lunau *et al.* 2011; Rodríguez-Gironés & Santamaría 2004). Furthermore, bees and birds are noteworthy the most prominent pollinator groups among insects and vertebrates, respectively  while bee- and bird-pollinated flowers have evolved several times across the angiosperm phylogeny ( Ollerton *et al.* 2011; Stephens *et al.* 2023).

In this study, we used a wide set of bee and bird-pollinated plant species globally distributed and spanning the angiosperm phylogeny to investigate the evolutionary association between pollinator type (bees vs. birds) and floral color. Specifically, we characterized the UV chroma and color categories (red, white and yellow) of the flowers to investigate whether UV chroma and floral color are evolutionary labile or constrained by shared ancestry. Moreover, we sought to explore whether the evolution of UV chroma reflects adaptations to the specific type of pollinator and associated sensory exclusion processes, by employing different adjusted Brownian motion (BM) and Ornstein-Uhlenbeck (OU) models of trait evolution. These models allow the adjustment of different evolutionary parameters that can help us better interpret the evolutionary routes of the UV chroma. Adaptative optima, evolutive rate, and selective strength are key concepts in evolutionary biology. Optima refer to the ideal value of a trait for a given species, rate is the speed at which a trait changes over time, and selective strength measures how strongly natural selection favors or disfavors a trait (see more details below). Specifically, we tested if bee- and bird-pollinated red, white, and yellow flowers diverge in their adaptive optima, rate and selective strength of UV chroma. Following the sensory exclusion hypothesis, we predict that the optima, rate and selective strength of UV chroma in red bird-flowers lineages are lower than for red bee-flowers lineages. On the other hand, the optima, rate and selective strength of UV-chroma in white bird-flowers lineages should be higher as compared to white bee-flower lineages. Using the same rationale, we anticipate higher UV chroma optimum, rate and selective strength in yellow bee-flowers lineages compared to bird-flower lineages.

## MATERIAL AND METHODS

### *Database*

The species under study are part of an curated dataset that includes spectral reflectances of flowers, color categories, floral visitors, and categorized pollination systems for 292 angiosperm species (Oliveira *et al.* in prep- chapter 1). Among these, 250 species contribute previously unpublished data, significantly enhancing our comprehension of floral color diversity. The spectral reflectance information is based on a compilation of *in situ* measurements by two of the coauthors during several field trips and botanical garden specimen collections (K. Lunau and S. Papiorek) and on Coimbra *et al.* (2020) dataset reflectance. These species are phylogenetically spread among to 205 genera in 76 families. The most representative families in number of species were Asphodelaceae (21%), Asteraceae (20%), Bromeliaceae (30%), and Fabaceae (37%) (Table S1) and spanned across the Tropical and Temperate zones of the globe, from 66.31ºN to 43.64ºS. Among them 87 species are concentrated in the Neotropics, 160 species are concentrated in areas outside the Neotropics (extra-neotropical), and 45 species occur in both regions. The altitudinal range of these species varies from -300(records on Palestine, near to Dead Sea) to 4,669 meters. The temperature and annual precipitation levels range from -2.1°C to 29.7°C and 4 to 5446 mm, respectively. Annual UV-B irradiation levels range from 3019 to 9.979.344.482 J m-2 d-.

***Spectral reflectance***

The reflectance data is exclusively focused on 300 to 700 nm wavelengths, range that falls within the spectral sensitivity of animal pollinators. It was initially acquired using a spectrophotometer (USB 2000, USB 4000; Ocean Optics) at 45°, calibrated with white barium sulfate (BaSo4) standard and no light as a black standard (Lunau *et al.* 2011; Papiorek *et al.* 2016; Coimbra *et al.* 2020). Our data collection encompassed a variety of floral components, including petals, sepals, stamens, and bracts, provided they prominently exhibited the primary color and attractant for the species at long distances, thereby serving as the first long-distance communication channel between flowers and animals (Table S1; Menzel *et al.* 1997; Spaethe *et al.* 2001). To standardize the terminology, all these distinct structures were collectively referred to as "flowers".

***Color categories and UV chroma***

We categorized the colors of the species' flowers based on their reflection(+) or not (-) in the UV(u), blue(b), green(g), and red(r) spectral ranges (300-700 nm). We established thresholds such as 0.1 (10%) for UV, 0.3 (30%) for blue, 0.4 (40%) for green, 0.5 (50%) to distinguish green flowers from blue and red ones, and 0.6 (60%) for red, as adapted from the Camargo *et al.* (2019) and Coimbra *et al.* (2020) (Table S1). This resulted in the following color categories: cyan (2 u-b+g+r- or u+b+g+r-), green (3 u-b-g+r- or u+b-g+r-), black (3 u-b-g-r- or u+b-g-r-), blue (24 u-b+g-r- or u+b+g-r-), pink (46 u-b+g-r+ or u+b+g-r+), yellow (47 u-b-g+r+ or u+b-g+r+), white (75 u-b+g+r+ or u+b+g+r+), and red (94 u-b-g-r+ or u+b-g-r+), . Additionally, we calculated UV chroma considering the proportion of UV reflectance (300-400 nm) in relation to the total measured spectrum (300-700 nm). We then organized the species in two sets: one set (hereafter white-red-flowers set) in which flowers were categorized into white, red, or other colors, i.e. including yellow, pink, green, cyan, blue and black colors, and another (hereafter yellow-flowers set) in which flowers were categorized as yellow or other colors, i.e. including white, red, pink, green, cyan, blue and black colors (Table S1). We considered these two sets because they represent different visual phenomena in bees' and birds' visual systems. In white and red flowers, the presence or absence of UV reflection will determine whether these animals use the chromatic or achromatic channel to discriminate them (Lunau *et al.* 2011). In yellow flowers, the reflectance and absorption of UV occur in specific areas, determining UV patterns within the flowers and their discrimination through chromatic channels (Papiorek *et al.* 2016). The "other" color category was included as a control to assess the range of differences in UV proportions between flowers with other color categories, as we do not expect patterns for these other colors.

***Pollinators***

Plant species were assigned in bee flowers (species with records of visitation/pollination only by bees or wasps) and bird flowers (species visited/pollinated only by birds) following the functional pollinator guilds classification of Ollerton *et al.* (2007). A list of pollinator references is provided in supplementary material (Table S1). This information was compiled from literature obtained from Google Scholar and ISI Web of Science databases using keywords such as "species name"*"pollination" or "species name"*"pollinator." To increase the reach of our search, we considered different types of methodologies and researches including theses, dissertations and reviews for which information about frequency of visitation and/or pollination by bees or birds were available. We could assign main floral visitors/pollinators as bees for 157 species and birds (134 species).

***Phylogeny***

Inferences about the phylogenetic relationships of species were based on the time-calibrated phylogeny ALLMB (Smith & Brown 2018) that were the one which included the largest number of species sampled here. This phylogeny combines genetic data from GenBank and phylogenetic data from the Open Tree of Life, with a backbone provided by Magallón *et al.* (2015). To include as many species as possible, we assumed that distances within the same genus or between sister genera are smaller than those at other hierarchical levels, and we corrected for missing species in the phylogeny by substituting them with species from the same genus if present in the tree, or with species from sister genera if absent, which creates polytomies by adding absent genera or species to their closest taxa. Polytomies were then automatically solved (multi2di- ape package Paradis *et al.* 2004; Paradis and Schliep 2019). The resulting tree was used as the basis for the analyses performed subsequently.

***Ancestral reconstruction***

We conducted ancestral reconstruction of color categories and UV chroma for each of the two sets (white-red-flowers and yellow-flowers) to infer the evolutionary history of these traits along the phylogeny and determine whether evolution of color categories was labile or conserved by phylogenetic relationships. To reconstruct color categories, we first fitted different evolutionary models since we had no prior hypothesis regarding a modular evolution of the different color categories considered (Harmon *et al.* 2008). We selected the ER (equal rates), ARD (all different rates), and SYM (symmetrical rates) models by comparing Akaike weights and ΔAICc, and used the best-fitted model to perform a stochastic character mapping with 1000 simulations to evaluate the robustness of the generated reconstruction (Revell 2012). In the ER model, an equal transition rate is assumed among state pairs, while in the ARD model, different transition rates are allowed. The SYM model indicates that the transition rate from one state to another is the same. However, distinct pairs of trait states can exhibit varying rates of change. We also investigated the reconstruction of UV chroma based on the Brownian motion model and estimates of internal node states using maximum likelihood and interpolated each edge state, considering its continuous nature (Felsenstein 1985; Revell 2012).

***Trait evolution***

To explore if the evolution of UV chroma of white-red-flowers and yellow-flowers was associated with color categories and pollinator types (bee vs. bird), we built distinct Brownian motion (BM) and Ornstein –Uhlenbeck (OU) models of trait evolution (Hansen 1997; O'meara *et al.* 2006; Beaulieu *et al.* 2012). The BM model assume that traits evolve randomly or under stabilizing selection following a changing optimal value, while the OU model assume that the evolution of traits occurs under a selective regime. The OU model estimates the optimal phenotype values (θ) toward which populations evolve in an OU process, the rate of phenotypic change ($\sigma^2$), i.e. the level of random fluctuations in the evolutionary process, and selective strength (α), i.e. the degree of attraction to θ and the rate at which UV chroma converges to the optimum (Hansen, 1997; Butler & King, 2004; Beaulieu *et al.*, 2012). We fitted seven models to UV chroma for each of the two sets of flowers following the model-fitting framework of de Alencar *et al.* (2017): (1) BM1- BM model of single-rate, (2) OU1- OU model of single optimum, (3) BMS- multi-rate BM model allowing different $\sigma^2$ values between color and pollinator categories, (4) OUM- OU model assuming different θ values and singles σ2 and α values for each color and pollinator category, (5) OUMV- OU model allowing distinct σ2 and θ values for each color and pollinator category, (6) OUMA- OU model allowing different α and θ values for each color and pollinator category and (7) OUMVA- OU model that assumes different σ2 , α, and θ values for each color and pollinator category. We also fitted simmap trees estimated under color categories and pollinator types (Beaulieu *et al.* 2016) and calculated ΔAICc to investigate which model best explained UV chroma evolution in each simmap tree simulated. The best fit models were those with ΔAICc lesser than two (Burnham & Anderson 2004).

According to the selection of the best-fit model, we employed a Generalized Linear Mixed Model (GLMM) to investigate the interactive effects of variables pollinator type and color category on θ considering the model simulation as a random variable. This tool allowed for a detailed analysis of the intricate interplay between these factors, accounting for the potential influence of selected model simulation dependencies. We opted for the Gaussian family due to the continuous and normal nature of the data. We also utilized Estimated Marginal Means (emmeans) analysis to explore the estimated marginal means for the combinations of pollinator type and color categories. As a post hoc test, we assessed the significance of differences between these combinations, employing p-values adjusted for multiple comparisons using the Tukey correction.

***Statistical packages***

We used the R software environment, version 4.2.1 (R Core Team 2023) to conduct all analyses. We employed different packages and functions to meet the specific objectives of the study addressing specific data manipulation, analysis, and visualization needs. We used pavo (Maia *et al.* 2013, 2019) and forcats (Wickham 2023) packages to explore spectral properties of colors and conduct color categorization and manipulation of categorical factors. Regarding phylogenetic reconstruction of continuous and discrete traits, we employed a combination of phytools (Revell, 2012) and geiger (Harmon *et al.* 2008) packages, respectively. The ape (Paradis *et al.* 2004; Paradis and Schliep 2019), ggplot2 (Wickham *et al.* 2016), and ggtree (Yu *et al.* 2017) packages were used to import and manipulate phylogenetic trees, correct polytomies as well as to visualize results through graphics. In addition, we used OUwie package (Beaulieu *et al.* 2016) to fit evolutionary models and the packages glmmTMB (Magnusson *et al.* 2017), car (Fox *et al.* 2019) and emmeans (Lenth 2023) were used to fit the GLMMs and the estimated marginal means.

## RESULTS

***Color categories and UV chroma***

Within the "white-red flowers" set, 124 species (42.5%) were categorized as "other," 94 species (32.5%) as "red," and 74 species (25.4%) as "white". In the "yellow flowers" set, the "yellow" category comprised 46 species (16%), while the "other" category encompassed 246 species (84%) (Table S1).

The observed UV chroma values exhibited a substantial range of variability across the studied species. On the lower end of the spectrum, the recorded minimum UV chroma was 0.000001 (*Brownea ariza* Benth. - Fabaceae and *Vriesea neoglutinosa* Mez - Bromeliaceae). Conversely, at the higher end, the maximum value was of 0.77 (*Heliconia bihai* (L.) L. - Heliconiaceae). The mean UV chroma across all species was 0.096 ± 0.11. Notably, 197 species (67.46%) displayed a UV chroma below 0.1 (UV-), while 93 species (31.8%) exhibited a UV chroma exceeding 0.1 (UV+, Table S1).

***Ancestral state reconstruction***

Among white-red flowers set, ARD and SYM models provided the best fit. Despite the ARD model displayed a slightly lower AICc, the differences between SYM and ARD were minimal. Therefore, we made the decision to proceed with our analyses using the SYM model because this model is simpler. The observed changes between color states were notably higher when transitioning between the 'Red' and 'Other' colors compared to transitions involving the 'White' color. Additionally, changes observed between 'White' and 'Other' colors were found to be greater than those observed between 'White' and 'Red' colors. On average, the analysis estimated that there were at least approximately 4,704 changes between color category states (Fig. 1a, Table S2). In yellow flowers, the ARD model provided the best fit (Table S4). On average, the analysis estimated that there were at least approximately 1,342 changes between yellow-other and other-yellow color categories (Fig. 1b, Table S3).

Within the same context, ancestral state reconstructions using UV chroma revealed a great degree of variability and frequency in state changes (Fig. 1). The scattered appearance of different color categories, among white-red and yellow-flowers sets, and UV chroma states within the phylogenetic structure attests to an inherent lability that characterizes the evolution of these color traits in the species studied (Fig 1). However, considering the oldest nodes of the phylogenetic tree, the ancestral state reconstruction highlights white and yellow chroma ancestry among white-red and yellow-flower sets, respectively. Likewise, an UV chroma of 0.13 is considered the most likely ancestral state considering the probabilities derived from the 95% confidence intervals reconstructed using maximum probability estimation.

***Trait evolution***

Among each of the seven evolutionary models fitted, the OUMV and OUMA models provided the best fit across most of stochastic mappings from white-red and yellow-flowers set, respectively. In the white-red flowers, the OUMV model accounted for 68% of the total fits followed by the OU1 model which fitted in 39% of the cases, while in the yellow flowers the OUMA model fitted 74% of total cases, followed by OU1 that fitted 23% of the cases (Table 1).

White-red flowers set showed distinct values of UV chroma optimum (θ) and varying rates of phenotypic change ($\sigma^2$) for each color category and pollinator type. Higher values of both θ and σ2 were associated with the evolutionary trajectory of red and white floral hues in bee-pollinated species, in comparison to their bird-pollinated counterparts (Fig. 2a). However, it is important to highlight a notable trend that emerges in the context of white flowers. While white bee- and bird-pollinated flowers exhibited only a small difference in UV chroma optima (emmeans: 0.008, $p<0.001$; Table S4), there was a marked distinction in the dispersion surrounding these optimal values. Notably, white bird-pollinated flowers displayed a substantially higher variation in optimal values, including the highest values in the dataset, compared to their bee-pollinated counterparts (Fig. 2b). Moreover, white bee-pollinated species also exhibited a greater degree of variability around the rate of phenotypic change (σ2) of UV chroma (Fig. 2a). Results also reveal that the estimated optimum values and rates are lower in the “bee-other” and “bird-other” categories compared to white and red categories. During the evolution of UV chroma, optima values for white-red and other floral colors depend on pollinators and color category (Pollinator type* Color category – $\chi^2$: 980.77, Df:2, p< 2.2e-16; Table S5). We identified the highest UV chroma values in red bee-pollinated flowers (emmeans:0.038, p<0.001), followed by white bee-flowers (emmeans:0.008, p<0.001) and flowers of other colors bird-pollinated (emmeans:0.004, p<0.001) when contrasted with optima values from the same color categories but with the opposite pollinator type (Table S4).

Yellow-flowers set showed variable values of UV chroma optimum (θ) and the selective strength in which this trait evolves (α). Yellow bee-pollinated flowers exhibited lower optimal values (θ) of UV chroma than those of yellow bird-pollinated flowers (Fig. 3a). These lower optimal UV chroma values indicate that the adaptive optimum for UV chroma is higher in lineages pollinated by birds. In contrast, when examining other color categories within both bee- and bird-pollinated species, we found no significant differences between them (Table S5). However, these other color categories differed substantially from yellow flowers, displaying lower UV chroma values than this color category and highlighting the unique adaptive strategies of yellow flowers independently of pollinator type (Table S5). Moreover, our analysis revealed that yellow and other-colored bee- pollinated flowers displayed higher selective strength to UV chroma optimum (α) than bird-pollinated flowers of the same colors (Fig. 3b). This suggests a faster rate of evolutionary change in UV chroma towards the optimum value among bee-pollinated flowers. The GLMM analysis revealed that the optima values of UV chroma for yellow and other floral colors depend on pollinators and color category (Pollinator type* Color category - $\chi^2$: 4.0945, Df:1, p< 0.05). The UV chroma values among most combinations of pollinator types and colors were not statistically different. However, the "bee other - bee yellow" contrast emerged as an exception, indicating that flowers of other colors pollinated by bees have a significantly lower marginal mean of optimal UV chroma than yellow bee-pollinated flowers (Df: 3654; t: 3.025; p=0.0133) (Table S6).

## DISCUSSION

Our study revealed a wide variation of an important floral color trait across bee- and bird-pollinated angiosperms, the UV chroma. Additionally, the analyzes showed variable rates of change between color states when analyzing ancestral state reconstructions for color categories (red-white-others; yellow-others) and for UV chroma. Although we did not definitively determine ancestral states, color category and UV chroma displayed multiple transitions, suggesting the labile nature of these color traits. Our findings also indicate a potential selection force driving the evolution of white, red and yellow flowers. Bee-pollinated red and white flowers showed higher optima than bird-pollinated ones, while bird-pollinated yellow flowers exhibited the highest optima. Moreover, the rate of phenotypic change (σ2) or the selective strength around these optima (α) also differed. Bee-pollinated white and red flowers displayed a greater phenotypic change around the UV chroma optimum, and bee-pollinated species showed a stronger rate of evolution towards UV chroma optimum in yellow and other colored flowers. Our findings clearly indicate sensory attraction and exclusion in red flowers, while the evidence for these processes was more mixed in white and yellow flowers.

We observed a wide range of UV chroma values across species, reflecting different levels of UV reflectance. Most species (67.46%) exhibited an average UV chroma below 0.1, indicating that the other one-third of these species reflects UV. This proportion is quite significant considering that UV reflectance is consistently lower in intensity and less frequent compared to reflectance in other ranges of the spectrum in flowers (Chittka *et al.* 1994; Tunes *et al.* 2021). However, it is important to acknowledge that this substantial proportion might be attributed the subset of studied plants, i.e. bee- and bird-pollinated species. These results indicate that UV reflection may be more common than anticipated when considering certain groups of pollinators, such as bees and birds. Likewise this pattern might be attributed to the different distribution of pigments responsible for UV reflectance and absorbance within the floral structures, once floral colors are the result of a combination of factors, including intricate structural aspects as the selective light absorption or reflection facilitated by pigments, beyond to the selective pressures of pollinators and of abiotic factors (Vignolini *et al.* 2013; Koski *&* Ashman 2016; Moyroud *&* Glover 2017; Van Der Kooi *et al.* 2019; Dalrymple *et al.* 2020; Koski *et al.* 2020). Factors such as UV exposure, temperature, and precipitation play a pivotal role in shaping the synthesis of these pigments, influencing floral traits and reproductive strategies (Koski *&* Ashman 2016; Dalrymple *et al.* 2020; Koski *et al.* 2020). Aside from its role as a visual signal to attract UV-sensitive pollinators, floral UV chroma also serves a protective function against UV radiation-induced damage to plant reproductive structures (Koski *&* Ashman 2014, 2015b; Brock *et al.* 2016; Papiorek *et al.* 2016). Flowers with higher levels of UV-absorbing pigments reduce the reflection of UV light onto their anthers, thereby enhancing the viability of pollen under UV stress (Koski *&* Ashman 2015a). Therefore, the intricate interplay between UV-reflecting and absorbing pigments, their functions in attracting pollinators, and their protective role significantly contributes to the diversity and distribution of flower colors among plant species.

The scattered emergence of different color categories and UV chroma values across the evolutionary time points to a labile evolution of these floral traits. Indeed, several studies on floral reflectance have suggested that phylogenetic relatedness does not strongly influence general floral color properties such as hue and saturation (Muchhala *et al.* 2014; Shrestha *et al.* 2014; Gómez *et al.* 2015; Bergamo *et al.* 2018). However, UV reflectance can either be constrained by evolutionary relatedness (Koski *&* Ashman 2016; Tunes *et al.* 2021), or exhibit substantial variation even among closely related species depending on the clade (Rieseberg *&* Schilling 1985; Naruhashi 1999; Koski *&* Ashman 2016). These findings highlight the complexity of the relationship between floral UV traits and the evolutionary history of plant species. Surprisingly, this particular aspect has poorly been explored. Towards a comprehensive understanding of the evolutionary trajectories of floral UV features, it will be important to widen the scope of our dataset, including a broader array of plant species with different pollination systems.

Both the macroevolutionary models and GLMMs unveiled a remarkable pattern of floral UV chroma evolution, highlighting the pivotal role played by both pollinator type and flower color category. The variation in photoreceptor sensitivity among pollinator groups, such as bees and birds, has long been recognized (Briscoe & Chittka 2001; Ödeen & Håstad 2010). Our results support that differences in their visual systems are a selective pressure behind the divergence in flower coloration, particularly within the context of white, red and yellow flowers. Elevated UV chroma optimum values (θ) estimated were associated with red bee-pollinated flowers, in comparison with their bird-pollinated counterparts, thus, interaction with bees favored higher adaptive optimum of UV chroma in red flowers. These findings strongly support the sensorial exclusion hypothesis, in which bees focus their foraging efforts on flowers with pronounced chromatic signals, particularly in red flowers with a secondary reflectance peak in the UV band (Chen *et al.* 2020b). In contrast, birds appear to exploit less conspicuous, achromatic floral colors in the bee vision, effectively exploring a specialized niche of red flowers that absorb UV light (Lunau *et al.* 2011; Bergamo *et al.* 2016; Camargo *et al.* 2019).

The macroevolutionary model for white-red flower set indicated slightly higher UV chroma values in white bee-pollinated flowers in comparison with their bird-pollinated counterparts. This contradicts what is expected by the sensory exclusion hypothesis, i.e. higher UV reflectance in white bird-pollinated flowers. This is because the absence of an intensity coding channel in bee color perception makes it challenging for bees to distinguish white UV-reflecting flowers against the green foliage background (Chittka 1992; Chittka & Menzel 1992; Kevan *et al.* 1996), discouraging bee visitation in white UV-reflecting flowers (Kevan *et al.* 1996; Lunau *et al.* 2011b; Camargo *et al.* 2019). Upon visualizing the various scenarios outlined by the model simulations, it is noticeable that bird-pollinated white flowers displayed greater dispersion of their optima, presenting the highest optimal values of UV chroma. This suggests that sensory exclusion pressures resulting in high UV chroma optimum have occurred in white bird-pollinated flowers, but in specific contexts.

In certain color hues, UV reflection emerges as an effective strategy to enhance visibility for its receivers because it enhances overall brightness (Chittka & Thomson 2001; Chittka & Raine 2006; Kevan *et al.* 2001). Brightness may be particularly important for birds as they possess double cones that are specialized in perceiving light intensity (Hart 2001). In this context, the OUMV model also revealed a higher rate of phenotypic change in UV chroma ($\sigma^2$) throughout the evolutionary history of white bee-pollinated flowers. This suggests that the strength of stabilizing selection is weaker for white flowes bee-pollinated than for white flowers bird-pollinated. This may be due to both sensory exclusion of bees and attraction of birds resulting in the same selective pressure towards enhanced UV chroma in white bird-pollinated flowers. Nevertheless, it is important to note that the role of UV in bird vision has been scarcely investigated in the context of foraging for floral resources. Furthermore, such lower rate of phenotypic change might be attributed to the superior visual acuity of birds (Ödeen & Håstad 2003, 2010; Kelber 2019). The enhanced visual acuity might have imposed a greater need for the stabilization of color traits, including those related to UV light, in order to meet the demands of the perceptual systems of birds.

Contrary to the expected, we found higher UV chroma optimum for yellow bird-flowers than yellow bee-flowers. In yellow flowers, intra-floral patterns of UV reflectance have been linked to a pivotal role in visually guiding bees (Lunau 1993; Lunau *et al.* 1996; Papiorek *et al.* 2016; Tunes *et al.* 2021; Saab *et al.* 2021). Typically, bee-pollinated yellow flowers have apical parts containing yellow carotenoids that reflect UV light, while the central parts additionally possess UV-absorbing flavonoids (Thompson *et al.* 1972; Harborne & Smith 1978). Such intra-floral pattern may reduce the overall UV-reflectance when considering the whole flower, leading to an association between lower UV chroma and yellow bee-pollinated flowers. In contrast, yellow bird-pollinated flowers lack UV nectar guides (Papiorek *et al.* 2016; Camargo *et al.* 2018). Yellow flowers with UV reflectance are a non-spectral color in bird vision (i.e. a color formed by non-adjacent photoreceptors), which were recently showed to be important in hummingbird visual foraging (Stoddard *et al.* 2020). In contrast, we found a faster rate of evolutionary change towards the UV chroma optimum (α) in bee-pollinated flowers (both yellow and others colors). This rapid shift in the evolutionary rate may reflect a lesser historical evolutionary constraint, once again highlighting the potential influence of pollinators, especially bees, on the evolution of UV patterns. Moreover, yellow flowers showed the highest UV chroma optima among bee-flowers, higher than red, white and flowers of other colors. This finding reinforces the influence of bee pollination on optimal values of UV chroma and its faster evolutionary transition among yellow flowers.

By investigating a wide range of bee- and bird-pollinated plant species, we have provided valuable insights into some of the mechanisms generating the remarkable floral color diversity in the angiosperms. Our results support that both attracting primary pollinators but also excluding floral antagonists are important processes in the evolution of floral UV chroma. We have found clear evolutionary signatures of these two processes in red flowers, both in terms of adaptative optima and evolutionary rates. However white and yellow flowers do not exhibit such clear patterns, and evidences of these processes were less pronounced, primarily indicated by the dispersion of optima in the case of white bird-flowers and by higher selective strength in the case of yellow bee-flowers. These findings contribute to our understanding of the ecological and evolutionary processes that have shaped flower coloration over extensive timescales. Further research in this field may delve deeper into the molecular and genetic basis of floral color adaptation, offering a comprehensive view of the evolution of plant-pollinator interactions.

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**TABLES**

Table 1- Number of fittings for each model in the analyses of the UV chroma evolution in the studied subset white-red and yellow flowers. In the white-red subset, the UV chroma evolution was calculated based on the categories of white, red, and other bee and bird-pollinated flowers. In the yellow subset, UV chroma evolution was calculated based on the categories of yellow and other bee and bird-pollinated flowers. Each column represents the model type, best fit, and ties (ΔAICc less than two) relative to the adjusted simulated sample of simmaps fitted for each model separately. The best model frequency in each line does not sum the number of fittings of each reference model (1000) because some simmaps did not suggest a best model. In total, 971 simmaps were analyzed out of 1000 simmaps simulated for the white-red flowers, while for yellow-flowers, 915 were considered. Among these, the OUMV model best fitted in 663 cases for the white-red flowers and the OUMA best fitted in 682 times for the yellow flowers (gray highlight).

| Subset | Model | Best fit | Ties | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BM | BMS | OU1 | OUM | OUMA | OUMV | OUMVA |
| White-Red flowers | BM | 0 | - | | | | | | |
| | BMS | 0 | 0 | - | | | | | |
| | OU1 | 378 | 0 | 0 | - | | | | |
| | OUM | 5 | 0 | 0 | 5 | - | | | |
| | OUMA | 8 | 0 | 0 | 0 | 0 | - | | |
| | OUMV | 663 | 0 | 0 | 89 | 0 | 0 | - | |
| | OUMVA | 111 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| Yellow flowers | BM | 0 | - | | | | | | |
| | BMS | 0 | 0 | - | | | | | |
| | OU1 | 209 | 0 | 0 | - | | | | |
| | OUM | 26 | 0 | 0 | 18 | - | | | |
| | OUMA | 682 | 0 | 0 | 113 | 12 | - | | |
| | OUMV | 40 | 0 | 0 | 0 | 0 | 0 | - | |
| | OUMVA | 94 | 0 | 0 | 1 | 0 | 2 | 0 | - |

**FIGURES**

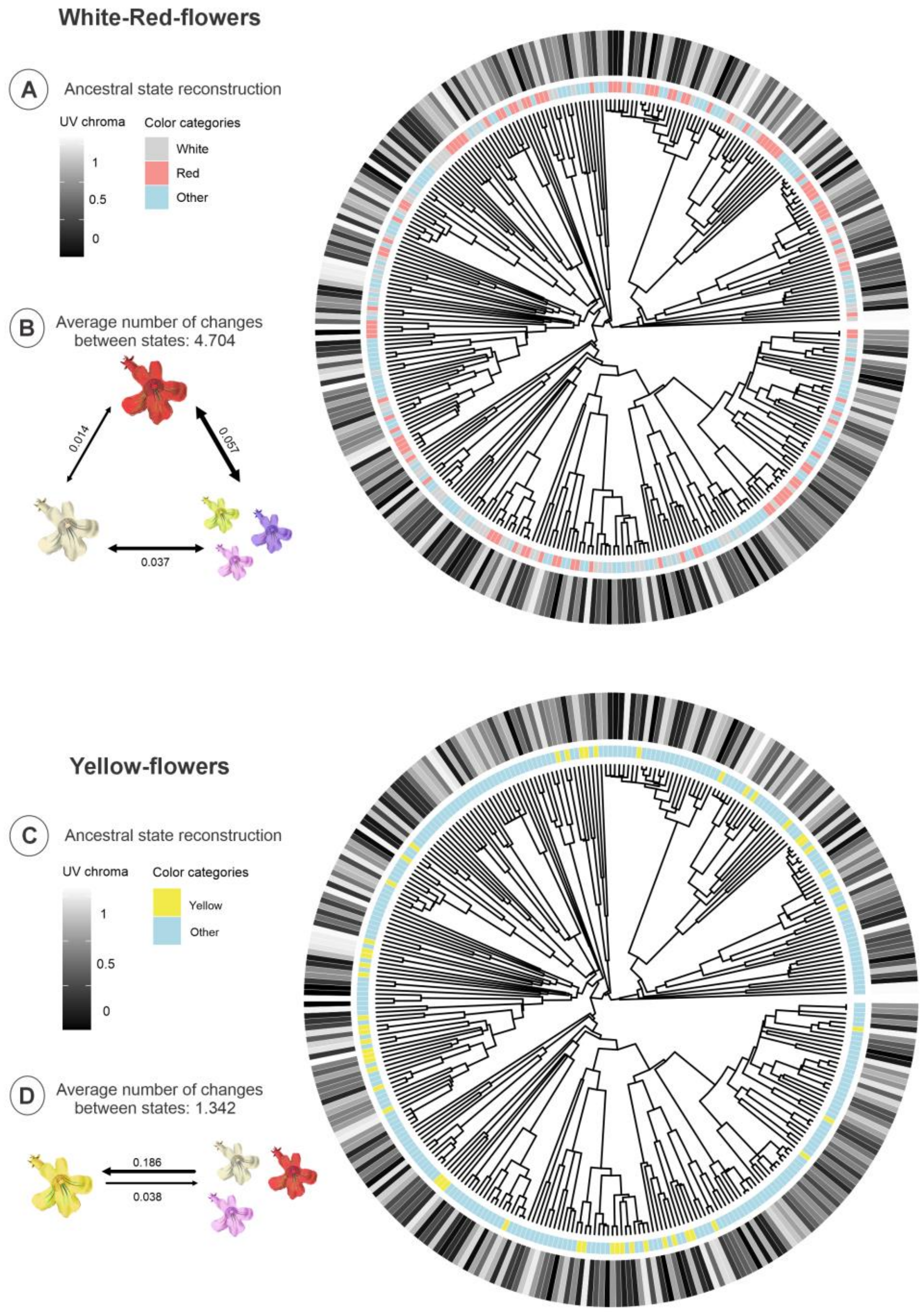


Figure 1. (A) Ancestral state reconstruction of color categories and UV chroma for the white-red flowers subset. (B) Transition rates among the color category states (white, red, and other colors) using the SYM (symmetrical rates) model. (C) Ancestral state reconstruction of color categories and UV chroma for the yellow flowers subset, and (D) Transition rates among the color category states (yellow and other colors) using the ARD (all different rates) model. The thickness of the arrows indicates the frequency of change between states. Both analyses were conducted considering 292 species spread across 205 genera in 76 families. Flower image sources: Watson, L., and Dallwitz, M.J. 1992 onwards. The families of flowering plants: descriptions, illustrations, identification, and information retrieval. Version: 15th April 2024. delta-intkey.com

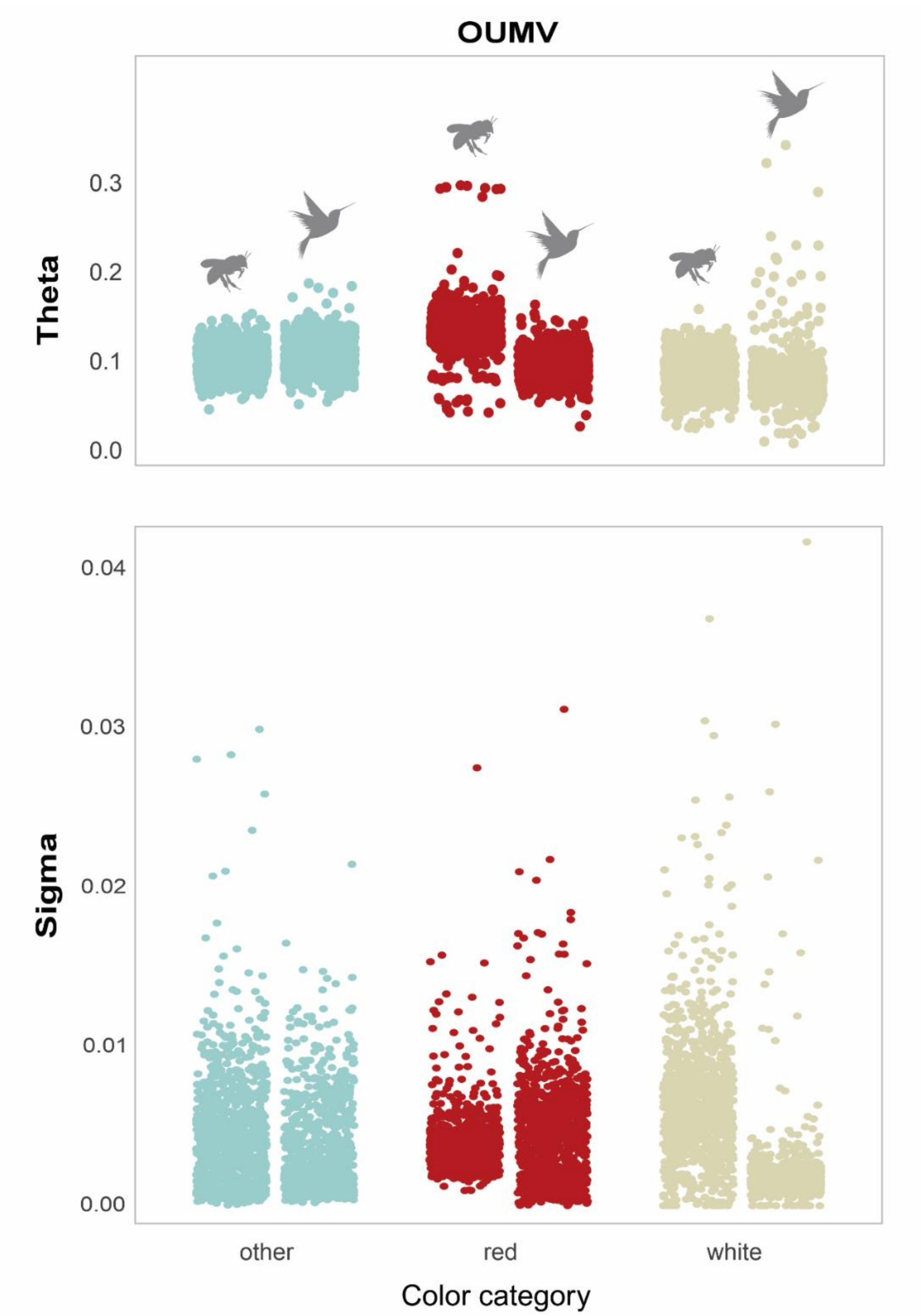


Figure 2. Estimates of parameters from the OUMV model, selected as the best evolutionary model fitted in the analyses of UV chroma evolution among the white-red flowers subset. (A) Adaptive optima (θ - theta) for each color category and pollinator type within this group of flowers. (B) Rates of phenotypic change (σ2 – sigma) around the optima for each of these color categories and pollinator types. The results reveal that species pollinated by bees with red and white flowers have higher values both of θ and σ2, indicating that these species exhibit higher UV chroma optima and have higher phenotypic fluctuations around these optima. The results also show that the optimum values and estimated rates are lower in the 'bee-other' and 'bird-other' categories compared to the white and red categories. Pollinators vector sources: Freepik Company S.L. Version: 15th April 2024. freepik.com

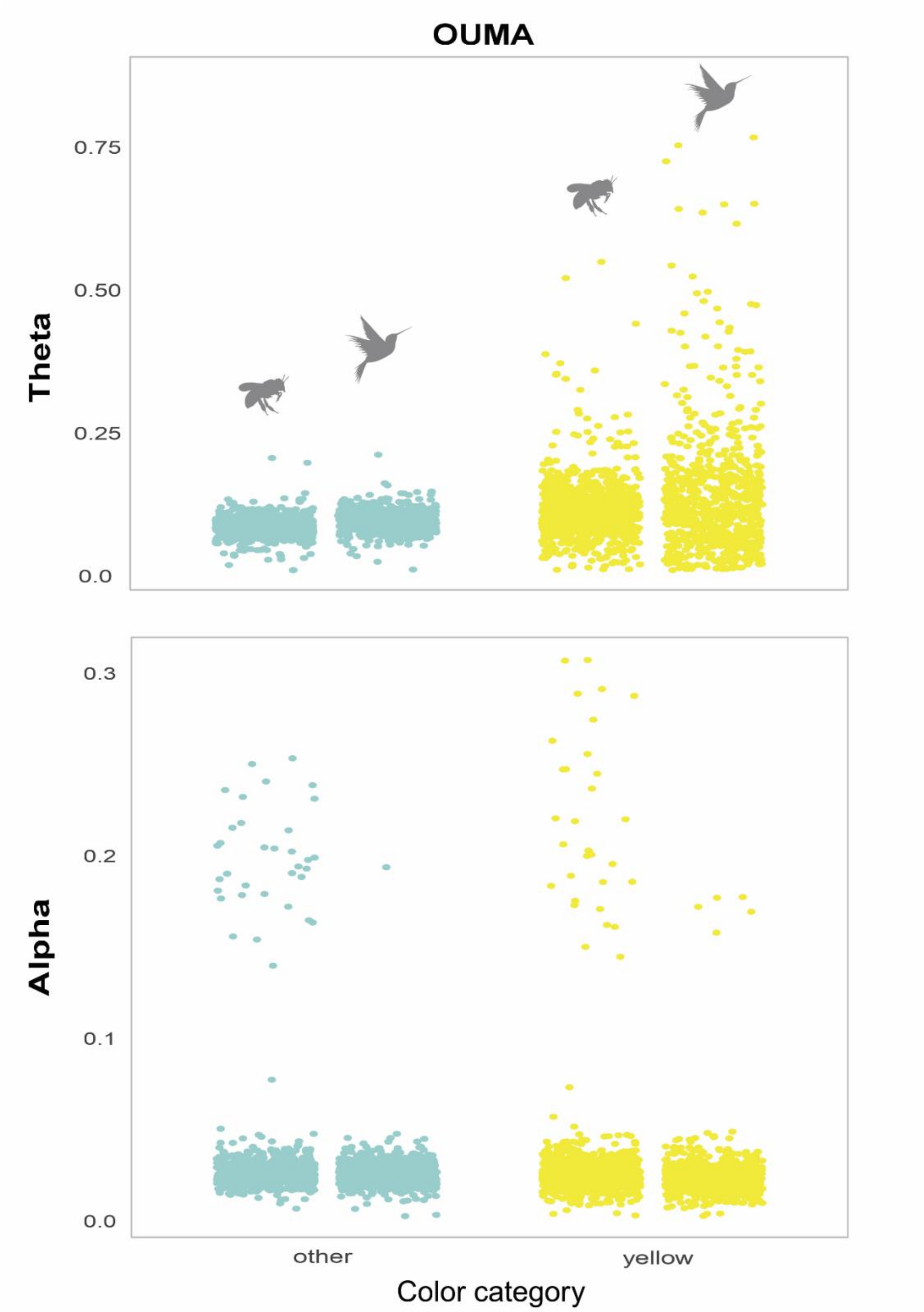


Figure 3. Estimates of parameters derived from the OUMA model, selected as the best evolutionary model utilized in the analysis of UV chroma evolution within the yellow flowers subset. (A) Adaptive optima (θ - theta) for each color category and pollinator type within this flower group. (B) Selective strength (α - alpha) around the optima. The results reveal that yellow bird-pollinated flowers exhibited higher optimal values of UV chroma. In contrast, other color categories among both bee- and bird-pollinated species did not exhibit significant differences among themselves but displayed lower UV chroma values compared to the yellow category. Additionally, the findings indicated that yellow and other-colored bee-pollinated flowers displayed a faster rate of evolutionary change in UV chroma towards the optima. Pollinators vector sources: Freepik Company S.L. Version: 15th April 2024. freepik.com

## MATERIAL SUPLEMENTAR

**Supplementary Table S1.** List of 292 selected plant species designated for macroevolutionary analysis. The table includes the botanical classification of the plant species, their attractant structures (S), geographical occurrence areas (N- neotropical, EM -extra-neotropical, G- global), pollination system categorizations (PS), color categories assigned, and their respective UV chroma values (following Camargo *et al.* 2019 and Coimbra *et al.* 2020). Attractant structures (S) are classified as P-petal, SP-sepal, B-bract, and ST-stamen. VG refers to categorizing visitors into groups based on their specific behavior, size, and function during flower visits. PS involves categorizing the pollination systems that plants use based on the functional groups of floral visitors that are present in those systems. Color categories comprise 16 subdivisions, including those that are UV absorbent (UV-) and UV reflectant (UV+). Species are organized based on their botanical families, in 205 genera and 76 distinct botanical families.

| Species | Genus | Family | S | Area | VG | OS | Color | UV Chroma | RI | Database |
|---|---|---|---|---|---|---|---|---|---|---|
| *Acacia podalyriifolia G.Don* | Acacia | Fabaceae | ST | G | bee | bee | UV-Yellow | 0.034 | 283 | SP and KL dataset |
| *Aconitum anthora L.* | Aconitum | Ranunculaceae | P | EN | bee | bee | UV+Yellow | 0.068 | 5 | SP and KL dataset |
| *Aconitum napellus L.* | Aconitum | Ranunculaceae | P | EN | bee | bee | UV+Blue | 0.089 | 6 | SP and KL dataset |
| *Aechmea aquilega (Salisb.) Griseb.* | Aechmea | Bromeliaceae | P | G | bird | bird | UV-Red | 0.008 | 3 | Coimbra et al. 2020 |
| *Aechmea blanchetiana (Baker) L.B.Sm.* | Aechmea | Bromeliaceae | B | N | bird | bird | UV-Red | 0.013 | 9 | SP and KL dataset |
| *Aechmea bromeliifolia (Rudge) Baker* | Aechmea | Bromeliaceae | P | G | bird | bird | UV-Red | 0.007 | 10 | SP and KL dataset |
| *Aechmea eurycorymbus Harms* | Aechmea | Bromeliaceae | P | N | bird | bird | UV-Yellow | 0.013 | 7 | SP and KL dataset |
| *Aechmea fulgens Brongn.* | Aechmea | Bromeliaceae | P | N | bird | bird | UV+Pink | 0.091 | 13 | SP and KL dataset |
| *Aechmea pectinata Baker* | Aechmea | Bromeliaceae | P | N | bird | bird | UV+White | 0.058 | 15 | SP and KL dataset |
| *Aechmea recurvata (Klotzsch) L.B.Sm.* | Aechmea | Bromeliaceae | P | N | bird | bird | UV+Pink | 0.258 | 16 | SP and KL dataset |
| *Agapetes hosseana Diels* | Agapetes | Ericaceae | P | EN | bird | bird | UV-Red | 0.167 | 17 | SP and KL dataset |
| *Agapetes serpens (Wight) Sleumer* | Agapetes | Ericaceae | P | EN | bird | bird | UV+Red | 0.107 | 17 | SP and KL dataset |
| *Agastache mexicana (Kunth) Lint & Epling* | Agastache | Lamiaceae | P | G | bird | bird | UV+Pink | 0.05 | 284 | SP and KL dataset |
| *Alcea rosea L.* | Alcea | Malvaceae | P | EN | bee | bee | UV+Pink | 0.065 | 7 | SP and KL dataset |
| *Alkanna strigosa Boiss. & Hohen.* | Alkanna | Boraginaceae | P | G | bee | bee | UV+Blue | 0.109 | 1 | Coimbra et al. 2020 |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Allamanda blanchetii A.DC.* | Allamanda | Apocynaceae | P | G | bee | bee | UV-Pink | 0.051 | 19 | SP and KL dataset |
| *Allamanda schottii Pohl* | Allamanda | Apocynaceae | P | G | bee | bee | UV-Yellow | 0.038 | 21 | SP and KL dataset |
| *Aloe africana Mill.* | Aloe | Asphodelaceae | P | EN | bird | bird | UV-Yellow | 0.044 | 22 | SP and KL dataset |
| *Aloe bakeri Scott-Elliot* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Yellow | 0.138 | 16 | SP and KL dataset |
| *Aloe bellatula Reynolds* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Red | 0.071 | 16 | SP and KL dataset |
| *Aloe ciliaris Haw.* | Aloe | Asphodelaceae | P | EN | bird | bird | UV-Red | 0.056 | 16 | SP and KL dataset |
| *Aloe descoingsii Reynolds* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Red | 0.074 | 16 | SP and KL dataset |
| *Aloe plicatilis (L.) Mill.* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Red | 0.047 | 16 | SP and KL dataset |
| *Aloe viguieri H.Perrier* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Red | 0.153 | 16 | SP and KL dataset |
| *Aloe vogtsii Reynolds* | Aloe | Asphodelaceae | P | EN | bird | bird | UV-Yellow | 0.031 | 23 | SP and KL dataset |
| *Alpinia purpurata (Vieill.) K.Schum.* | Alpinia | Zingiberaceae | B | G | bird | bird | UV-Red | 0.06 | 24 | SP and KL dataset |
| *Alpinia zerumbet (Pers.) B.L.Burtt & R.M.Sm.* | Alpinia | Zingiberaceae | P | EN | bee | bee | UV+Yellow | 0.06 | 25 | SP and KL dataset |
| *Amherstia nobilis Wall.* | Amherstia | Fabaceae | P | EN | bird | bird | UV-Red | 0.058 | 47 | SP and KL dataset |
| *Anagyris foetida L.* | Anagyris | Fabaceae | P | EN | bee | bee | UV-Yellow | 0.056 | 1 | Coimbra et al. 2020 |
| *Ananas bracteatus (Lindl.) Schult. & Schult.f.* | Ananas | Bromeliaceae | B | N | bird | bird | UV-Red | 0.038 | 27 | SP and KL dataset |
| *Anchusa strigosa Banks & Sol.* | Anchusa | Boraginaceae | P | EN | bee | bee | UV+Blue | 0.112 | 1 | Coimbra et al. 2020 |
| *Anemone nemorosa L.* | Anemone | Ranunculaceae | P | EN | bee | bee | UV-White | 0.009 | 1 | Coimbra et al. 2020 |
| *Anigozanthos flavidus DC.* | Anigozanthos | Haemodoraceae | P | EN | bird | bird | UV-Cyan | 0.029 | 2 | SP and KL dataset |
| *Apeiba tibourbou Aubl.* | Apeiba | Malvaceae | P | N | bee | bee | UV+Yellow | 0.26 | 29 | SP and KL dataset |
| *Aquilegia einseleana F.W.Schultz* | Aquilegia | Ranunculaceae | P | EN | bee | bee | UV-Blue | 0.073 | 31 | SP and KL dataset |
| *Arctostaphylos uva-ursi (L.) Spreng.* | Arctostaphylos | Ericaceae | P | EN | bee | bee | UV-White | 0.033 | 1 | Coimbra et al. 2020 |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Asphodeline liburnica (Scop.) Rchb.* | Asphodeline | Asphodelaceae | P | EN | bee | bee | UV+Yellow | 0.088 | 34 | SP and KL dataset |
| *Asphodelus aestivus Brot.* | Asphodelus | Asphodelaceae | P | EN | bee | bee | UV+White | 0.089 | 34 | SP and KL dataset |
| *Astragalus amalecitanus Boiss.* | Astragalus | Fabaceae | P | EN | bee | bee | UV-White | 0.024 | 1 | Coimbra et al. 2020 |
| *Baccharis trimera (Less.) DC.* | Baccharis | Asteraceae | P | N | bee | bee | UV-Yellow | 0.015 | 12 | SP and KL dataset |
| *Banksia prionotes Lindl.* | Banksia | Proteaceae | ST | EN | bird | bird | UV+Red | 0.063 | 35 | SP and KL dataset |
| *Begonia coccinea Hook.* | Begonia | Begoniaceae | P | G | bee | bee | UV+White | 0.12 | 40 | SP and KL dataset |
| *Berberis darwinii Hook.* | Berberis | Berberidaceae | P | EN | bee | bee | UV+Yellow | 0.142 | 42 | SP and KL dataset |
| *Bidens ferulifolia (Jacq.) Sweet* | Bidens | Asteraceae | P | EN | bee | bee | UV+Yellow | 0.089 | 43 | SP and KL dataset |
| *Billbergia amoena (Lodd.) Lindl.* | Billbergia | Bromeliaceae | P | N | bird | bird | UV+Green | 0.166 | 44 | SP and KL dataset |
| *Billbergia nutans H.Wendl. ex Regel* | Billbergia | Bromeliaceae | B | G | bird | bird | UV-Red | 0.046 | 16 | SP and KL dataset |
| *Billbergia pyramidalis (Sims) Lindl.* | Billbergia | Bromeliaceae | B | G | bird | bird | UV-Red | 0.004 | 45 | SP and KL dataset |
| *Billbergia viridiflora H.Wendl.* | Billbergia | Bromeliaceae | B | N | bird | bird | UV+Red | 0.175 | 16 | SP and KL dataset |
| *Brownea grandiceps Jacq.* | Brownea | Fabaceae | P | G | bird | bird | UV+Red | 0.753 | 46 | SP and KL dataset |
| *Byrsonima verbascifolia (L.) DC.* | Byrsonima | Malpighiaceae | P | N | bee | bee | UV+Yellow | 0.636 | 51 | SP and KL dataset |
| *Calanthe vestita Wall. ex Lindl.* | Calanthe | Orchidaceae | P | EN | bee | bee | UV-White | 0.007 | 16 | SP and KL dataset |
| *Calicotome villosa (Poir.) Link* | Calicotome | Fabaceae | P | EN | bee | bee | UV+Yellow | 0.06 | 1 | Coimbra et al. 2020 |
| *Callianthe megapotamica (A.Spreng.) Dorr* | Callianthe | Malvaceae | P | G | bird | bird | UV-Yellow | 0.047 | 52 | SP and KL dataset |
| *Callianthe picta (Gillies ex Hook. & Arn.) Donnell* | Callianthe | Malvaceae | P | G | bird | bird | UV-Red | 0.126 | 53 | SP and KL dataset |
| *Callistemon viminalis (Sol. ex Gaertn.) G.Don* | Callistemon | Myrtaceae | ST | EN | bird | bird | UV+Red | 0.115 | 2 | SP and KL dataset |
| *Camellia japonica L.* | Camellia | Theaceae | P | EN | bird | bird | UV+Pink | 0.138 | 55 | SP and KL dataset |
| *Camellia sasanqua Thunb.* | Camellia | Theaceae | P | EN | bird | bird | UV-Pink | 0.033 | 56 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Camellia sinensis (L.) Kuntze* | Camellia | Theaceae | P | G | bee | bee | UV+White | 0.047 | 17 | SP and KL dataset |
| *Campanula cochleariifolia Lam.* | Campanula | Campanulaceae | P | EN | bee | bee | UV+Blue | 0.249 | 57 | SP and KL dataset |
| *Campanula poscharskyana Degen* | Campanula | Campanulaceae | P | EN | bee | bee | UV+Blue | 0.093 | 58 | SP and KL dataset |
| *Campsis grandiflora (Thunb.) K.Schum.* | Campsis | Bignoniaceae | P | EN | bee | bee | UV+Red | 0.086 | 59 | SP and KL dataset |
| *Campsis radicans (L.) Seem.* | Campsis | Bignoniaceae | P | EN | bird | bird | UV-Red | 0.082 | 17 | SP and KL dataset |
| *Canarina canariensis (L.) Vatke* | Canarina | Campanulaceae | P | EN | bird | bird | UV+Red | 0.136 | 60 | SP and KL dataset |
| *Cantua buxifolia Juss. ex Lam.* | Cantua | Polemoniaceae | P | G | bird | bird | UV+Pink | 0.12 | 61 | SP and KL dataset |
| *Centaurea aegyptiaca L.* | Centaurea | Asteraceae | P | EN | bee | bee | UV+White | 0.05 | 1 | Coimbra et al. 2020 |
| *Centaurea ammocyanus Boiss.* | Centaurea | Asteraceae | P | EN | bee | bee | UV+Pink | 0.062 | 1 | Coimbra et al. 2020 |
| *Centaurea pallescens Delile* | Centaurea | Asteraceae | P | EN | bee | bee | UV-White | 0.005 | 1 | Coimbra et al. 2020 |
| *Centropogon cornutus (L.) Druce* | Centropogon | Campanulaceae | P | G | bird | bird | UV-Red | 0.057 | 66 | SP and KL dataset |
| *Centropogon valerii Standl.* | Centropogon | Campanulaceae | P | N | bird | bird | UV-Red | 0.052 | 66 | SP and KL dataset |
| *Cercis siliquastrum L.* | Cercis | Fabaceae | P | EN | bee | bee | UV-Pink | 0.013 | 1 | Coimbra et al. 2020 |
| *Chaenomeles japonica (Thunb.) Lindl. ex Spach* | Chaenomeles | Rosaceae | P | EN | bee | bee | UV-Red | 0.081 | 69 | SP and KL dataset |
| *Chasmanthe aethiopica (L.) N.E.Br.* | Chasmanthe | Iridaceae | P | EN | bird | bird | UV+Red | 0.07 | 70 | SP and KL dataset |
| *Chelone lyonii Pursh* | Chelone | Plantaginaceae | P | EN | bee | bee | UV+Pink | 0.062 | 71 | SP and KL dataset |
| *Cirsium oleraceum (L.) Scop.* | Cirsium | Asteraceae | P | EN | bee | bee | UV-White | 0.017 | 1 | Coimbra et al. 2020 |
| *Cistus creticus (Viv.) Greuter & Burdet* | Cistus | Cistaceae | P | EN | bee | bee | UV-Pink | 0.009 | 73 | SP and KL dataset |
| *Cistus inflatus Pourr. ex J.-P.Demoly* | Cistus | Cistaceae | P | EN | bee | bee | UV-White | 0.015 | 74 | SP and KL dataset |
| *Citrus aurantium L.* | Citrus | Rutaceae | P | G | bird | bird | UV-White | 0.019 | 75 | SP and KL dataset |
| *Clidemia hirta (L.) D. Don* | Clidemia | Melastomataceae | P | EN | bee | bee | UV-White | 0.033 | 12 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Clusia lanceolata Cambess.* | Clusia | Clusiaceae | P | N | bee | bee | UV+White | 0.252 | 77 | SP and KL dataset |
| *Clusia lanceolata Cambess.* | Clusia | Clusiaceae | P | N | bee | bee | UV+White | 0.252 | 77 | SP and KL dataset |
| *Clytostoma callistegioides (Cham.) Baill.* | Clytostoma | Bignoniaceae | P | G | bee | bee | UV-Pink | 0.053 | 78 | SP and KL dataset |
| *Cochlospermum vitifolium (Willd.) Spreng.* | Cochlospermum | Bixaceae | P | N | bee | bee | UV+Yellow | 0.128 | 80 | SP and KL dataset |
| *Codonanthe gracilis (Mart.) Hanst.* | Codonanthe | Gesneriaceae | P | N | bee | bee | UV+White | 0.059 | 17 | SP and KL dataset |
| *Collaea argentina Griseb.* | Collaea | Fabaceae | P | N | bee | bee | UV+Pink | 0.073 | 85 | SP and KL dataset |
| *Columnea magnifica Klotzsch ex Oerst.* | Columnea | Gesneriaceae | P | N | bird | bird | UV+Red | 0.104 | 86 | SP and KL dataset |
| *Columnea magnifica Klotzsch ex Oerst.* | Columnea | Gesneriaceae | P | N | bird | bird | UV+Red | 0.082 | 86 | SP and KL dataset |
| *Columnea microcalyx Hanst.* | Columnea | Gesneriaceae | P | N | bird | bird | UV-Red | 0.052 | 86 | SP and KL dataset |
| *Columnea scandens L.* | Columnea | Gesneriaceae | P | G | bird | bird | UV-Red | 0.072 | 87 | SP and KL dataset |
| *Coreopsis grandiflora Hogg ex Sweet* | Coreopsis | Asteraceae | P | EN | bee | bee | UV-Yellow | 0.045 | 89 | SP and KL dataset |
| *Corylus avellana L.* | Corylus | Bertulaceae | P | EN | bee | bee | UV-Yellow | 0.011 | 1 | Coimbra et al. 2020 |
| *Corymbia ficifolia (F.Muell.) K.D.Hill & L.A.S.Johnson* | Corymbia | Myrtaceae | ST | EN | bird | bird | UV-Red | 0.07 | 90 | SP and KL dataset |
| *Costus afer Ker Gawl.* | Costus | Costaceae | P | EN | bee | bee | UV+White | 0.384 | 42 | SP and KL dataset |
| *Costus afer Ker Gawl.* | Costus | Costaceae | P | EN | bee | bee | UV+White | 0.739 | 42 | SP and KL dataset |
| *Costus erythrophyllus Loes.* | Costus | Costaceae | P | N | bee | bee | UV+White | 0.197 | 92 | SP and KL dataset |
| *Costus malortieanus H.Wendl.* | Costus | Costaceae | P | G | bee | bee | UV+Yellow | 0.092 | 94 | SP and KL dataset |
| *Costus pulverulentus C.Presl* | Costus | Costaceae | P | N | bee | bee | UV+Red | 0.14 | 94 | SP and KL dataset |
| *Costus spicatus (Jacq.) Sw.* | Costus | Costaceae | P | N | bird | bird | UV-Pink | 0.025 | 94 | SP and KL dataset |
| *Crinodendron patagua Molina* | Crinodendron | Elaeocarpaceae | P | N | bee | bee | UV-White | 0.033 | 95 | SP and KL dataset |
| *Crotalaria agatiflora Schweinf.* | Crotalaria | Fabaceae | P | EN | bird | bird | UV+Green | 0.1 | 97 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Curcuma longa L.* | Curcuma | Zingiberaceae | P | G | bee | bee | UV+White | 0.134 | 100 | SP and KL dataset |
| *Cyclamen persicum Mill.* | Cyclamen | Primulaceae | P | EN | bee | bee | UV-White | 0.008 | 1 | Coimbra et al. 2020 |
| *Dahlstedtia pinnata (Benth.) Malme* | Dahlstedtia | Fabaceae | P | N | bird | bird | UV+Pink | 0.071 | 45 | Coimbra et al. 2020 |
| *Dalechampia spathulata (Scheidw.) Baill.* | Dalechampia | Euphorbiaceae | L | N | bee | bee | UV+Pink | 0.069 | 104 | SP and KL dataset |
| *Dendrobium nobile Lindl.* | Dendrobium | Orchidaceae | P | EN | bee | bee | UV-Pink | 0.052 | 16 | SP and KL dataset |
| *Desfontainia spinosa Ruiz & Pav.* | Desfontainia | Columelliaceae | P | N | bird | bird | UV-Red | 0.039 | 107 | SP and KL dataset |
| *Dianthus superbus L.* | Dianthus | Caryophyllaceae | P | EN | bee | bee | UV+White | 0.057 | 109 | SP and KL dataset |
| *Dichorisandra thyrsiflora J.C.Mikan* | Dichorisandra | Commelinaceae | P | EN | bee | bee | UV+Blue | 0.116 | 255 | SP and KL dataset |
| *Digitalis parviflora Jacq.* | Digitalis | Plantaginaceae | P | EN | bee | bee | UV-Red | 0.071 | 210 | SP and KL dataset |
| *Digitalis purpurea L.* | Digitalis | Plantaginaceae | P | EN | bee | bee | UV+Pink | 0.051 | 210 | SP and KL dataset |
| *Duranta erecta L.* | Duranta | Verbenaceae | P | EN | bee | bee | UV-Blue | 0.248 | 237 | SP and KL dataset |
| *Echium angustifolium Mill.* | Echium | Boraginaceae | P | EN | bee | bee | UV-Pink | 0.131 | 1 | Coimbra et al. 2020 |
| *Echium candicans L.f.* | Echium | Boraginaceae | P | EN | bee | bee | UV-Blue | 0.024 | 271 | SP and KL dataset |
| *Echium hierrense Webb ex Bolle* | Echium | Boraginaceae | P | EN | bee | bee | UV+Pink | 0.071 | 140 | SP and KL dataset |
| *Echium vulgare L.* | Echium | Boraginaceae | P | EN | bee | bee | UV+Blue | 0.151 | 47 | SP and KL dataset |
| *Eichhornia azurea (Sw.) Kunth* | Eichhornia | Pontederiaceae | P | N | bee | bee | UV-Blue | 0.292 | 117 | SP and KL dataset |
| *Emilia coccinea (Sims) G.Don* | Emilia | Asteraceae | P | EN | bee | bee | UV+White | 0.248 | 186 | SP and KL dataset |
| *Ensete lasiocarpum (Franch.) Cheesman* | Musella | Musaceae | B | EN | bee | bee | UV+Yellow | 0.109 | 189 | SP and KL dataset |
| *Entelea arborescens R.Br.* | Entelea | Malvaceae | P | EN | bee | bee | UV-White | 0.005 | 125 | SP and KL dataset |
| *Epimedium versicolor E.Morren* | Epimedium | Berberidaceae | P | EN | bee | bee | UV+Yellow | 0.08 | 260 | SP and KL dataset |
| *Eremurus stenophyllus (Boiss. & Buhse) Baker* | Eremurus | Asphodelaceae | P | EN | bee | bee | UV+Yellow | 0.061 | 16 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Erica caffra L.* | Erica | Ericaceae | P | EN | bee | bee | UV+White | 0.061 | 17 | SP and KL dataset |
| *Erica mammosa L.* | Erica | Ericaceae | P | EN | bird | bird | UV+White | 0.102 | 236 | SP and KL dataset |
| *Erica versicolor Andrews* | Erica | Ericaceae | P | EN | bird | bird | UV-Red | 0.006 | 236 | SP and KL dataset |
| *Erigeron canadensis L.* | Erigeron | Asteraceae | P | EN | bee | bee | UV-White | 0.033 | 1 | Coimbra et al. 2020 |
| *Eriobotrya japonica (Thunb.) Lindl.* | Eriobotrya | Rosaceae | P | EN | bird | bird | UV-White | 0.035 | 207 | SP and KL dataset |
| *Erythrina falcata Benth.* | Erythrina | Fabaceae | P | N | bird | bird | UV-Red | 0.023 | 143 | SP and KL dataset |
| *Erythrina fusca Lour.* | Erythrina | Fabaceae | P | G | bird | bird | UV+White | 0.054 | 209 | SP and KL dataset |
| *Erythrina humeana Spreng.* | Erythrina | Fabaceae | P | G | bird | bird | UV-Red | 0.087 | 17 | SP and KL dataset |
| *Erythrina speciosa Andrews* | Erythrina | Fabaceae | P | N | bird | bird | UV+Red | 0.094 | 45 | Coimbra et al. 2020 |
| *Erythrochiton brasiliensis Nees & Mart.* | Erythrochiton | Rutaceae | P | N | bird | bird | UV+White | 0.109 | 192 | SP and KL dataset |
| *Erythronium oregonum Applegate* | Erythronium | Liliaceae | P | EN | bee | bee | UV+White | 0.049 | 217 | SP and KL dataset |
| *Eschscholzia californica Cham.* | Eschscholzia | Papaveraceae | P | EN | bee | bee | UV-Yellow | 0.032 | 280 | SP and KL dataset |
| *Euphorbia pulcherrima Willd. ex Klotzsch* | Euphorbia | Euphorbiaceae | B | N | bird | bird | UV-Red | 0.101 | 207 | SP and KL dataset |
| *Fosterella penduliflora (C.H.Wright) L.B.Sm.* | Fosterella | Bromeliaceae | P | N | bee | bee | UV-White | 0.043 | 16 | SP and KL dataset |
| *Freycinetia cumingiana Gaudich.* | Freycinetia | Pandanaceae | B | EN | bird | bird | UV+Red | 0.33 | 135 | SP and KL dataset |
| *Freylinia lanceolata (L.) G.Don* | Freylinia | Scrophulariaceae | P | EN | bee | bee | UV-Yellow | 0.044 | 214 | SP and KL dataset |
| *Fuchsia boliviana CarriÃ¨re* | Fuchsia | Onagraceae | P | N | bird | bird | UV+Red | 0.138 | 52 | SP and KL dataset |
| *Fuchsia loxensis Kunth* | Fuchsia | Onagraceae | SP | N | bird | bird | UV+Pink | 0.086 | 2 | SP and KL dataset |
| *Fuchsia magdalenae Munz* | Fuchsia | Onagraceae | P | N | bird | bird | UV+Red | 0.131 | 2 | SP and KL dataset |
| *Fuchsia microphylla Kunth* | Fuchsia | Onagraceae | P | G | bird | bird | UV+Pink | 0.142 | 114 | SP and KL dataset |
| *Fuchsia paniculata Lindl.* | Fuchsia | Onagraceae | P | G | bird | bird | UV+Pink | 0.075 | 2 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Fuchsia regia (Vand. ex Vell.) Munz* | Fuchsia | Onagraceae | P | N | bird | bird | UV-Red | 0.081 | 253 | SP and KL dataset |
| *Fuchsia vulcanica AndrÃ©* | Fuchsia | Onagraceae | P | N | bird | bird | UV-Red | 0.07 | 2 | SP and KL dataset |
| *Galium verum L.* | Galium | Rubiaceae | P | EN | bee | bee | UV-Yellow | 0.015 | 1 | Coimbra et al. 2020 |
| *Gasteria pulchra (Aiton) Haw.* | Gasteria | Asphodelaceae | P | EN | bird | bird | UV-Red | 0.007 | 170 | Coimbra et al. 2020 |
| *Gentiana acaulis L.* | Gentiana | Gentianaceae | P | EN | bee | bee | UV+Blue | 0.178 | 112 | SP and KL dataset |
| *Gentiana asclepiadea L.* | Gentiana | Gentianaceae | P | EN | bee | bee | UV+Blue | 0.171 | 218 | SP and KL dataset |
| *Gesneria ventricosa Sw.* | Gesneria | Gesneriaceae | P | N | bird | bird | UV-Red | 0.045 | 17 | SP and KL dataset |
| *Gomphocarpus physocarpus E.Mey.* | Gomphocarpus | Apocynaceae | P | G | wasp | bee | UV+White | 0.055 | 149 | SP and KL dataset |
| *Gossypium herbaceum L.* | Gossypium | Malvaceae | P | G | bee | bee | UV+White | 0.246 | 208 | SP and KL dataset |
| *Grevillea banksii R.Br.* | Grevillea | Proteaceae | P | G | bird | bird | UV-Red | 0.04 | 148 | SP and KL dataset |
| *Grevillea rosmarinifolia A.Cunn.* | Grevillea | Proteaceae | P | EN | bird | bird | UV+Pink | 0.063 | 148 | SP and KL dataset |
| *Greyia sutherlandii Hook. & Harv.* | Greyia | Francoaceae | P | EN | bird | bird | UV+Red | 0.121 | 211 | SP and KL dataset |
| *Handroanthus heptaphyllus (Vell.) Mattos* | Handroanthus | Bignoniaceae | P | G | bee | bee | UV-Pink | 0.02 | 199 | SP and KL dataset |
| *Heliconia angusta Vell.* | Heliconia | Heliconiaceae | B | G | bird | bird | UV+Red | 0.099 | 45 | SP and KL dataset |
| *Heliconia bihai (L.) L.* | Heliconia | Heliconiaceae | B | N | bird | bird | UV+Red | 0.773 | 158 | SP and KL dataset |
| *Heliconia farinosa Raddi* | Heliconia | Heliconiaceae | B | N | bird | bird | UV-Red | 0.052 | 258 | SP and KL dataset |
| *Heliconia metallica Planch. & Linden ex Hook.* | Heliconia | Heliconiaceae | P | G | bird | bird | UV-Red | 0.074 | 246 | Coimbra et al. 2020 |
| *Heliconia rostrata Ruiz & Pav.* | Heliconia | Heliconiaceae | P | G | bird | bird | UV+Red | 0.068 | 45 | SP and KL dataset |
| *Hellenia speciosa (J.Koenig) S.R.Dutta* | Hellenia | Costaceae | P | G | bee | bee | UV+White | 0.124 | 242 | SP and KL dataset |
| *Hesperis pendula DC.* | Hesperis | Brassicaceae | P | EN | bee | bee | UV-Green | 0.016 | 1 | Coimbra et al. 2020 |
| *Heterocentron elegans (Schltdl.) Kuntze* | Heterocentron | Melastomataceae | P | N | bee | bee | UV+Pink | 0.21 | 238 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Hibiscus schizopetalus (Dyer) Hook.f.* | Hibiscus | Malvaceae | P | G | bird | bird | UV+Red | 0.103 | 51 | SP and KL dataset |
| *Hoffmannia refulgens (Hook.) Hemsl.* | Hoffmannia | Rubiaceae | P | N | bee | bee | UV+Red | 0.117 | 17 | SP and KL dataset |
| *Hypericum maculatum Crantz* | Hypericum | Hypericaceae | P | EN | bee | bee | UV+Yellow | 0.228 | 165 | SP and KL dataset |
| *Impatiens niamniamensis Gilg* | Impatiens | Balsamiaceae | P | EN | bird | bird | UV-Yellow | 0.031 | 52 | SP and KL dataset |
| *Impatiens noli-tangere L.* | Impatiens | Balsamiaceae | P | EN | bird | bird | UV+Yellow | 0.236 | 229 | SP and KL dataset |
| *Impatiens scabrida DC.* | Impatiens | Balsamiaceae | P | EN | bee | bee | UV-Yellow | 0.051 | 229 | SP and KL dataset |
| *Incarvillea delavayi Bureau & Franch.* | Incarvillea | Bignoniaceae | P | EN | bee | bee | UV+Pink | 0.08 | 137 | SP and KL dataset |
| *Iris domestica (L.) Goldblatt & Mabb.* | Iris | Iridaceae | P | EN | bee | bee | UV-Red | 0.297 | 190 | SP and KL dataset |
| *Jatropha podagrica Hook.* | Jatropha | Euphorbiaceae | P | EN | bird | bird | UV-Red | 0.041 | 2 | SP and KL dataset |
| *Kennedia coccinea Vent.* | Kennedia | Fabaceae | P | EN | bird | bird | UV-Red | 0.093 | 194 | SP and KL dataset |
| *Kniphofia uvaria (L.) Oken* | Kniphofia | Asphodelaceae | P | EN | bird | bird | UV-Red | 0.043 | 274 | SP and KL dataset |
| *Kohleria spicata (Kunth) Oerst.* | Kohleria | Gesneriaceae | P | N | bird | bird | UV+White | 0.113 | 201 | SP and KL dataset |
| *Kohleria spicata (Kunth) Oerst.* | Kohleria | Gesneriaceae | P | N | bird | bird | UV+Red | 0.124 | 201 | SP and KL dataset |
| *Lamprocapnos spectabilis (L.) Fukuhara* | Lamprocapnos | Papaveraceae | P | EN | bee | bee | UV+Pink | 0.11 | 257 | SP and KL dataset |
| *Lapageria rosea Ruiz & Pav.* | Lapageria | Philesiaceae | P | N | bird | bird | UV+Pink | 0.128 | 116 | SP and KL dataset |
| *Leopoldia longipes (Boiss.) Losinsk.* | Leopoldia | Asparagaceae | P | EN | bee | bee | UV-Blue | 0.048 | 1 | Coimbra et al. 2020 |
| *Lessertia frutescens (L.) Goldblatt & J.C. Manning* | Lessertia | Fabaceae | P | EN | bird | bird | UV+Red | 0.102 | 249 | SP and KL dataset |
| *Leucospermum glabrum E. Phillips* | Leucospermum | Proteaceae | ST | EN | bird | bird | UV+Yellow | 0.079 | 205 | SP and KL dataset |
| *Leycesteria formosa Wall.* | Leycesteria | Caprifoliaceae | P | EN | bee | bee | UV-White | 0.035 | 17 | SP and KL dataset |
| *Libertia ixioides (G.Forst.) Spreng.* | Libertia | Iridaceae | P | EN | bee | bee | UV-White | 0.03 | 118 | SP and KL dataset |
| *Linum grandiflorum Desf.* | Linum | Linaceae | P | EN | bee | bee | UV+Red | 0.293 | 2 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Lobelia anceps L.f.* | Lobelia | Campanulaceae | P | EN | bee | bee | UV-Blue | 0.003 | 17 | Coimbra et al. 2020 |
| *Lobelia siphilitica L.* | Lobelia | Campanulaceae | P | EN | bee | bee | UV+Blue | 0.074 | 172 | SP and KL dataset |
| *Lobelia tupa L.* | Lobelia | Campanulaceae | P | N | bird | bird | UV+Red | 0.135 | 206 | SP and KL dataset |
| *Lonicera fragrantissima Lindl. & J. Paxton* | Lonicera | Caprifoliaceae | P | EN | bee | bee | UV+White | 0.053 | 256 | SP and KL dataset |
| *Lotus berthelotii Masf.* | Lotus | Fabaceae | P | EN | bird | bird | UV-Red | 0.064 | 60 | SP and KL dataset |
| *Lycium shawii Roem. & Schult.* | Lycium | Solanaceae | P | EN | bee | bee | UV-White | 0.018 | 1 | Coimbra et al. 2020 |
| *Macroptilium atropurpureum (DC.) Urb.* | Macroptilium | Fabaceae | P | G | bee | bee | UV+Black | 0.256 | 272 | SP and KL dataset |
| *Malouetia arborea (Vell.) Miers* | Malouetia | Apocynaceae | P | N | bee | bee | UV-White | 0.004 | 166 | SP and KL dataset |
| *Malva alcea L.* | Malva | Malvaceae | P | EN | bee | bee | UV+Pink | 0.115 | 181 | SP and KL dataset |
| *Mammillaria sheldonii (Britton & Rose) Boed.* | Mammillaria | Cactaceae | P | N | bee | bee | UV+Pink | 0.139 | 2 | SP and KL dataset |
| *Manettia cordifolia Mart.* | Manettia | Rubiaceae | P | N | bird | bird | UV+Red | 0.245 | 132 | SP and KL dataset |
| *Medinilla magnifica Lindl.* | Medinilla | Melastomataceae | P | EN | bee | bee | UV+Pink | 0.118 | 264 | SP and KL dataset |
| *Melaleuca elliptica Labill.* | Melaleuca | Myrtaceae | ST | EN | bird | bird | UV-Red | 0.057 | 2 | SP and KL dataset |
| *Melaleuca hypericifolia Sm.* | Melaleuca | Myrtaceae | P | EN | bird | bird | UV+Red | 0.105 | 226 | SP and KL dataset |
| *Melaleuca quadrifida (R.Br.) Craven & R.D.Edwards* | Melaleuca | Myrtaceae | ST | EN | bird | bird | UV+Red | 0.132 | 129 | SP and KL dataset |
| *Melastoma malabathricum L.* | Melastoma | Melastomataceae | P | EN | bee | bee | UV-White | 0.011 | 195 | SP and KL dataset |
| *Mimosa polycarpa Kunth* | Mimosa | Fabaceae | ST | N | bee | bee | UV+Pink | 0.043 | 188 | SP and KL dataset |
| *Mimulus cardinalis Douglas ex Benth.* | Mimulus | Phrymaceae | P | EN | bird | bird | UV+Red | 0.097 | 245 | SP and KL dataset |
| *Moehringia trinervia (L.) Clairv.* | Moehringia | Caryophyllaceae | P | EN | bee | bee | UV-White | 0.021 | 1 | Coimbra et al. 2020 |
| *Moricandia nitens (Viv.) E.A.Durand & Barratte* | Moricandia | Brassicaceae | P | EN | bee | bee | UV+Pink | 0.147 | 1 | Coimbra et al. 2020 |
| *Mutisia acuminata Ruiz & Pav.* | Mutisia | Asteraceae | P | N | bird | bird | UV+Yellow | 0.078 | 204 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Mutisia acuminata Ruiz & Pav.* | Mutisia | Asteraceae | P | N | bird | bird | UV+Red | 0.088 | 203 | SP and KL dataset |
| *Mutisia coccinea A.St.-Hil.* | Mutisia | Asteraceae | P | N | bird | bird | UV+Black | 0.217 | 244 | SP and KL dataset |
| *Mutisia coccinea A.St.-Hil.* | Mutisia | Asteraceae | P | N | bird | bird | UV-Red | 0.042 | 244 | SP and KL dataset |
| *Nanorrhinum scoparium* | Nanorrhinum | Plantaginaceae | P | EN | bee | bee | UV-Yellow | 0.027 | 1 | Coimbra et al. 2020 |
| *Napaea dioica L.* | Napaea | Malvaceae | P | EN | bee | bee | UV+White | 0.037 | 169 | SP and KL dataset |
| *Neoregelia cruenta (Graham) L.B.Sm.* | Neoregelia | Bromeliaceae | P | N | bird | bird | UV-Blue | 0.034 | 146 | Coimbra et al. 2020 |
| *Nerine sarniensis (L.) Herb.* | Nerine | Amaryllidaceae | P | EN | bee | bee | UV-Red | 0.057 | 16 | SP and KL dataset |
| *Nicotiana rustica L.* | Nicotiana | Solanaceae | P | G | bee | bee | UV+Yellow | 0.1 | 17 | SP and KL dataset |
| *Oenothera lindheimeri Engelm. & A.Gray* | Oenothera | Onagraceae | P | EN | bee | bee | UV+Red | 0.042 | 126 | SP and KL dataset |
| *Oncidium ornithorhynchum Kunth* | Oncidium | Orchidaceae | P | N | bee | bee | UV-Pink | 0.052 | 231 | SP and KL dataset |
| *Opuntia fragilis (Nutt.) Haw.* | Opuntia | Cactaceae | P | EN | bird | bird | UV+Pink | 0.191 | 197 | SP and KL dataset |
| *Pachypodium bispinosum (L.f.) A.DC.* | Pachypodium | Apocynaceae | P | EN | bee | bee | UV+White | 0.063 | 17 | SP and KL dataset |
| *Pandorea jasminoides (Lindl.) K.Schum.* | Pandorea | Bignoniaceae | P | EN | bee | bee | UV-Pink | 0.101 | 222 | SP and KL dataset |
| *Pandorea jasminoides (Lindl.) K.Schum.* | Pandorea | Bignoniaceae | P | EN | bee | bee | UV+White | 0.046 | 222 | SP and KL dataset |
| *Papaver rhoeas L.* | Papaver | Papaveraceae | P | EN | bee | bee | UV-Red | 0.055 | 1 | Coimbra et al. 2020 |
| *Passiflora citrina J.M.MacDougal* | Passiflora | Passifloraceae | P | N | bee | bee | UV+Yellow | 0.063 | 196 | SP and KL dataset |
| *Passiflora edulis Sims* | Passiflora | Passifloraceae | P | N | bee | bee | UV-White | 0.038 | 255 | SP and KL dataset |
| *Paullinia cupana Kunth* | Paullinia | Sapindaceae | P | G | bee | bee | UV-White | 0.032 | 248 | SP and KL dataset |
| *Pavonia multiflora A. St.-Hil.* | Pavonia | Malvaceae | SP | N | bird | bird | UV-Red | 0.084 | 17 | SP and KL dataset |
| *Pelargonium crithmifolium Sm.* | Pelargonium | Geraniaceae | P | EN | bee | bee | UV+White | 0.092 | 259 | SP and KL dataset |
| *Penstemon pinifolius Greene* | Penstemon | Plantaginaceae | P | EN | bird | bird | UV+Red | 0.099 | 184 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Pentas lanceolata (Forssk.) Deflers* | Pentas | Rubiaceae | P | EN | bee | bee | UV-Red | 0.06 | 255 | SP and KL dataset |
| *Philadelphus coronarius L.* | Philadelphus | Hydrangeaceae | P | EN | bee | bee | UV+White | 0.042 | 231 | SP and KL dataset |
| *Phlomoides tuberosa (L.) Moench* | Phlomoides | Lamiaceae | P | EN | bee | bee | UV+White | 0.07 | 215 | SP and KL dataset |
| *Phragmanthera usuiensis (Oliv.) M.G.Gilbert* | Phragmanthera | Loranthaceae | P | EN | bird | bird | UV+Red | 0.101 | 183 | SP and KL dataset |
| *Phygelius capensis E. Mey. ex Benth.* | Phygelius | Scrophulariaceae | P | EN | bird | bird | UV-Pink | 0.062 | 136 | SP and KL dataset |
| *Pieris japonica (Thunb.) D. Don ex G. Don* | Pieris | Ericaceae | P | EN | bee | bee | UV-White | 0.031 | 261 | SP and KL dataset |
| *Pinguicula alpina L.* | Pinguicula | Lentibulariaceae | P | EN | bee | bee | UV-White | 0.01 | 1 | Coimbra et al. 2020 |
| *Pitcairnia heterophylla (Lindl.) Beer* | Pitcairnia | Bromeliaceae | P | N | bird | bird | UV+Red | 0.122 | 16 | SP and KL dataset |
| *Pitcairnia punicea Scheidw.* | Pitcairnia | Bromeliaceae | P | N | bird | bird | UV-Red | 0.01 | 180 | SP and KL dataset |
| *Polygala myrtifolia L.* | Polygala | Polygalaceae | P | EN | bee | bee | UV+Pink | 0.143 | 2 | SP and KL dataset |
| *Potentilla heptaphylla L.* | Potentilla | Rosaceae | P | EN | bee | bee | UV+Yellow | 0.081 | 1 | Coimbra et al. 2020 |
| *Proboscidea fragrans (Lindl.) Decne.* | Proboscidea | Martyniaceae | P | G | bee | bee | UV-Pink | 0.004 | 113 | SP and KL dataset |
| *Protea comptonii Beard* | Protea | Proteaceae | ST | EN | bird | bird | UV+White | 0.203 | 124 | SP and KL dataset |
| *Protea nubigena Rourke* | Protea | Proteaceae | P | EN | bird | bird | UV+White | 0.064 | 124 | SP and KL dataset |
| *Psychotria nuda (Cham. & Schltdl.) Wawra* | Psychotria | Rubiaceae | P | N | bird | bird | UV-Yellow | 0.027 | 103 | SP and KL dataset |
| *Puya santosii Cuatrec.* | Puya | Bromeliaceae | P | EN | bird | bird | UV+Cyan | 0.143 | 16 | SP and KL dataset |
| *Qualea multiflora Mart.* | Qualea | Vochysiaceae | P | N | bee | bee | UV+White | 0.259 | 212 | SP and KL dataset |
| *Quesnelia arvensis (Vell.) Mez* | Quesnelia | Bromeliaceae | B | N | bird | bird | UV-Pink | 0.017 | 45 | Coimbra et al. 2020 |
| *Quesnelia liboniana (De Jonghe) Mez* | Quesnelia | Bromeliaceae | P | N | bird | bird | UV+Blue | 0.11 | 202 | Coimbra et al. 2020 |
| *Renealmia petasites Gagnep.* | Renealmia | Zingiberaceae | P | N | bird | bird | UV+White | 0.052 | 142 | SP and KL dataset |
| *Rhipsalis baccifera (J.S.Muell.) Stearn* | Rhipsalis | Cactaceae | P | G | bird | bird | UV+White | 0.06 | 162 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Rhipsalis elliptica G.Lindb. ex K.Schum.* | Rhipsalis | Cactaceae | P | N | bee | bee | UV+White | 0.047 | 122 | SP and KL dataset |
| *Rhododendron lochae F.Muell.* | Rhododendron | Ericaceae | P | EN | bird | bird | UV+Red | 0.141 | 279 | SP and KL dataset |
| *Rivina humilis L.* | Rivina | Phytolaccaceae | P | EN | bee | bee | UV-White | 0.005 | 174 | SP and KL dataset |
| *Russelia equisetiformis Schltdl. & Cham.* | Russelia | Plantaginaceae | P | EN | bird | bird | UV-Red | 0.035 | 182 | SP and KL dataset |
| *Salvia cacaliifolia Benth.* | Salvia | Lamiaceae | P | N | bird | bird | UV+Blue | 0.085 | 276 | SP and KL dataset |
| *Salvia canariensis L.* | Salvia | Lamiaceae | P | EN | bee | bee | UV+Pink | 0.056 | 277 | SP and KL dataset |
| *Salvia patens Cav.* | Salvia | Lamiaceae | P | G | bird | bird | UV+Blue | 0.113 | 275 | SP and KL dataset |
| *Salvia splendens Sellow ex Schult.* | Salvia | Lamiaceae | P | EN | bird | bird | UV+Red | 0.21 | 255 | SP and KL dataset |
| *Salvia urica Epling* | Salvia | Lamiaceae | P | N | bee | bee | UV+Blue | 0.147 | 241 | SP and KL dataset |
| *Schizanthus pinnatus Ruiz & Pav.* | Schizanthus | Solanaceae | P | N | bee | bee | UV-White | 0.029 | 4 | SP and KL dataset |
| *Scrophularia xanthoglossa Boiss.* | Scrophularia | Scrophulariaceae | P | EN | bee | bee | UV-Black | 0.037 | 1 | Coimbra et al. 2020 |
| *Scutellaria costaricana H.Wendl.* | Scutellaria | Lamiaceae | P | N | bird | bird | UV-Red | 0.048 | 17 | SP and KL dataset |
| *Senecio inaequidens DC.* | Senecio | Asteraceae | P | EN | bee | bee | UV-Yellow | 0.047 | 16 | SP and KL dataset |
| *Senecio inaequidens DC.* | Senecio | Asteraceae | P | EN | bee | bee | UV+Yellow | 0.167 | 16 | SP and KL dataset |
| *Senna artemisioides Isely* | Senna | Fabaceae | P | EN | bee | bee | UV-Yellow | 0.054 | 200 | SP and KL dataset |
| *Senna bicapsularis (L.) Roxb.* | Senna | Fabaceae | P | G | bee | bee | UV+Yellow | 0.187 | 200 | SP and KL dataset |
| *Sesamum indicum L.* | Sesamum | Pedaliaceae | P | G | bee | bee | UV+White | 0.05 | 164 | SP and KL dataset |
| *Silene aegyptiaca (L.) L.f.* | Silene | Caryophyllaceae | P | EN | bee | bee | UV+Pink | 0.071 | 1 | Coimbra et al. 2020 |
| *Sinningia aggregata (Ker Gawl.) Wiehler* | Sinningia | Gesneriaceae | P | N | bird | bird | UV+Red | 0.074 | 223 | SP and KL dataset |
| *Sinningia eumorpha H.E. Moore* | Sinningia | Gesneriaceae | P | N | bee | bee | UV-White | 0.016 | 223 | SP and KL dataset |
| *Sinningia eumorpha H.E. Moore* | Sinningia | Gesneriaceae | P | N | bee | bee | UV+White | 0.045 | 223 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Sinningia macropoda (Sprague) H.E. Moore* | Sinningia | Gesneriaceae | P | N | bird | bird | UV-Red | 0.077 | 223 | SP and KL dataset |
| *Sinningia sellovii (Mart.) Wiehler* | Sinningia | Gesneriaceae | P | N | bird | bird | UV-Red | 0.068 | 223 | SP and KL dataset |
| *Solanum betaceum Cav.* | Solanum | Solanaceae | P | N | bee | bee | UV-White | 0.06 | 102 | SP and KL dataset |
| *Sophora macrocarpa Sm.* | Sophora | Fabaceae | P | N | bird | bird | UV+Yellow | 0.071 | 144 | SP and KL dataset |
| *Spathiphyllum cannifolium (Dryand. ex Sims) Schott* | Spathiphyllum | Araceae | B | N | bee | bee | UV+White | 0.736 | 278 | SP and KL dataset |
| *Spathodea campanulata P.Beauv.* | Spathodea | Bignoniaceae | P | EN | bird | bird | UV-Red | 0.084 | 265 | SP and KL dataset |
| *Stifftia chrysantha J.C.Mikan* | Stifftia | Asteraceae | P | N | bird | bird | UV-Yellow | 0.015 | 207 | SP and KL dataset |
| *Strelitzia reginae Banks* | Strelitzia | Strelitziaceae | B | EN | bird | bird | UV+Red | 0.068 | 168 | SP and KL dataset |
| *Streptosolen jamesonii (Benth.) Miers* | Streptosolen | Solanaceae | P | N | bird | bird | UV-Red | 0 | 116 | SP and KL dataset |
| *Swartzia oblata Cowan* | Swartzia | Fabaceae | P | EN | bee | bee | UV-White | 0.033 | 227 | SP and KL dataset |
| *Swartzia simplex (Sw.) Spreng.* | Swartzia | Fabaceae | P | N | bee | bee | UV+Yellow | 0.219 | 228 | Coimbra et al. 2020 |
| *Symphytum brachycalyx Boiss.* | Symphytum | Boraginaceae | P | EN | bee | bee | UV-White | 0.008 | 1 | Coimbra et al. 2020 |
| *Tacinga palmadora (Britton & Rose) N.P.Taylor & Stuppy* | Tacinga | Cactaceae | P | N | bird | bird | UV-Red | 0.01 | 191 | SP and KL dataset |
| *Telopea speciosissima (Sm.) R. Br.* | Telopea | Proteaceae | B | EN | bird | bird | UV+Red | 0.123 | 232 | SP and KL dataset |
| *Tillandsia aeranthos (Loisel.) L.B.Sm.* | Tillandsia | Bromeliaceae | P | G | bird | bird | UV-Blue | 0.124 | 253 | SP and KL dataset |
| *Tillandsia ionantha Planch.* | Tillandsia | Bromeliaceae | B | G | bird | bird | UV+Blue | 0.177 | 154 | SP and KL dataset |
| *Tripora divaricata (Maxim.) P.D.Cantino* | Tripora | Lamiaceae | P | EN | bee | bee | UV+Blue | 0.136 | 263 | SP and KL dataset |
| *Vaccinium vitis-idaea L.* | Vaccinium | Ericaceae | P | EN | bee | bee | UV-White | 0.017 | 1 | Coimbra et al. 2020 |
| *Vellozia candida J.C.Mikan* | Vellozia | Velloziaceae | P | N | bee | bee | UV-White | 0.008 | 270 | SP and KL dataset |
| *Verbena bonariensis L.* | Verbena | Verbenaceae | P | EN | bee | bee | UV+Pink | 0.081 | 255 | SP and KL dataset |
| *Vicia faba L.* | Vicia | Fabaceae | P | EN | bee | bee | UV+White | 0.064 | 150 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Vriesea neoglutinosa Mez* | Vriesea | Bromeliaceae | B | N | bird | bird | UV-Red | 0 | 146 | SP and KL dataset |
| *Zephyranthes candida (Lindl.) Herb.* | Zephyranthes | Amaryllidaceae | P | EN | bee | bee | UV-White | 0.024 | 16 | SP and KL dataset |
| *Zeyheria montana Mart.* | Zeyheria | Bignoniaceae | P | N | bird | bird | UV+Yellow | 0.287 | 121 | SP and KL dataset |
| *Zilla spinosa (L.) Prantl* | Zilla | Brassicaceae | P | EN | bee | bee | UV-Pink | 0.044 | 1 | Coimbra et al. 2020 |

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**Supplementary Table S2**. Evolutionary models with AIC and transition rates values. To perform this reconstruction, we first analysed which of the following evolutionary models best fit the data on the "white-red" flowers dataset: ER (equal rates), ARD (all different rates), and SYM (symmetrical). The best model was selected by comparing Akaike weights (AICc) and ΔAIC. The values of transition rates are: W (white), R (red) and O (Other) and the trace between them indicates the direction of change of state. The best model is highlighted in gray shade.

| | **AICc** | **ΔAIC** | **Red -White** | **White-Red** | **Red-Other** | **Other- Red** | **White-Other** | **Other-White** |
|---|---|---|---|---|---|---|---|---|
| **ER** | 711.7734 | 9.7248 | 1.000239 | 1.000239 | 1.000239 | 1.000239 | 1.000239 | 1.000239 |
| **ARD** | 702.0486 | 0.0000 | 0.921324 | 1.212737 | 0.190734 | 0.139850 | 0.00000 | 0.00000 |
| **SYM** | 702.8541 | 0.8054 | 0.13642 | 0.13642 | 0.057296 | 0.057296 | 0.037301 | 0.037301 |

**Supplementary Table S3**. AICc values of evolutionary models with values of transition rates. To perform this reconstruction, we first analysed which of the following evolutionary models best fits the data on the "yellow" flowers dataset: ER (equal rates), ARD (all different rates), and SYM (symmetrical). The best model was selected by comparing Akaike weights (AICc) and ΔAIC. The values of transition rates are: Y (yellow) and O (Other) and the trace between them indicates the direction of change of state. The best selected model is highlighted in gray shade.

| | **AICc** | **ΔAIC** | **Yellow -Other** | **Other-Yellow** |
|---|---|---|---|---|
| **ER** | 332.0395 | 38.753 | 0.00508 | 0.00508 |
| **ARD** | 293.2862 | 0.0000 | 0.186498 | 0.037749 |
| **SYM** | 332.0395 | 38.753 | 0.00508 | 0.00508 |

**Supplementary Table S4.** Comparisons of estimated marginal means for combinations of pollinator system and color categories within the white-red flowers dataset

| Pollination system | Color category | Estimate | SE | t | p |
|---|---|---|---|---|---|
| Bee x Bird | Other - Red | -0.03401 | 0.000994 | -34.208 | <.0001 |
| | Other - White | 0.01185 | 0.000994 | 11.921 | <.0001 |
| | Red - White | 0.04586 | 0.000994 | 46.129 | <.0001 |
| Bird x Bird | Other - White | 0.02515 | 0.000994 | 25.297 | <.0001 |
| | Other - Red | 0.00899 | 0.000994 | 9.045 | <.0001 |
| | Red - White | 0.01616 | 0.000994 | 16.252 | <.0001 |
| Bee x Bird | Other - Red | 0.0045 | 0.000994 | 4.53 | <.0001 |
| | Other - Other | -0.00449 | 0.000994 | -4.514 | <.0001 |
| | Other - White | 0.02066 | 0.000994 | 20.782 | <.0001 |
| | Red - Red | 0.03851 | 0.000994 | 38.738 | <.0001 |
| | White - White | 0.00881 | 0.000994 | 8.861 | <.0001 |
| | Red - White | 0.05467 | 0.000994 | 54.99 | <.0001 |
| Bird x Bee | Other - Red | -0.02952 | 0.000994 | -29.693 | <.0001 |
| | Other - White | 0.01634 | 0.000994 | 16.436 | <.0001 |
| | Red - White | 0.00735 | 0.000994 | 7.391 | <.0001 |

**Supplementary Table S5.** Comparisons of estimated marginal means for combinations of pollinator system and color categories within the yellow flowers dataset. Significant comparisons are highlighted in bold.

| Pollination system | Color category | Estimate | SE | p |
|---|---|---|---|---|
| Bee x Bee | Other - Yellow | -0.00703 | 0.00232 | **0.0133** |
| Bird x Bird | Other - Yellow | -0.00038 | 0.00232 | 0.9984 |
| Bee x Bird | Other - Other | -0.00251 | 0.00232 | 0.7018 |
| | Other - Yellow | -0.00289 | 0.00232 | 0.599 |
| | Yellow - Yellow | 0.00414 | 0.00232 | 0.2823 |
| Bird x Bee | Other - Yellow | -0.00452 | 0.00232 | 0.2094 |

# CAPÍTULO 3

*Manuscrito a ser submetido como Research paper*

## Spatial dynamics of ultraviolet chroma in flowers: how do biotic and abiotic impact on global floral color variation


### ABSTRACT

The UV spectrum plays a pivotal role in determining floral color, attractiveness to pollinators and protection against UV irradiance, being influenced by both biotic and abiotic factors, as previously shown. Therefore, areas sharing similar biotic and abiotic conditions should exhibit similar floral UV chroma (i.e. proportion of UV reflectance) expression, contributing to the emergence of large-scale spatial patterns. Investigating such spatial dynamics is crucial for understanding how these factors shape the composition of UV chroma within angiosperms on a global scale which could help us discover other dynamics involved in the evolution of flower color diversity. In this study, we examined a diverse array of angiosperm species from various geographic regions, collecting extensive data on UV chroma. We assessed spatial autocorrelation on floral reflectance and employed a spatial regression model, allowing us to explore spatial relationships between species' UV chroma and abiotic factors (altitude, annual precipitation, mean annual temperature, and mean annual radiation) and biotic factors (pollination system and color categories). We found a positive spatial autocorrelation in UV chroma among the studied angiosperms, indicating a tendency for species with similar UV chroma to cluster geographically. Notably, Neotropical regions exhibited clusters with higher UV chroma, in contrast to extra-neotropical regions. UV chroma was higher in species occurring in wetter, and to a lesser extent, warmer, areas. In addition, flowers with green and blue colors, as well as with bat, bee and vertebrate+insects pollination systems, exhibited higher UV chroma. Our results underscore the intricate interplay between biotic and abiotic factors, challenging conventional expectations on the primary role of abiotic stressors leading to higher UV chroma in temperate regions. We here provide evidence on the spatial structure of UV chroma at a global scale, which is imperative for understanding the evolutionary and ecological processes influencing floral color evolution, especially in the context of ongoing anthropogenic global changes impacting climate and pollination dynamics.



### KEYWORDS

angiosperm diversity; floral color evolution; geographical clustering, floral pigmentation; macroecological patterns; spatial autocorrelation; ultraviolet radiation

**INTRODUCTION**

Most flowering plants depend on the interactions with pollinators to ensure their reproductive success and the color of these flowers plays a fundamental role in establishing interactions with pollinators, as most of them rely, to some extent, on vision to locate flowers and their resources in nature (Chittka and Raine 2006; Ollerton et al. 2011). Floral color diversity is influenced by a myriad of biotic and abiotic factors, such as pollinators, floral antagonists, temperature, UV irradiation, precipitation, and altitude (Schemske and Bierzychudek 2001; Koski and Ashman 2015, 2016; Koski et al. 2020, Verloop et al. 2020; Oliveira et al. in prep). The UV spectrum, encompassing features like UV chroma (i.e. the ratio of UV reflectance to total reflectance) and a bullseye pattern (i.e. intrafloral UV patterns, UV-absorbing in the petal base and UV-reflecting in the petal tip), plays a significant role shaping floral color and its geographic variation (Koski 2020). Climatic conditions associated with geography influence the colors of flowers, with pigment patterns potentially representing adaptations to these abiotic stressors. For instance, the variation in UV-absorbing areas in flowers is linked to the incidence of UV radiation in the regions where the plants grow. Plants in locations with high UV radiation tend to have larger UV-absorbing areas on their petals, which may protect anthers and pollen grains from damage caused by UV stress (Koski & Ashman 2014, 2015a, b; Brock et al. 2016). On the other hand, local accumulation of UV-absorbing pigments can also create temperature and humidity gradients on the petal surface, capturing heat or reducing water loss (Nakabayashi et al 2014 a, b; Koski et al 2020). Species facing lower temperatures and precipitation tend to have larger UV-absorbing areas, suggesting these variations may be adaptive for minimizing cooling through transpiration and preventing thermal and water stress ( Koski and Ashman 2016; Todesco et al 2022).

Across the globe, there is significant climatic variation. Higher latitude and temperate regions experience lower UV incidences, along with more pronounced winters and drier periods. In contrast, lower latitudes and tropical areas are characterized by higher UV radiation, temperatures, and precipitation with less seasonal variation throughout the year (Kottek et al. 2006; Peel et al. 2007; Fortunel et al. 2014). As variations in such climatic factors have already been documented to influence floral colors, it is likely that theclimatic patterns observed globally could lead to global patterns of variation in UV expression. Assessing the spatial structure of UV chroma is crucial for understanding the ecological processes driving the evolution of floral colors and predicting the evolutionary trajectories of this trait across space. Such understanding is especially urgent in light of recent anthropogenic global changes that may alter climate and pollination dynamics, impacting floral color and consequently plant fitness.

UV reflectance in flowers is the result of a differential accumulation of pigments, such as flavonoids and carotenoids, capable of absorbing and reflecting UV light (Thompson et al. 1972; Kevan et al. 1996; Grotewold 2006). There is evidence of the heritability and phylogenetic constraints of UV floral patterns (Grotewold 2006; Koski and Ashman 2013; de Camargo et al. 2019; Koski 2020b; Tunes et al. 2021). However, depending on the clade, UV floral reflectance was evolutionary labile among different evolutionary lineages (Muchhala et al. 2014; Gómez et al. 2015; Koski and Ashman 2016). This reinforces that selective pressures may contribute to the diversity of UV floral reflectance among species. Furthermore, some studies investigated the evolutionary shift between bullseye patterns, discovering that the presence of UV and human-visible patterns evolved independently (Koski and Ashman 2016). Such disparate evolutionary patterns suggest that it is difficult to assign the variation of floral UV chroma in the Angiosperms to a single ecological or evolutionary factor.

The UV spectrum has been recognized for its role on floral attractiveness to pollinators (Johnson and Andersson 2002; Koski and Ashman 2013, 2014). Along with other floral color traits, UV reflectance varies along geographic and environmental gradients, and plant-pollinator interactions are commonly considered the primary factor explaining such variation (Schemske and Bierzychudek 2001; Rausher 2008; Koski and Ashman 2015b, 2016; Koski et al. 2020). This because pollinator assemblages also vary along altitudinal and latitudinal gradients, contributing to the observed interspecific variation in floral UV chroma due to specific adaptations to distinct visual systems (Dyer 1996; Jones et al. 1999; Hoiss et al. 2012; Koski and Ashman 2014, 2015b). Bees, flies, and butterflies are often highly sensitive to UV light and capable of perceiving UV patterns associated with flowers of various colors (Lunau et al. 1996; Kandori and OhSaki 1998; Briscoe and Chittka 2001). Therefore, it is expected that flowers visited mainly by these insects, which show preferences for such floral UV expression, would exhibit higher levels of UV. Moreover, the UV expression in flowers also depends on the expression of other color spectra. For example, yellow flowers pollinated by bees and birds differ in their UV spectral reflectance. Typically, bee-pollinated flowers exhibit UV reflectance patterns, while bird-pollinated flowers tend to be entirely UV-absorbing (Lunau 2007; Davies et al. 2012, Papiorek et al. 2015). The presence of such patterns creates higher achromatic contrast in bee-pollinated flowers compared to those pollinated by birds (Papiorek et al. 2015). These patterns aid in the detection, orientation, and guidance of bees towards the floral reward in these flowers (Owen and Bradshaw 2011; Leonard and Papaj 2011). In other color spectra of flowers pollinated by these animals, such as red and white, the amount of UV reflectance can influence the spectral purity of these colors. Spectral purity, in turn, affects flower attractiveness as it is directly related to the visual preferences of bees (Lunau and Maier 1995; Lunau et al. 1996; Van Der Kooi et al. 2019). Thus, red and white colors are more attractive to bees if they reflect and absorb UV light, respectively (Lunau et al. 2011). Conversely, the opposite UV reflectance patterns are found for red and white bird-pollinated flowers, which results in inconspicuous colors to bees and a private sensory niche for birds (Lunau et al. 2011, Bergamo et al. 2016, Camargo et al. 2019).

Besides enhancing attractiveness, UV can also act as a floral filter, discouraging potential floral antagonists as observed in red, white and yellow flowers (Lunau et al. 2011, Papiorek et al. 2015, Oliveira et al. in prep). Not only pollinators but other floral visitors from herbivores to floral antagonists are also recognized as agents of selection on floral color (Strauss and Irwin 2004; Oliveira et al. in prep). In contrast, the role of abiotic factors has been overlooked in comparison with biotic factors in shaping floral color diversity. Abiotic factors can impact the production of floral pigments and consequently floral color diversity. For instance, distantly related species in similar environmental conditions can exhibit similar floral colors (Koski and Ashman, 2016). Geography and climate, including altitude, temperature, UVB radiation, and precipitation, have been identified as predictors of floral reflectance, thereby contributing to observed spatial variation in floral UV spectrum (Schemske and Bierzychudek 2001; Coberly and Rausher 2003; Arista et al. 2013; Koski and Ashman 2015, 2016; Dalrymple et al. 2020; Koski et al. 2020). The pigments responsible for flower colors confer resistance to abiotic stressors, such as high temperatures, low precipitation, high ultraviolet radiation, and low productivity environments (Schemske and Bierzychudek 2001; Rausher 2008; Arista et al. 2013; Koski and Ashman 2015a; Agati et al. 2021). Notably, UV absorption areas in flowers are generally larger at lower latitudes and higher altitudes, paralleling gradients of increasing UV exposure, increasing temperature and decreasing precipitation (Schemske and Bierzychudek 2001; Koski and Ashman 2015, 2016; Koski et al. 2020). Moreover, biotic and abiotic stressors may impose similar selective pressures. If floral pigments provide resistance to thermal stress, it can be predicted that higher temperatures will select for a higher average saturation and chromatic contrast in flower colors than those found at lower temperatures, which can directly affect pollinators attraction and plant fitness (Lunau 1992).

Although it is known that several biotic and abiotic factors shape floral traits (Caruso et al. 2019), most studies are still restricted to one clade or a specific environmental gradient. Thus, it is still lacking a macroecological analysis of the variation of UV chroma in flowers. Biotic and abiotic selective pressures on floral color indicate that areas sharing similar conditions should exhibit similar floral UV chroma, contributing to the formation of large-scale spatial patterns. Here, we explored spatial variation in UV chroma by employing quantitative analyses of the distribution of 463 angiosperm species across a latitudinal range from 66.31ºN to 43.64ºS, worldwide. We examined how spatial variation in UV chroma correlates with pollination systems, color categories and three key climatic variables (annual mean temperature, annual precipitation, and annual mean UV-B irradiance). It is important to note, for comparison purposes, that studies on the effect of abiotic variables on the UV spectrum typically focus on the size of the UV absorption area in flowers. However, the measure we use here, UV chroma, has an inverse relationship with this. The greater the UV absorption in the flower, the lower the UV chroma, and vice versa. Based on this, we expect to find different dynamics in the expression of UV chroma in flowers when considering variables such as temperature, precipitation, and UV radiation. Our predictions follow two scenarios: In the first scenario, as latitude increases and areas become colder and drier, plants face thermal and water stress. Absorbing more UV (expressing less UV chroma) may be advantageous for plants in these areas as it helps retain more heat, promoting their development and floral fitness. In this context, we expect to find a pattern of geographic clustering with species in temperate areas exhibiting lower UV chroma compared to those in tropical areas. However, if the protection against UV radiation is more critical, then we expect to observe the opposite pattern. In lower latitudes, UV radiation tends to increase, so absorbing more UV (thus having lower UV chroma) would also be beneficial for plants in these areas as UV absorption protects against radiation damage to flowers and enhances pollen viability. In this second scenario, we expect plants in the tropics to exhibit lower UV chroma compared to those in temperate areas. Additionally, we expect to find a positive association between UV chroma and pollination systems (e.g. bee, fly, and butterfly pollination) and certain colors (e.g. yellow), as shown in studies on a local scale. (Koski and Ashman 2015b, 2016; Bergamo et al. 2018, Lunau et al. 2011, Papiorek et al. 2015,).

## MATERIAL AND METHODS

### *Database*

This study focuses on 464 angiosperm species with georeferenced data, encompassing 7,176 occurrences across neotropical (118 species), extra-neotropical (294 species), and mixed (87 species) zones worldwide. The occurrences include altitudes ranging from -407 to 5,315 meters, mean annual temperatures from -2.1°C to 29.7°C, mean annual levels of precipitation from 3 to 7324 mm and UV-B radiation from 3019 to 9.979.344.482 J m-2 d-. The species display a wide range of color categories. Notably, white, red, and yellow colors are predominant among species pollinated by bees, insects, and birds. Floral visitors include bees, wasps, flies, beetles, butterflies, birds, bats and sporadically marsupials and lizards. Species pollinated by bees, insects, and birds comprise the majority of the recorded pollination systems in the dataset (Table S1). Information on latitude and longitude of the species was gathered from the Global Biodiversity Information Facility (GBIF.org) database and filtered to include only spatially valid records. The projection of the geographic coordinates was verified using Arcgis Pro 3.1.0.

### *Biotic Variables*

#### *Color categories and UV chroma*

The database includes an extensively documented dataset of floral spectral reflectance and biotic variables such as color categories, UV chroma values, floral visitors and pollination systems. The spectral reflectance dataset covers reflectance measurements made by two of the co-authors across several localities (KL and SP) and the database compiled by Coimbra et. al (2020). Reflectance data were restricted to wavelengths between 300 nm (ultraviolet) and 700 nm (red) and were used to categorize species into color categories based on their absorbance or reflectance in the UV, blue, green, and red spectral ranges considering specific cutoff points (adapted from Camargo et al. 2019 and Coimbra et al. 2020). For instance, 0.1 (equivalent to 10%) for UV, 0.3 (representing 30%) for blue, 0.4 (indicating 40%) for green, 0.5 (corresponding to 50%) to differentiate between green flowers and those of blue and red hues, and 0.6 (which denotes 60%) for red. Furthermore, the proportion of UV light in the spectrum measured for each flower (UV chroma) was calculated as the ratio of the UV reflectance (300-400 nm) to the total reflectance (300-700 nm) (Table S1).

#### *Pollination systems*

Pollination system data was compiled from Google Scholar and ISI Web of Science literature, using keywords such as "species name"*"pollination" or "species name"*"pollinator." We considered different types of methodologies including peerreviewed articles, theses, dissertations and reviews that provided information about frequency of visitation and/or pollination. We categorized pollination systems based on functional guilds of animals (Ollerton et al. 2007). Species were grouped into bee flowers (species visited/pollinated only by bees or wasps), beetle flowers (species visited/pollinated only by beetles), fly flowers (species visited/pollinated only by flies), butterfly flowers (species visited/pollinated only by butterflies), moth flowers (species visited/pollinated only by moths), bat flowers (species visited/pollinated only by bats), bird flowers (species visited/pollinated only by birds), bee+insect flowers (species visited/pollinated by both bees and other insects), insect flowers (species visited/pollinated by more than one group of insects other than bees), vertebrate+insect flowers (species visited/pollinated by birds, bats, and insects), and vertebrate flowers (species visited/pollinated by birds, bats, marsupials, and lizards) (Tables S1).

### *Abiotic Variables*

We included four abiotic variables related to geography and climate to database, including altitude, precipitation, temperature and UV-B irradiance, that have previously been shown to be important determinants of floral color diversity. Data for altitude, temperature and precipitation were extracted from the WorldClim data base (version 1.4; Hijmans et al. 2005; Fick and Hijmans 2017), with interpolated mean monthly climatic data from the period 1950–2000 (available online at http://www.worldclim.org/). We used annual precipitation (AP- mm) and annual mean temperature (AMT- °C), degraded from 10 minutes (~340 km2) resolution. Annual mean UV-B irradiance (AMR) were obtained from Beckmann et al. (2014).

### *Geographic distribution of UV chroma across species*

To visualize the data spatial distribution, we mapped georeferenced point data onto a world map shapefile using an appropriate USGS projection within ArcGIS Pro 3.1.0 (Fig. S1-4).

We used the Global Moran's Index and Local Indicator of Spatial Autocorrelation (LISA) statistics in ArcGIS to assess the spatial interdependence among species based on their UV chroma (Moran 1950; Griffith 1987; Anselin 1995). These analytical tools allowed us to investigate spatial autocorrelation patterns common in macroecological scales (Legendre 1993). The Global Moran's Index provides an overview of autocorrelation patterns of UV chroma among studied species, typically ranging from -1.0 to 1.0, indicating dispersion (negative autocorrelation) and clustering (positive autocorrelation) patterns, respectively. Simultaneously, the LISA analysis helped identify clustered distributions (HH or LL) and dispersed distributions (HL or LH) among species exhibiting similar or dissimilar UV chroma values, respectively. The HH clusters represents locations where species with high UV chroma values are found and are surrounded by species with similar high UV chroma values. Similarly, the LL clusters represents species locations with low UV chroma values surrounded by neighbors with low UV chroma values. Moreover, areas overlapping with the previous clusters, displaying negative spatial autocorrelation are represented by clusters concentrating species with low UV chroma values surrounded by high-value neighbors (LH) and clusters including species with high UV chroma values surrounded by low-value neighbors (HL).

The Moran and LISA statistics were based on a spatial distance matrix calculated using Euclidean distances after converting geographical coordinates into a planar coordinate system using the Robinson projection. We chose this approach due to the point-based nature of our data. We conducted an assessment using different threshold distances (500, 1000, and 1600 km) to establish the spatial matrix. The selection of the 1600 km threshold was based on careful consideration of Moran index values, z-scores, p-values, and the visualization of spatial patterns (Table S2). This choice was made to align with our research objectives, aiming to capture gradual pattern changes over larger scales, encompassing the considerable spatial variability present in our dataset.

### *Effect of abiotic and biotic factors on UV chroma across species*

We computed a correlation matrix to examine relationships and correlations between the dependent variable (UV chroma) and several independent variables (altitude, AMT, AP, AMR, pollination system, and species color category) (Table S3). Additionally, we calculated the Variance Inflation Factor (VIF) to evaluate multicollinearity and checked for spatial autocorrelation in the residuals in a fitted multiple linear regression model that included all independent variables using Moran's Index (Table S4). We applied a logit transformation due to the observed non-normality of UV chroma, which is adequate for proportion variables.

Spatial autocorrelation has been recognized as a factor that could potentially inflate type I errors in traditional statistical tests and influence parameter estimates (Legendre 1993; Lennon 2000). As spatial autocorrelation was evident in our dataset, we employed a spatial regression model with Gaussian distribution explicitly incorporating the spatial structure of observations as a correlated random term (Rousset and Ferdy 2014; Rousset 2017). This model aimed to explore the spatial relationship between species' UV chroma and various abiotic (altitude, AP, AMT, and AMR) and biotic (pollination system and color categories) factors. The spatial term, characterized by a multivariate normal distribution with a mean vector of 0 and a covariance matrix among locations, was computed utilizing a Matérn function (Gneiting et al. 2010). This term captures the unexplained variation not accounted for by traditional variables and reflects the spatial structure not modeled by the remaining covariates. To globally assess whether the variation explained by the independent variables is significant, we conducted a Type II ANOVA using the Satterthwaite method. Additionally, we performed a Tukey test for multiple comparisons among the means of different levels of the categorical variables (pollination system and color categories).

### *Statistical software*

Spatial analysis and statistical modeling were performed using ArcGIS Pro 3.1.0 and R (2023.03.0). In ArcGIS Pro we performed the analysis of the Global Moran Index and LISA using the Global Moran's I and Anselin Local Moran's I tools, respectively (Mitchel 2005a,b). In R, we assessed data normality and multicollinearity using the tidyverse package (Wickham and Wickham 2017). The car package (Fox et al. 2012) was used to compute a matrix of correlation based on Pearson's coefficient, the ANOVA analysis and Tukey test. For spatial object manipulation, we used the sf package (Pebesma and Bivand 2023). To create spatial weight matrices of the observations and convert the neighborhood object into a list of weights, we ran the dnearneigh and nb2listw functions from the spdep package (Bivand and Wong 2018; Bivand 2022; Pebesma and Bivand 2023). The DHARMa and spamm packages (Hartig and Hartig 2017; Rousset 2023) provided functions such as testSpatialAutocorrelation and fitme to test residual spatial autocorrelation and fit the spatial regression model, respectively.

## RESULTS

### *Geographic distribution of UV chroma across species*

We found a substantial spatial autocorrelation of UV chroma, indicating geographic patterns both on a global and local scales. The global spatial analysis, as indicated by the Global Moran's I statistic, revealed a spatial autocorrelation (Global Moran's I: 0.26, $p < 0.01$), suggesting that UV chroma values tend to be similar in nearby locations. Moreover, we found a spatial $R^2 = 0.31$, further stressing the existence of geographic patterns of UV chroma (Fig. 1A).

In addition to the global pattern, UV chroma exhibited distinct local clustering (Fig. 1A). Clusters of high UV chroma values (HH - 0.339465 ± 0.220558) were concentrated mainly in neotropical regions, the eastern part of southern Africa, and southern China, with an average index of 1.96 ± 3.76 ($p < 0.01$). Conversely, clusters of low UV chroma values (LL - 0.043623 ± 0.028357) were predominantly found in extra-neotropical (temperate) regions, with an average index of 0.16 ± 0.11 ($p < 0.01$). Both HH and LL clusters exhibited a positive spatial autocorrelation, further confirming the presence of local patterns (Table S5, Fig.

1b). The analysis also revealed transitional zones, concentrated mainly in neotropical areas, where species with low UV chroma values were surrounded by high-value neighbors (LH clusters) and vice versa (HL clusters, Table S5, Fig. 1, Fig. S5-6).

***Effect of abiotic and biotic factors on UV chroma across species***

The spatial regression model achieved a good fit explaining approximately 39% of the total observed spatial variation in UV chroma among species (pseudo R2: 0.39, Table 1 and Table S6). In addition, the relatively weak random effects and low residual variance suggest that the model successfully captured a great portion of the spatial structure and spatial variation in UV chroma across different geographical locations, dealing satisfactorily with the observed spatial autocorrelation. This was confirmed by the low nu (0.088) and rho (0.1568) values, indicating that spatial variability is relatively well explained by the predictors included in the model and that the spatial structure is being satisfactorily captured by the model. The lambda parameter indicates the magnitude of spatial variation unexplained by the predictors in the model. We found a relatively low lambda of 1.151, suggesting that although there is some spatial variability unexplained by the predictors, the model is capturing a good portion of the spatial structure. Lastly, the relatively low residual variance (phi: 0.169997) indicates that the residual variability unexplained by the model is small and that it fits the data well.

The spatial regression revealed a positive relationship between annual precipitation and UV chroma (Table 1; F: 6.90, $p = 0.009$). Increases in annual precipitation were associated with a log-odds increase of 0.00009961 in UV chroma (Table1; Fig. 2). On the other hand, annual mean temperature was marginally significant (Table 1; F 3.29, $p = 0.073$). Increases in annual mean temperature were associated with a marginal log-odds increase of 0.01063 in UV chroma (Table1; Fig. 2). Furthermore, UV chroma differed between pollination systems and color (Table S7-S8; pollination systems - $F = 32.91$, $p < 0.001$; color categories - $F = 35.70$, $p < 0.001$). Green and blue colors were associated with a higher amount of floral UV chroma in comparison with all other floral colors (Table S7, Fig 2.). In contrast with insects, beetle, moth, butterfly, fly and bird pollination systems, the bee, bat and vertebrate+insects systems were associated with a higher amount of UV chroma (Table S8, Fig 2.).

**DISCUSSION**

Our study revealed geographic patterns of UV chroma in the flowers of the studied angiosperms. We observed a significant positive spatial autocorrelation in UV chroma both at global and local scales. This suggests that species with similar levels of floral UV chroma tend to cluster geographically. Clusters with high UV chroma were predominantly observed in neotropical regions while clusters of low UV chroma were more present in extra-neotropical areas. Blue and green flowers, as well as those with bat, bee and vertebrate+insects pollination systems, were related with higher UV chroma. Additionally, UV chroma was associated with wetter and hotter conditions. Pollinators have been considered the main drivers in the evolution and diversification of flower color (Rausher 2008; Koski and Ashman 2014; Trunschke et al. 2021). However, this paradigm of flower color diversity shaped primarily through biotic interactions does not fully address the complexity of UV chroma distribution, because geographic factors also significantly influence floral UV pigmentation (Koski and Ashman 2015a, b, 2016; Peach et al. 2020). Our results indicate that UV chroma exhibits a remarkable pattern of geographical variation that is influenced by a complex interplay of biotic and abiotic factors on a macroecological scale.

Our findings revealed spatial autocorrelation in the UV chroma values of the studied plants across the globe. However, the observed distribution of UV chroma contradicts our prior expectations of higher UV chroma in extra-neotropical regions found in local-scale studies (Koski and Ashman 2015a, 2016; Peach et al. 2020). Although local higher incidences of UV radiation, temperature, and rain of regions closer to the equator should favor a higher expression of UV-absorbing pigments, consequently lower UV chroma, this was not sufficient to result in a correspondent macroecological pattern. Thus, the geographical clusters of UV chroma indicates that the large-scale spatial expression of species' UV chroma appears to be shaped by a complex interaction between abiotic and biotic factors. We also found scattered clusters formed by species exhibiting both high and low values of UV chroma, representing transition zones. These geographic transition areas may indicate unique ecosystems or special ecological environments where competition or other structuring processes between plant species can be particularly intense due to the overlap of pollinator guilds or the influence of local geographical gradients (Sargent and Ackerly 2008; McEwen and Vamosi 2010; Kemp et al. 2019; Bergamo et al. 2020; Albor et al. 2022). In neotropical areas, this relationship is further complicated by a prevalence of red and white flowers with pollination systems by bees and birds, due to pressures to exclude bees in bird flowers (Lunau et al. 2011l Bergamo et al. 2016). Sensorial exclusion is linked to distinct expression of UV chroma depending on color category and pollination system, for instance, UV-absorbing in bird-red flowers but UV-reflecting in bee-red and the opposite for white flowers (Lunau et al. 2011; Camargo et al. 2019). Although less frequently, we also found scattered clusters in extra-neotropical areas, and the lower amount of UV chroma exhibited by species there may reflect adaptations to match the visual abilities and preferences of pollinators (Dyer et al. 2012; Garcia et al. 2020). In these locations, colors were more diverse, with pollination systems predominantly by invertebrates such as bees, wasps, and flies, which were the systems associated with lower floral UV chroma.

The dynamic interaction between the color discrimination abilities and visual preferences of pollinators with floral color determine the assemblages of colors in an area (Dyer et al. 2012, 2021; Garcia et al. 2020). Specifically, we found that green and blue flowers exhibited the highest UV chroma values. Blue and green colors may have exhibited more UV chroma due to a higher similarity with the green foliage reflectance and the need for these colors to be conspicuous against such background (Camargo et al. 2014; van der Kooi et al. 2019a). Moreover, bees and fly flowers were among those with higher UV chroma. Bees and flies are often associated with flowers on the blue to violet spectrum, which are pollinator guilds sensitive to UV (Briscoes and Chittka 2001). Thus, blues flowers that exhibit UV patterns may be more conspicuous to these pollinator guilds (Chittka et al. 1994; Briscoe and Chittka 2001; Kastinger and Weber 2001; Lunau 2014; Dyer et al. 2016, 2021; Reverté et al. 2016; Hannah et al. 2019; Dunn et al. 2020). Futhermore, the presence of intrafloral UV patterns are common in bee-pollinated flowers, which may contribute with a higher amount of UV chroma in such flowers in comparison with UV-absorving flowers (Lunau et al. 1996; Kandori and OhSaki 1998; Briscoe and Chittka 2001; Koski and Ashman 2014; Hirota et al. 2019). The results regarding pollination systems indicate that flowers pollinated by bats and vertebrates+insects also exhibit higher UV chroma compared to invertebrate and bird flowers. Bats have widespread UV vision, especially during twilight, periods in which light can be relatively abundant, so the presence of more UV chroma in flowers visited by these animals can provide an important clue for them when searching in the nature (Gorresen et al. 2015; Domingos-Melo et al. 2021). On the other hand, the higher amount of UV chroma in plants with vertebrate+insect pollination systems may represent the role of this trait in attracting both bees and bats, which are also part of this mixed system. This is particularly significant considering that other representatives include birds and other insects, which, comparatively, generally exhibit lower UV chroma. Additionally, it is essential to highlight that pollinators can use different signals in the search for resources. Therefore, plants associated with different guilds of insect pollinators may express different sensory cues beyond visual ones involving UV patterns, such as olfactory, heat, and tactile signals, or even a combination of these signals, creating specific channels with their more effective pollinators (Telles et al. 2017; Wester and Lunau 2017).

In addition to the biotic factors, geographical transition areas may also reflect the influence of geographical gradients of abiotic factors as precipitation and temperature. Local studies have found that floral UV-absorving pigmentation being higher (lower UV chroma) in species experiencing lower precipitation (Schemske and Bierzychudek 2001; Warren and Mackenzie 2001). Indirectly, precipitation affects soil conditions and nutrient availability, which could reflect in the production of anthocyanins and other UV-absorbing and reflective pigments in water stress conditions, impacting flower colors (Austin and Vitousek 1998; Chalker-Scott 1999). Contrary, there is no evidence showing that water stress exhibits any influence on UV chroma at macroecological scales. In addition, our results reenforces a pattern of higher UV chroma in flowers in the tropics, that are more humid and warmer environments. Precipitation has been indicated as a predictor of blue vs. red color morph frequencies in *Lysimachia arvensis* (L.) U. Manns and Anderb., in its distribution area (Arista et al. 2013). Our results further suggest that precipitation could also influence other color properties and color morph frequencies via its impact on floral UV. Finally, in a lesser extent, our finds also point that UV chroma expression on flowers depends on some degree of warm stressor adaptation. It is worth noting that flavonoids, the most common contributors to floral UV pigmentation, also confers protection against stress caused by high temperatures (Rausher 2008). Moreover, the spectral composition and intensity of light reflected or absorbed by flowers can affect their internal temperature (van der Kooi et al. 2019b). The temperature can differentially affect the fitness of flowers with variable color saturation (Coberly and Rausher 2003). In this sense, the expression of colors in flowers, as well as UV chroma, may act as an adaptive mechanism representing an evolutionary strategy to prevent photochemical damage and protect the reproductive structures of flowers.

We have not detected a significant relationship between UV chroma, altitude and UVB irradiation, even though they have contributed to shape floral UV reflectance patterns in local studies (Koski and Ashman 2015b, 2016; Bergamo et al. 2018). The relationship between abiotic conditions and floral color varies along altitudinal gradients. In temperate areas, for example, precipitation increases with altitude (Körner 2007), which can indirectly impact flower pigmentation and, consequently, the amount of UV chroma they exhibit. Some studies have pointed to a reduction in UV chroma at higher altitudes due to increased UV radiation absorption by flowers in temperate regions (Koski and Ashman 2015b, 2016; Bergamo et al. 2018). Altitudinal patterns are complex because pollinator species composition, behavior, and preferences also change with altitude and are notably context-dependent (Koski, 2015; Koski and Ashman, 2015; Bergamo et al., 2018). On the other hand, UV irradiation positively influences flower UV absorption on micro and macroevolutionary scales (Koski and Ashman, 2015a; Koski and Ashman 2016; Dalrymple et al. 2020; Koski et al. 2020). UV radiation to which plants are exposed can vary widely under different conditions and environments. We found a positive correlation between UV irradiance and temperature (Table S2), which positively influenced UV chroma. Thus, these contrasting forces on UV chroma may have hindered the relationship between UV irradiance and UV chroma at a global scale. Moreover, floral UV chroma may be influenced not only by the amount of UV-B radiation they receive but also by other factors such as the spectral composition of radiation, intensity, and duration of UV-B exposure (Koski and Ashman 2016; Koski et al. 2020).

We here assessed the geographical variation of ultraviolet chroma in flowers, revealing associations with both biotic (color category and pollination system) and abiotic (precipitation and to a lesser extent, temperature) factors. The positive spatial autocorrelation in UV chroma confirms the geographical clusters of species similar levels of UV reflectance. Surprisingly, neotropical regions exhibited clusters of high UV chroma and of transition zones of both high and low UV chroma. These patterns challenge traditional expectations of higher UV chroma in temperate zones to cope with abiotic stressors. Even though local scale studies have emphasized the role of dryness, altitude and UV irradiance, especially in temperate zones, in fostering higher UV chroma, we found either opposite patterns (positive association with precipitation) or no effect (altitude and irradiance) at a global scale. This highlights the importance of investigating macroecological scales to better understand which factors drive broad spatial patterns in floral traits. The documented spatial structure of UV chroma, considering both biotic and abiotic factors, is crucial for comprehending the ecological processes that shape the evolution of floral color. In the context of climate change, the flexibility in ultraviolet chroma reveals adaptive responses of plants, providing valuable insights for ecosystem management and biodiversity conservation in the face of ongoing environmental change.

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**TABLES**

Table 1. Estimates of fixed and random parameters from the adjusted spatial regression model using Maximum Likelihood (ML). SE indicates conditional standard error values associated with each estimate. Significance codes (*** p<0.001; ** p< 0.01; * p<0.05; . p< 0.1) indicate the probability of rejecting the null hypothesis that the coefficient is zero. They are based on Type II Analysis of Variance with the Satterthwaite method

| Variable | Categories | Estimate | SE | t-value |
|---|---|---|---|---|
| Intercept | | -2.533e+00 | 1.928e-01 | -13.13395 |
| AMT | | 1.063e-02 | 5.864e-03 | 1.81294 . . |
| Altitude | | -1.496e-05 | 4.212e-05 | -0.35529 |
| AP | | 9.961e-05 | 3.791e-05 | 2.62765 ** |
| AMR | | -1.712e-11 | 1.068e-11 | -1.60266 |
| Pollinatin system | bee | -1.796e-02 | 1.173e-01 | -0.15303 *** |
| | bee-insects | -3.862e-01 | 1.198e-01 | -3.22331 |
| | beetle | -1.377e+00 | 1.665e-01 | -8.26752 |
| | bird | -2.975e-01 | 1.193e-01 | -2.49458 |
| | butterfly | -2.258e-01 | 1.456e-01 | -1.55096 |
| | fly | -3.043e-01 | 1.449e-01 | -2.09968 |
| | insects | 5.599e-01 | 1.467e-01 | 3.81556 |
| | moth | -6.014e-01 | 1.519e-01 | -3.95959 |
| | vertebrate | -2.543e-01 | 2.117e-01 | -1.20123 |
| | vertebrate-insects | 1.889e-01 | 1.359e-01 | 1.39054 |
| | blue | 6.836e-01 | 1.001e-01 | 6.82824 *** |
| Color category | cyan | -9.577e-01 | 2.362e-01 | -4.05530 |
| | green | 8.683e-01 | 1.838e-01 | 4.72440 |
| | pink | 5.984e-02 | 9.947e-02 | 0.60157 |
| | red | -3.992e-03 | 9.820e-02 | -0.04065 |
| | white | -6.271e-02 | 9.508e-02 | -0.65957 |
| | yellow | -1.241e-01 | 9.589e-02 | -1.29419 |

**FIGURES**

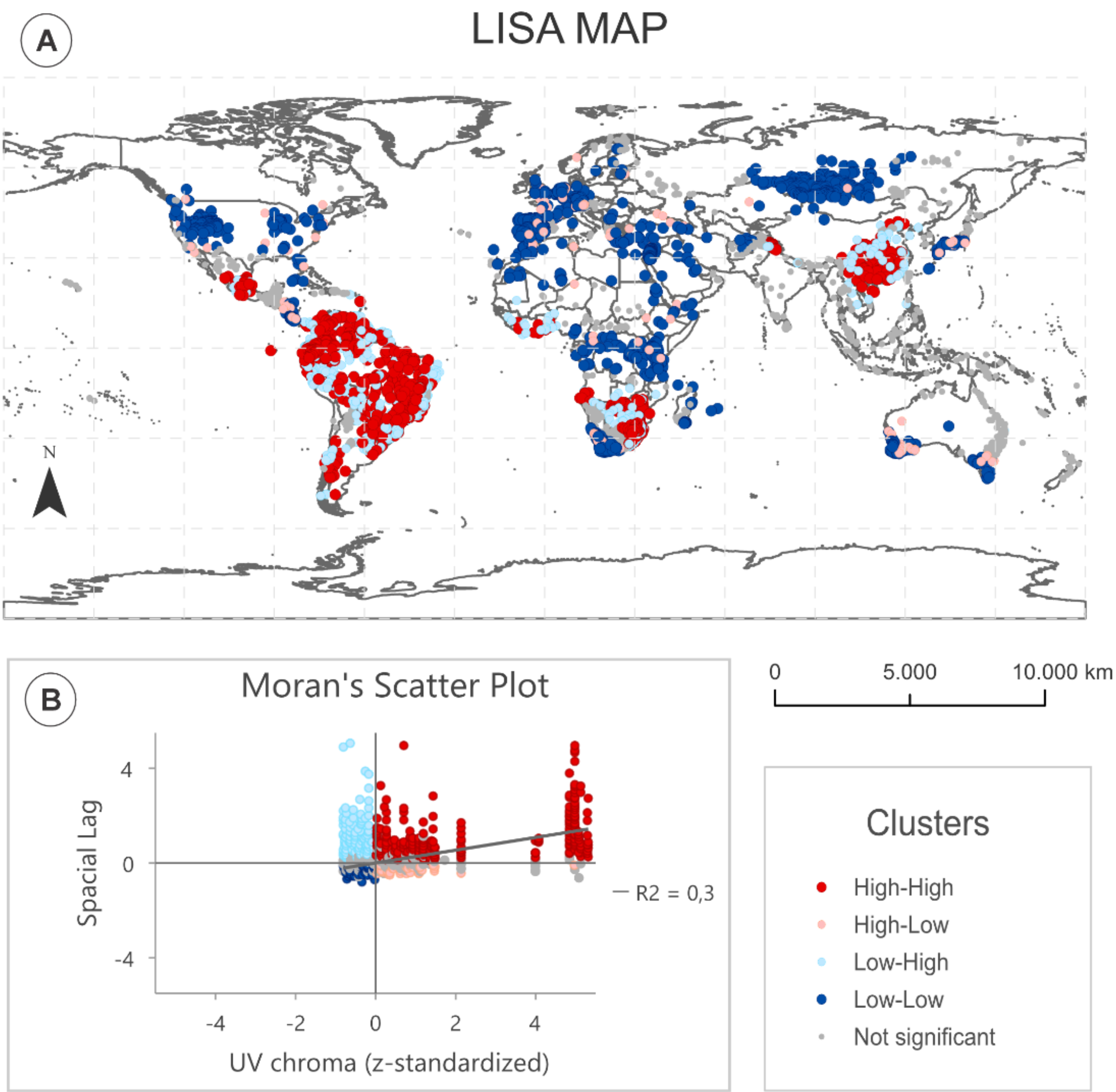


Figure 1. A- LISA map representing the local UV chroma clusters. Color points in the map designate distinct UV chroma clusters. The red points indicate a cluster with higher UV chroma (HH), while the dark blue points denote a cluster with lower UV chroma (LL). Additionally, pink and light blue points represent dispersed clusters where low UV chroma values are encircled by high-value neighbors (LH) and high UV chroma values are surrounded by low-value neighbors (HL), respectively. B- Moran Scatterplot illustrating UV chroma spatial alignment, demonstrating a positive spatial autocorrelation.

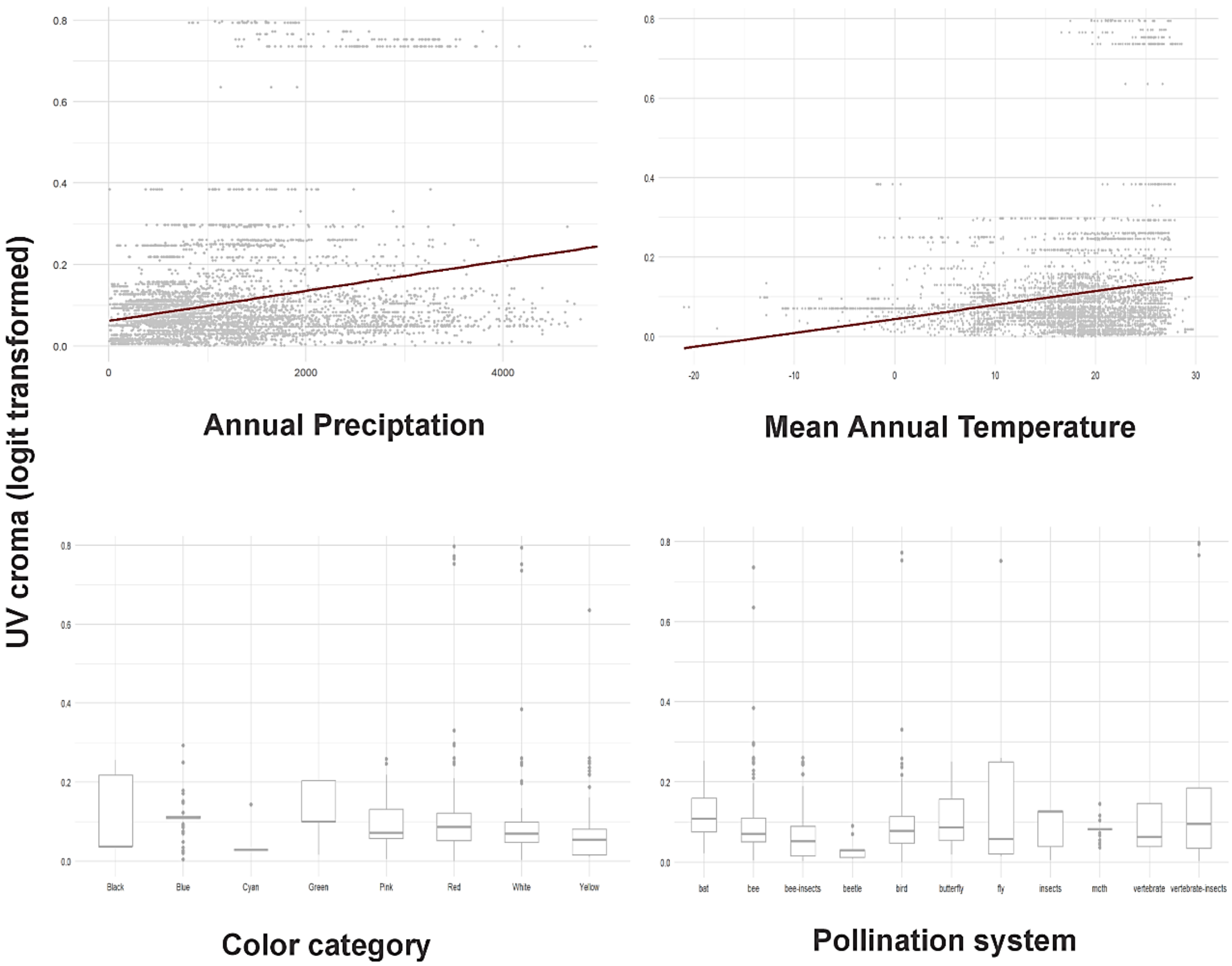


Figure 2. The relationship between the predictor variables and the UV chroma. The first two subplots highlighted the positive and significative relationship between UV chroma and annual precipitation (AP) and annual mean temperature (AMT). The last two subplots represent the distribution of UV chroma values across different color categories and pollination system.

**MATERIAL SUPLEMENTAR**

**Supplementary Table S1.** List of 464 plant species selected for a detailed analysis of UV chroma distribution on their flowers. Botanical classification of the plant species (complete binomial, genus and family), their attractant structures (S), geographical occurrence areas (N- neotropical, EM -extra-neotropical, G- global), functional visitor group classifications (VG), pollination system categorizations (PS), color categories (color), UV chroma values (UV), reference index (RI), and the data sources from which reflectance information was gathered (database). Attractant structures (S) are categorized as P-petal, SP-sepal, L-leaf, B-bract, and ST-stamen. VG refers to categorizing visitors into groups based on their specific behavior, size, and function during flower visits. PS involves categorizing the pollination systems that plants use based on the functional groups of floral visitors that are present in those systems. The color categories feature 16 subdivisions of colors including the UV absorbent (UV-) and UV reflectant (UV+) ones (following Camargo et al. 2019 and Coimbra et al. 2020). The data sources for this information come from two main databases: one is a comprehensive database (referred to here as "SP and KL dataset") previously compiled by coauthors Drs. Klaus Lunau and Sarah Papiorek , and the other dataset was collected from Coimbra et al. 2020. The species are arranged according to their botanical families, spanning across 379 genera and 102 distinct botanical families.

| Species | Genus | Family | S | Area | VG | PS | Color | UV | RI | Database |
|---|---|---|---|---|---|---|---|---|---|---|
| *Aaronsohnia factorovskyi Warb. & Eig* | Aaronsohnia | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.014 | 1 | Coimbra et al. 2020 |
| *Acacia podalyriifolia G.Don* | Acacia | Fabaceae | ST | G | bee | bee | UV-Yellow | 0.034 | 283 | SP and KL dataset |
| *Acalypha hispida Burm.f.* | Acalypha | Euphorbiaceae | ST | G | bee-beetle-butterfly-fly | bee-insects | UV-Red | 0.089 | 2 | SP and KL dataset |
| *Acca sellowiana (O.Berg) Burret* | Acca | Myrtaceae | ST | G | bee-bat-bird-mammal | vertebrate-insects | UV+Red | 0.146 | 3; 336 | SP and KL dataset |
| *Acnistus arborescens (L.) Schltdl.* | Acnistus | Solanaceae | P | N | bee-butterfly-fly | bee-insects | UV+White | 0.071 | 4 | SP and KL dataset |
| *Aconitum anthora L.* | Aconitum | Ranunculaceae | P | EN | bee | bee | UV+Yellow | 0.068 | 5 | SP and KL dataset |
| *Aconitum napellus L.* | Aconitum | Ranunculaceae | P | EN | bee | bee | UV+Blue | 0.089 | 6 | SP and KL dataset |
| *Aechmea aquilega (Salisb.) Griseb.* | Aechmea | Bromeliaceae | P | G | bird | bird | UV-Red | 0.008 | 3 | Coimbra et al. 2020 |
| *Aechmea blanchetiana (Baker) L.B.Sm.* | Aechmea | Bromeliaceae | B | N | bird | bird | UV-Red | 0.013 | 9 | SP and KL dataset |
| *Aechmea bromeliifolia (Rudge) Baker* | Aechmea | Bromeliaceae | P | G | bird | bird | UV-Red | 0.007 | 10; 7 | Coimbra et al. 2020 |
| *Aechmea caudata Lindm.* | Aechmea | Bromeliaceae | P | G | bird-bee-butterfly | vertebrate-insects | UV+Red | 0.765 | 12 | SP and KL dataset |
| *Aechmea eurycorymbus Harms* | Aechmea | Bromeliaceae | P | N | bird | bird | UV-Yellow | 0.013 | 7; 12 | Coimbra et al. 2020 |
| *Aechmea fulgens Brongn.* | Aechmea | Bromeliaceae | P | N | bird | bird | UV+Pink | 0.091 | 13 | SP and KL dataset |
| *Aechmea nudicaulis (L.) Griseb.* | Aechmea | Bromeliaceae | B | N | bird-bee | vertebrate-insects | UV-Red | 0.003 | 14; 255 | SP and KL dataset |
| *Aechmea pectinata Baker* | Aechmea | Bromeliaceae | P | N | bird | bird | UV+White | 0.058 | 15; 7 | Coimbra et al. 2020 |
| *Aechmea recurvata (Klotzsch) L.B.Sm.* | Aechmea | Bromeliaceae | P | N | bird | bird | UV+Pink | 0.258 | 16 | SP and KL dataset |
| *Agapetes hosseana Diels* | Agapetes | Ericaceae | P | EN | bird | bird | UV-Red | 0.167 | 17 | SP and KL dataset |
| *Agapetes serpens (Wight) Sleumer* | Agapetes | Ericaceae | P | EN | bird | bird | UV+Red | 0.107 | 17 | SP and KL dataset |
| *Agastache mexicana (Kunth) Lint & Epling* | Agastache | Lamiaceae | P | G | bird | bird | UV+Pink | 0.050 | 284 | SP and KL dataset |
| *Ainsworthia trachycarpa Boiss.* | Ainsworthia | Apiaceae | P | EN | beetle | beetle | UV-White | 0.008 | 387 | Coimbra et al. 2020 |
| *Vriesea extensa L.B.Sm.* | Alcantarea | Bromeliaceae | P | N | bat | bat | UV+Yellow | 0.253 | 18 | SP and KL dataset |
| *Alcea rosea L.* | Alcea | Malvaceae | P | EN | bee | bee | UV+Pink | 0.065 | 7 | SP and KL dataset |
| *Alkanna strigosa Boiss. & Hohen.* | Alkanna | Boraginaceae | P | G | bee | bee | UV+Blue | 0.109 | 1 | Coimbra et al. 2020 |
| *Allamanda blanchetii A.DC.* | Allamanda | Apocynaceae | P | G | bee | bee | UV-Pink | 0.051 | 19 | SP and KL dataset |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Allamanda cathartica L.* | Allamanda | Apocynaceae | P | N | bee-beetle | bee-insects | UV+Yellow | 0.098 | 20; 367 | SP and KL dataset |
| *Allamanda schottii Pohl* | Allamanda | Apocynaceae | P | G | bee | bee | UV-Yellow | 0.038 | 21 | SP and KL dataset |
| *Aloe africana Mill.* | Aloe | Asphodelaceae | P | EN | bird | bird | UV-Yellow | 0.044 | 22 | SP and KL dataset |
| *Aloe bakeri Scott-Elliot* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Yellow | 0.138 | 16 | SP and KL dataset |
| *Aloe bellatula Reynolds* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Red | 0.071 | 16 | SP and KL dataset |
| *Aloe ciliaris Haw.* | Aloe | Asphodelaceae | P | EN | bird | bird | UV-Red | 0.056 | 16 | SP and KL dataset |
| *Aloe descoingsii Reynolds* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Red | 0.074 | 16 | SP and KL dataset |
| *Aloe plicatilis (L.) Mill.* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Red | 0.047 | 16 | SP and KL dataset |
| *Aloe viguieri H.Perrier* | Aloe | Asphodelaceae | P | EN | bird | bird | UV+Red | 0.153 | 16 | SP and KL dataset |
| *Aloe vogtsii Reynolds* | Aloe | Asphodelaceae | P | EN | bird | bird | UV-Yellow | 0.031 | 23 | SP and KL dataset |
| *Alpinia purpurata (Vieill.) K.Schum.* | Alpinia | Zingiberaceae | B | G | bird | bird | UV-Red | 0.060 | 24 | SP and KL dataset |
| *Alpinia zerumbet (Pers.) B.L.Burtt & R.M.Sm.* | Alpinia | Zingiberaceae | P | EN | bee | bee | UV+Yellow | 0.060 | 25 | SP and KL dataset |
| *Amherstia nobilis Wall.* | Amherstia | Fabaceae | P | EN | bird | bird | UV-Red | 0.058 | 47 | SP and KL dataset |
| *Anagyris foetida L.* | Anagyris | Fabaceae | P | EN | bee | bee | UV-Yellow | 0.056 | 1 | Coimbra et al. 2020 |
| *Ananas bracteatus (Lindl.) Schult. & Schult.f.* | Ananas | Bromeliaceae | B | N | bird | bird | UV-Red | 0.038 | 27; 302 | Coimbra et al. 2020 |
| *Anchusa strigosa Banks & Sol.* | Anchusa | Boraginaceae | P | EN | bee | bee | UV+Blue | 0.112 | 1 | Coimbra et al. 2020 |
| *Androsace chamaejasme Wulfen* | Androsace | Primulaceae | P | EN | bee-fly | bee-insects | UV+White | 0.039 | 28 | SP and KL dataset |
| *Anemone coronaria L.* | Anemone | Ranunculaceae | P | EN | beetle | beetle | UV-Red | 0.028 | 1 | Coimbra et al. 2020 |
| *Anemone nemorosa L.* | Anemone | Ranunculaceae | P | EN | bee | bee | UV-White | 0.009 | 1 | Coimbra et al. 2020 |
| *Anigozanthos flavidus DC.* | Anigozanthos | Haemodoraceae | P | EN | bird | bird | UV-Cyan | 0.029 | 2; 297 | SP and KL dataset |
| *Anthemis melampodina Delile* | Anthemis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.012 | 1 | Coimbra et al. 2020 |
| *Anthemis pseudocotula Boiss.* | Anthemis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.015 | 1 | Coimbra et al. 2020 |
| *Anthurium obtusum (Engl.) Grayum* | Anthurium | Araceae | P | G | bee-beetle-butterfly-fly | bee-insects | UV+White | 0.048 | 16 | SP and KL dataset |
| *Apeiba tibourbou Aubl.* | Apeiba | Malvaceae | P | N | bee | bee | UV+Yellow | 0.260 | 29; 379 | SP and KL dataset |
| *Aquilegia caerulea E.James* | Aquilegia | Ranunculaceae | P | EN | bee-moth | bee-insects | UV-Blue | 0.034 | 367; 338 | SP and KL dataset |
| *Aquilegia chrysantha A.Gray* | Aquilegia | Ranunculaceae | P | EN | bee-moth | bee-insects | UV-Yellow | 0.034 | 31 | SP and KL dataset |
| *Aquilegia einseleana F.W.Schultz* | Aquilegia | Ranunculaceae | P | EN | bee | bee | UV-Blue | 0.073 | 31; 7 | SP and KL dataset |
| *Arabidopsis arenosa (L.) LawalrÃ©e* | Arabidopsis | Brassicaceae | P | EN | bee-fly | bee-insects | UV-White | 0.003 | 1 | Coimbra et al. 2020 |
| *Arctostaphylos uva-ursi (L.) Spreng.* | Arctostaphylos | Ericaceae | P | EN | bee | bee | UV-White | 0.033 | 1 | Coimbra et al. 2020 |
| *Arenaria serpyllifolia L.* | Arenaria | Caryophyllaceae | P | EN | fly | fly | UV-White | 0.025 | 1 | Coimbra et al. 2020 |
| *Arnica montana L.* | Arnica | Asteraceae | P | G | fly | fly | UV+Yellow | 0.103 | 32 | SP and KL dataset |
| *Asclepias incarnata L.* | Asclepias | Apocynaceae | P | EN | bee-moth | bee-insects | UV+Pink | 0.119 | 33 | SP and KL dataset |
| *Asphodeline liburnica (Scop.) Rchb.* | Asphodeline | Asphodelaceae | P | EN | bee | bee | UV+Yellow | 0.058 | 34 | SP and KL dataset |
| *Asphodelus aestivus Brot.* | Asphodelus | Asphodelaceae | P | EN | bee | bee | UV+White | 0.088 | 34; 1 | SP and KL dataset |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Asteriscus graveolens (Forssk.) Less.* | Asteriscus | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.089 | 1 | Coimbra et al. 2020 |
| *Astragalus amalecitanus Boiss.* | Astragalus | Fabaceae | P | EN | bee | bee | UV-White | 0.017 | 1 | Coimbra et al. 2020 |
| *Baccharis trimera (Less.) DC.* | Baccharis | Asteraceae | P | N | bee | bee | UV-Yellow | 0.024 | 12 | SP and KL dataset |
| *Banksia prionotes Lindl.* | Banksia | Proteaceae | ST | EN | bird | bird | UV+Red | 0.015 | 35 | SP and KL dataset |
| *Banksia serrata L.f.* | Banksia | Proteaceae | ST | EN | bird-marsupial | vertebrate | UV-Yellow | 0.063 | 36; 322 | SP and KL dataset |
| *Barringtonia racemosa (L.) Spreng.* | Barringtonia | Lecythidaceae | ST | EN | bat-moth | vertebrate-insects | UV+White | 0.038 | 37; 288 | SP and KL dataset |
| *Bauhinia variegata L.* | Bauhinia | Fabaceae | P | EN | bird-moth | vertebrate-insects | UV+Pink | 0.099 | 38; 353 | SP and KL dataset |
| *Begonia boliviensis A.DC.* | Begonia | Begoniaceae | P | G | bee-wasp | bee | UV+Red | 0.048 | 39 | SP and KL dataset |
| *Begonia coccinea Hook.* | Begonia | Begoniaceae | P | G | bee | bee | UV+White | 0.096 | 40;344 | SP and KL dataset |
| *Begonia microsperma Warb.* | Begonia | Begoniaceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 0.120 | 17 | SP and KL dataset |
| *Begonia minor Jacq.* | Begonia | Begoniaceae | P | EN | bee-beetle-fly | bee-insects | UV-Red | 0.219 | 17 | SP and KL dataset |
| *Begonia sericoneura Liebm.* | Begonia | Begoniaceae | P | N | bee-beetle-fly | bee-insects | UV+White | 0.091 | 17 | SP and KL dataset |
| *Bellis perennis L.* | Bellis | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV+White | 0.048 | 41 | SP and KL dataset |
| *Berberis darwinii Hook.* | Berberis | Berberidaceae | P | EN | bee | bee | UV+Yellow | 0.045 | 42; 303 | SP and KL dataset |
| *Bidens ferulifolia (Jacq.) Sweet* | Bidens | Asteraceae | P | EN | bee | bee | UV+Yellow | 0.042 | 43; 316 | SP and KL dataset |
| *Billbergia amoena (Lodd.) Lindl.* | Billbergia | Bromeliaceae | P | N | bird | bird | UV+Green | 0.142 | 44; 301 | SP and KL dataset |
| *Billbergia nutans H.Wendl. ex Regel* | Billbergia | Bromeliaceae | B | G | bird | bird | UV-Red | 0.089 | 16 | SP and KL dataset |
| *Billbergia pyramidalis (Sims) Lindl.* | Billbergia | Bromeliaceae | B | G | bird | bird | UV-Red | 0.166 | 45; 1 | Coimbra et al. 2020 |
| *Billbergia viridiflora H.Wendl.* | Billbergia | Bromeliaceae | B | N | bird | bird | UV+Red | 0.046 | 16 | SP and KL dataset |
| *Persicaria amplexicaulis (D.Don) Ronse Decr.* | Bistorta | Polygonaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+Pink | 0.004 | 2 | SP and KL dataset |
| *Brownea grandiceps Jacq.* | Brownea | Fabaceae | P | G | bird | bird | UV+Red | 0.175 | 46 | SP and KL dataset |
| *Brugmansia arborea (L.) Steud.* | Brugmansia | Solanaceae | P | G | moth | moth | UV-White | 0.177 | 47; 285 | SP and KL dataset |
| *Brunfelsia americana L.* | Brunfelsia | Solanaceae | P | G | moth-butterfly | insects | UV+White | 0.753 | 48 | SP and KL dataset |
| *Brunfelsia uniflora (Pohl) D.Don* | Brunfelsia | Solanaceae | P | N | moth-butterfly | insects | UV-Blue | 0.029 | 49; 348 | SP and KL dataset |
| *Buddleja davidii Franch.* | Buddleja | Scrophulariaceae | P | EN | butterfly | butterfly | UV+Pink | 0.038 | 50;306;307;308;309 | SP and KL dataset |
| *Byrsonima verbascifolia (L.) DC.* | Byrsonima | Malpighiaceae | P | N | bee | bee | UV+Yellow | 0.027 | 51 | SP and KL dataset |
| *Calanthe vestita Wall. ex Lindl.* | Calanthe | Orchidaceae | P | EN | bee | bee | UV-White | 0.069 | 16 | SP and KL dataset |
| *Calendula arvensis M.Bieb.* | Calendula | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.636 | 1 | Coimbra et al. 2020 |
| *Calicotome villosa (Poir.) Link* | Calicotome | Fabaceae | P | EN | bee | bee | UV+Yellow | 0.007 | 1 | Coimbra et al. 2020 |
| *Calliandra haematocephala Hassk.* | Calliandra | Fabaceae | ST | G | bird-bee | vertebrate-insects | UV+Red | 0.047 | 17 | SP and KL dataset |
| *Calliandra brevipes Benth.* | Calliandra | Fabaceae | ST | N | bird-bee | vertebrate-insects | UV+Pink | 0.060 | 12 | SP and KL dataset |
| *Calliandra tweedii Benth.* | Calliandra | Fabaceae | ST | N | bird-bee | vertebrate-insects | UV+Red | 0.185 | 12 | SP and KL dataset |
| *Callianthe megapotamica (A.Spreng.) Dorr* | Callianthe | Malvaceae | P | G | bird | bird | UV-Yellow | 0.096 | 52 | SP and KL dataset |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Callianthe picta (Gillies ex Hook. & Arn.) Donnell* | Callianthe | Malvaceae | P | G | bird | bird | UV-Red | 0.067 | 53 | SP and KL dataset |
| *Callistemon citrinus (Curtis) Skeels* | Callistemon | Myrtaceae | ST | EN | bird-bee-butterfly-wasp | vertebrate-insects | UV+Red | 0.047 | 54 | SP and KL dataset |
| *Callistemon viminalis (Sol. ex Gaertn.) G.Don* | Callistemon | Myrtaceae | ST | EN | bird | bird | UV+Red | 0.126 | 2 | SP and KL dataset |
| *Callopsis volkensii Engl.* | Callopsis | Araceae | P | EN | beetle-fly | insects | UV-White | 0.140 | 16 | SP and KL dataset |
| *Calluna vulgaris (L.) Hull* | Calluna | Ericaceae | P | EN | bee-beetle-fly | bee-insects | UV+Pink | 0.115 | 1 | Coimbra et al. 2020 |
| *Calvoa orientalis Taub.* | Calvoa | Melastomataceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+Pink | 0.029 | 2 | SP and KL dataset |
| *Camellia japonica L.* | Camellia | Theaceae | P | EN | bird | bird | UV+Pink | 0.126 | 55 | SP and KL dataset |
| *Camellia sasanqua Thunb.* | Camellia | Theaceae | P | EN | bird | bird | UV-Pink | 0.063 | 56; 17 | SP and KL dataset |
| *Camellia sinensis (L.) Kuntze* | Camellia | Theaceae | P | G | bee | bee | UV+White | 0.138 | 17 | SP and KL dataset |
| *Campanula cochleariifolia Lam.* | Campanula | Campanulaceae | P | EN | bee | bee | UV+Blue | 0.033 | 57; 325 | SP and KL dataset |
| *Campanula poscharskyana Degen* | Campanula | Campanulaceae | P | EN | bee | bee | UV+Blue | 0.047 | 58 | SP and KL dataset |
| *Campsis grandiflora (Thunb.) K.Schum.* | Campsis | Bignoniaceae | P | EN | bee | bee | UV+Red | 0.249 | 59 | SP and KL dataset |
| *Campsis radicans (L.) Seem.* | Campsis | Bignoniaceae | P | EN | bird | bird | UV-Red | 0.093 | 17 | SP and KL dataset |
| *Canarina canariensis (L.) Vatke* | Canarina | Campanulaceae | P | EN | bird | bird | UV+Red | 0.086 | 60 | SP and KL dataset |
| *Cantua buxifolia Juss. ex Lam.* | Cantua | Polemoniaceae | P | G | bird | bird | UV+Pink | 0.082 | 61; 17 | SP and KL dataset |
| *Capsella bursa-pastoris (L.) Medik.* | Capsella | Brassicaceae | P | EN | bee-fly | bee-insects | UV+White | 0.136 | 1 | Coimbra et al. 2020 |
| *Cardamine pratensis L.* | Cardamine | Brassicaceae | P | EN | bee-butterfly | bee-insects | UV-White | 0.120 | 62 | SP and KL dataset |
| *Caryocar brasiliense A.St.-Hil.* | Caryocar | Caryocaraceae | P | N | bird-bat-moth | vertebrate-insects | UV+White | 0.046 | 63 | SP and KL dataset |
| *Ceiba erianthos (Cav.) K.Schum.* | Ceiba | Malvaceae | P | N | bat | bat | UV-White | 0.024 | 64; 386 | SP and KL dataset |
| *Centaurea aegyptiaca L.* | Centaurea | Asteraceae | P | EN | bee | bee | UV+White | 0.794 | 1 | Coimbra et al. 2020 |
| *Centaurea ammocyanus Boiss.* | Centaurea | Asteraceae | P | EN | bee | bee | UV+Pink | 0.022 | 1 | Coimbra et al. 2020 |
| *Centaurea pallescens Delile* | Centaurea | Asteraceae | P | EN | bee | bee | UV-White | 0.050 | 1 | Coimbra et al. 2020 |
| *Centranthus ruber (L.) DC.* | Centranthus | Caprifoliaceae | P | EN | butterfly | butterfly | UV+Red | 0.062 | 65; 52 | SP and KL dataset |
| *Centropogon cornutus (L.) Druce* | Centropogon | Campanulaceae | P | G | bird | bird | UV-Red | 0.005 | 66 | SP and KL dataset |
| *Centropogon valerii Standl.* | Centropogon | Campanulaceae | P | N | bird | bird | UV-Red | 0.081 | 66 | SP and KL dataset |
| *Cercis siliquastrum L.* | Cercis | Fabaceae | P | EN | bee | bee | UV-Pink | 0.057 | 1 | Coimbra et al. 2020 |
| *Ceropegia dichotoma Haw.* | Ceropegia | Apocynaceae | P | EN | fly | fly | UV+Yellow | 0.052 | 67 | SP and KL dataset |
| *Cestrum elegans (Brongn. ex Neumann) Schltdl.* | Cestrum | Solanaceae | P | G | bird-butterfly-moth | vetebrate-insects | UV+Red | 0.013 | 68; 319 | SP and KL dataset |
| *Cestrum parqui (Lam.) L'HÃ©r.* | Cestrum | Solanaceae | P | EN | bird-butterfly-moth | vetebrate-insects | UV-Yellow | 0.058 | 68; 319 | SP and KL dataset |
| *Chaenomeles japonica (Thunb.) Lindl. ex Spach* | Chaenomeles | Rosaceae | P | EN | bee | bee | UV-Red | 0.106 | 69 | SP and KL dataset |
| *Chasmanthe aethiopica (L.) N.E.Br.* | Chasmanthe | Iridaceae | P | EN | bird | bird | UV+Red | 0.036 | 70; 321 | SP and KL dataset |
| *Chelone lyonii Pursh* | Chelone | Plantaginaceae | P | EN | bee | bee | UV+Pink | 0.081 | 71 | SP and KL dataset |
| *Cirsium eriophorum (L.) Scop.* | Cirsium | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV+Pink | 0.070 | 72; 380 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Cirsium oleraceum (L.) Scop.* | Cirsium | Asteraceae | P | EN | bee | bee | UV-White | 0.062 | 1 | Coimbra et al. 2020 |
| *Cistus creticus (Viv.) Greuter & Burdet* | Cistus | Cistaceae | P | EN | bee | bee | UV-Pink | 0.122 | 73; 375 | SP and KL dataset |
| *Cistus inflatus Pourr. ex J.-P.Demoly* | Cistus | Cistaceae | P | EN | bee | bee | UV-White | 0.017 | 74 | SP and KL dataset |
| *Citrus aurantium L.* | Citrus | Rutaceae | P | G | bird | bird | UV-White | 0.009 | 75; 292 | SP and KL dataset |
| *Cleome spinosa Jacq.* | Cleome | Cleomaceae | P | G | bat | bat | UV+Pink | 0.015 | 76; 332 | SP and KL dataset |
| *Clerodendrum thomsoniae Balf.f.* | Clerodendrum | Lamiaceae | P | G | butterfly | butterfly | UV+Red | 0.019 | 12 | SP and KL dataset |
| *Clerodendrum trichotomum Thunb.* | Clerodendrum | Lamiaceae | P | EN | butterfly | butterfly | UV+White | 0.108 | 12 | SP and KL dataset |
| *Clidemia hirta (L.) D. Don* | Clidemia | Melastomataceae | P | EN | bee | bee | UV-White | 0.110 | 12; 300 | SP and KL dataset |
| *Clusia lanceolata Cambess.* | Clusia | Clusiaceae | P | N | bee | bee | UV+White | 0.029 | 77 | SP and KL dataset |
| *Clytostoma callistegioides (Cham.) Baill.* | Clytostoma | Bignoniaceae | P | G | bee | bee | UV-Pink | 0.045 | 78 | SP and KL dataset |
| *Cobaea scandens Cav.* | Cobaea | Polemoniaceae | P | N | bat | bat | UV+Pink | 0.033 | 79; 289; 290 | SP and KL dataset |
| *Cochlospermum vitifolium (Willd.) Spreng.* | Cochlospermum | Bixaceae | P | N | bee | bee | UV+Yellow | 0.252 | 80; 368; 369 | SP and KL dataset |
| *Codiaeum variegatum (L.) Rumph. ex A.Juss.* | Codiaeum | Euphorbiaceae | ST | EN | bee-beetle-butterfly-fly | bee-insects | UV-White | 0.252 | 81 | SP and KL dataset |
| *Codonanthe gracilis (Mart.) Hanst.* | Codonanthe | Gesneriaceae | P | N | bee | bee | UV+White | 0.053 | 17 | SP and KL dataset |
| *Codonanthopsis crassifolia* | Codonanthe | Gesneriaceae | P | N | moth | moth | UV+White | 0.159 | 82 | SP and KL dataset |
| *Coelogyne cristata Lindl.* | Coelogyne | Orchidaceae | P | EN | moth | moth | UV+White | 0.128 | 83 | SP and KL dataset |
| *Coleonema album (Thunb.) Bartl. & H.L.Wendl.* | Coleonema | Rutaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+White | 0.034 | 84 | SP and KL dataset |
| *Collaea argentina Griseb.* | Collaea | Fabaceae | P | N | bee | bee | UV+Pink | 0.059 | 85 | SP and KL dataset |
| *Columnea magnifica Klotzsch ex Oerst.* | Columnea | Gesneriaceae | P | N | bird | bird | UV+Red | 0.083 | 86;10 | SP and KL dataset |
| *Columnea microcalyx Hanst.* | Columnea | Gesneriaceae | P | N | bird | bird | UV-Red | 0.047 | 86 | SP and KL dataset |
| *Columnea scandens L.* | Columnea | Gesneriaceae | P | G | bird | bird | UV-Red | 0.046 | 87 | SP and KL dataset |
| *Convolvulus arvensis L.* | Convolvulus | Convolvulaceae | P | EN | bee-fly | bee-insects | UV-White | 0.073 | 88 | SP and KL dataset |
| *Coreopsis grandiflora Hogg ex Sweet* | Coreopsis | Asteraceae | P | EN | bee | bee | UV-Yellow | 0.104 | 89 | SP and KL dataset |
| *Corylus avellana L.* | Corylus | Bertulaceae | P | EN | bee | bee | UV-Yellow | 0.082 | 1 | Coimbra et al. 2020 |
| *Corymbia ficifolia (F.Muell.) K.D.Hill & L.A.S.Johnson* | Corymbia | Myrtaceae | ST | EN | bird | bird | UV-Red | 0.052 | 90 | SP and KL dataset |
| *Costus afer Ker Gawl.* | Costus | Costaceae | P | EN | bee | bee | UV+White | 0.072 | 42;91 | SP and KL dataset |
| *Costus erythrophyllus Loes.* | Costus | Costaceae | P | N | bee | bee | UV+White | 0.023 | 92 | SP and KL dataset |
| *Costus lucanusianus J.Braun & K.Schum.* | Costus | Costaceae | P | EN | bird-bee | vertebrate-insects | UV+Red | 0.045 | 93 | SP and KL dataset |
| *Costus malortieanus H.Wendl.* | Costus | Costaceae | P | G | bee | bee | UV+Yellow | 0.011 | 94 | SP and KL dataset |
| *Costus pulverulentus C.Presl* | Costus | Costaceae | P | N | bee | bee | UV+Red | 0.070 | 94 | SP and KL dataset |
| *Costus spicatus (Jacq.) Sw.* | Costus | Costaceae | P | N | bird | bird | UV-Pink | 0.384 | 94 | SP and KL dataset |
| *Crataegus azarolus L.* | Crataegus | Rosaceae | P | EN | bee-beetle-fly | bee-insects | UV-White | 0.739 | 1 | Coimbra et al. 2020 |
| *Crepis aspera L.* | Crepis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.197 | 1 | Coimbra et al. 2020 |
| *Crepis hierosolymitana Boiss.* | Crepis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 0.117 | 1 | Coimbra et al. 2020 |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Crepis sancta (L.) Bornm.* | Crepis | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.092 | 1 | Coimbra et al. 2020 |
| *Crinodendron patagua Molina* | Crinodendron | Elaeocarpaceae | P | N | bee | bee | UV-White | 0.140 | 95 | SP and KL dataset |
| *Crocus angustifolius Weston* | Crocus | Iridaceae | P | EN | bee-fly | bee-insects | UV-Yellow | 0.025 | 96 | SP and KL dataset |
| *Crocus flavus Weston* | Crocus | Iridaceae | P | EN | bee-fly | bee-insects | UV-Yellow | 0.010 | 44;96 | SP and KL dataset |
| *Crotalaria agatiflora Schweinf.* | Crotalaria | Fabaceae | P | EN | bird | bird | UV+Green | 0.029 | 97; 187 | SP and KL dataset |
| *Cuphea ignea A.DC.* | Cuphea | Lythraceae | P | G | bird-butterfly | vertebrate-insects | UV-Red | 0.075 | 98 | SP and KL dataset |
| *Cuphea lanceolata W.T.Aiton* | Cuphea | Lythraceae | P | G | bee-butterfly-fly | bee-insects | UV+Pink | 0.026 | 99 | SP and KL dataset |
| *Curcuma longa L.* | Curcuma | Zingiberaceae | P | G | bee | bee | UV+White | 0.033 | 100 | SP and KL dataset |
| *Cyclamen hederifolium Aiton* | Cyclamen | Primulaceae | P | EN | bee-fly | bee-insects | UV-White | 0.035 | 101 | SP and KL dataset |
| *Cyclamen persicum Mill.* | Cyclamen | Primulaceae | P | EN | bee | bee | UV-White | 0.012 | 1 | Coimbra et al. 2020 |
| *Dahlstedtia pinnata (Benth.) Malme* | Dahlstedtia | Fabaceae | P | N | bird | bird | UV+Pink | 0.100 | 45 | Coimbra et al. 2020 |
| *Dalechampia spathulata (Scheidw.) Baill.* | Dalechampia | Euphorbiaceae | L | N | bee | bee | UV+Pink | 0.033 | 104; 2 | SP and KL dataset |
| *Deherainia smaragdina (Planch. ex Linden) Decne.* | Deherainia | Primulaceae | P | N | fly | fly | UV+Green | 0.157 | 105; 327 | SP and KL dataset |
| *Dendrobium nobile Lindl.* | Dendrobium | Orchidaceae | P | EN | bee | bee | UV-Pink | 0.134 | 16 | SP and KL dataset |
| *Desfontainia spinosa Ruiz & Pav.* | Desfontainia | Columelliaceae | P | N | bird | bird | UV-Red | 0.018 | 107; 327 | SP and KL dataset |
| *Deuterocohnia meziana Kuntze ex Mez* | Deuterocohnia | Bromeliaceae | P | N | bird-bee | vertebrate-insects | UV-Red | 0.008 | 108 | SP and KL dataset |
| *Dianthus carthusianorum L.* | Dianthus | Caryophyllaceae | P | EN | bee-butterfly | bee-insects | UV-Pink | 0.071 | 1 | Coimbra et al. 2020 |
| *Dianthus superbus L.* | Dianthus | Caryophyllaceae | P | EN | bee | bee | UV+White | 0.069 | 109 | SP and KL dataset |
| *Dianthus sylvestris Wulfen* | Dianthus | Caryophyllaceae | P | EN | butterfly- moth | insects | UV+Pink | 0.203 | 110;304 | SP and KL dataset |
| *Dichorisandra thyrsiflora J.C.Mikan* | Dichorisandra | Commelinaceae | P | EN | bee | bee | UV+Blue | 0.052 | 255; 370; 371 | SP and KL dataset |
| *Isoplexis canariensis (L.) Loudon* | Digitalis | Plantaginaceae | P | EN | bird-lizard | vertebrate | UV-Red | 0.039 | 210 | SP and KL dataset |
| *Digitalis parviflora Jacq.* | Digitalis | Plantaginaceae | P | EN | bee | bee | UV-Red | 0.005 | 210 | SP and KL dataset |
| *Digitalis purpurea L.* | Digitalis | Plantaginaceae | P | EN | bee | bee | UV+Pink | 0.014 | 210 | SP and KL dataset |
| *Duranta erecta L.* | Duranta | Verbenaceae | P | EN | bee | bee | UV-Blue | 0.057 | 237; 351 | SP and KL dataset |
| *Dyckia brevifolia Baker* | Dyckia | Bromeliaceae | P | N | bird-bee | vertebrate-insects | UV-Yellow | 0.098 | 239 | SP and KL dataset |
| *Echium angustifolium Mill.* | Echium | Boraginaceae | P | EN | bee | bee | UV-Pink | 0.116 | 1 | Coimbra et al. 2020 |
| *Echium candicans L.f.* | Echium | Boraginaceae | P | EN | bee | bee | UV-Blue | 0.067 | 271 | SP and KL dataset |
| *Echium hierrense Webb ex Bolle* | Echium | Boraginaceae | P | EN | bee | bee | UV+Pink | 0.071 | 140 | SP and KL dataset |
| *Echium rauwolfii Delile* | Echium | Boraginaceae | P | EN | bee | bee | UV+Pink | 0.051 | 1 | Coimbra et al. 2020 |
| *Echium vulgare L.* | Echium | Boraginaceae | P | EN | bee | bee | UV+Blue | 0.248 | 47;30 | SP and KL dataset |
| *Eichhornia azurea (Sw.) Kunth* | Eichhornia | Pontederiaceae | P | N | bee | bee | UV-Blue | 0.014 | 117; 291 | SP and KL dataset |
| *Emilia coccinea (Sims) G.Don* | Emilia | Asteraceae | P | EN | bee | bee | UV+White | 0.131 | 186 | SP and KL dataset |
| *Entelea arborescens R.Br.* | Entelea | Malvaceae | P | EN | bee | bee | UV-White | 0.024 | 125 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Epimedium versicolor E.Morren* | Epimedium | Berberidaceae | P | EN | bee | bee | UV+Yellow | 0.071 | 260 | SP and KL dataset |
| *Eremurus stenophyllus (Boiss. & Buhse) Baker* | Eremurus | Asphodelaceae | P | EN | bee | bee | UV+Yellow | 0.151 | 16 | SP and KL dataset |
| *Erica caffra L.* | Erica | Ericaceae | P | EN | bee | bee | UV+White | 0.151 | 17; 299 | SP and KL dataset |
| *Erica mammosa L.* | Erica | Ericaceae | P | EN | bird | bird | UV+White | 0.292 | 236 | SP and KL dataset |
| *Erica versicolor Andrews* | Erica | Ericaceae | P | EN | bird | bird | UV-Red | 0.248 | 236 | SP and KL dataset |
| *Erigeron canadensis L.* | Erigeron | Asteraceae | P | EN | bee | bee | UV-White | 0.005 | 1 | Coimbra et al. 2020 |
| *Eriobotrya japonica (Thunb.) Lindl.* | Eriobotrya | Rosaceae | P | EN | bird | bird | UV-White | 0.080 | 207 | SP and KL dataset |
| *Erysimum cheiranthoides L.* | Erysimum | Brassicaceae | P | EN | bee-fly | bee-insects | UV+Yellow | 0.061 | 1 | Coimbra et al. 2020 |
| *Erythrina crista-galli L.* | Erythrina | Fabaceae | P | EN | bird-bee | vertebrate-insects | UV+Red | 0.061 | 152; 68 | SP and KL dataset |
| *Erythrina falcata Benth.* | Erythrina | Fabaceae | P | N | bird | bird | UV-Red | 0.102 | 143; 310 | Coimbra et al. 2020 |
| *Erythrina fusca Lour.* | Erythrina | Fabaceae | P | G | bird | bird | UV+White | 0.006 | 209; 339 | Coimbra et al. 2020 |
| *Erythrina humeana Spreng.* | Erythrina | Fabaceae | P | G | bird | bird | UV-Red | 0.033 | 17 | SP and KL dataset |
| *Erythrina speciosa Andrews* | Erythrina | Fabaceae | P | N | bird | bird | UV+Red | 0.035 | 45 | Coimbra et al. 2020 |
| *Erythrochiton brasiliensis Nees & Mart.* | Erythrochiton | Rutaceae | P | N | bird | bird | UV+White | 0.070 | 192 | SP and KL dataset |
| *Erythronium oregonum Applegate* | Erythronium | Liliaceae | P | EN | bee | bee | UV+White | 0.163 | 217 | SP and KL dataset |
| *Eschscholzia californica Cham.* | Eschscholzia | Papaveraceae | P | EN | bee | bee | UV-Yellow | 0.023 | 280 | SP and KL dataset |
| *Etlingera elatior (Jack) R.M.Sm.* | Etlingera | Zingiberaceae | P | EN | bird-bee | vertebrate-insects | UV-Red | 0.054 | 242; 352 | SP and KL dataset |
| *Eucomis comosa (Houtt.) Wehrh.* | Eucomis | Asparagaceae | P | EN | bee-beetle-fly-wasp | bee-insects | UV-White | 0.087 | 251; 362 | SP and KL dataset |
| *Euphorbia atropurpurea Brouss. ex Willd.* | Euphorbia | Euphorbiaceae | P | EN | fly | fly | UV+Pink | 0.094 | 2 | SP and KL dataset |
| *Euphorbia hierosolymitana Boiss.* | Euphorbia | Euphorbiaceae | P | EN | fly | fly | UV-Yellow | 0.109 | 1 | Coimbra et al. 2020 |
| *Euphorbia pulcherrima Willd. ex Klotzsch* | Euphorbia | Euphorbiaceae | B | N | bird | bird | UV-Red | 0.049 | 207; 7 | SP and KL dataset |
| *Euryops pectinatus (L.) Cass.* | Euryops | Asteraceae | P | EN | bee-fly | bee-insects | UV+Yellow | 0.032 | 130;305 | SP and KL dataset |
| *Fosterella penduliflora (C.H.Wright) L.B.Sm.* | Fosterella | Bromeliaceae | P | N | bee | bee | UV-White | 0.054 | 16 | SP and KL dataset |
| *Freycinetia cumingiana Gaudich.* | Freycinetia | Pandanaceae | B | EN | bird | bird | UV+Red | 0.057 | 135 | SP and KL dataset |
| *Freylinia lanceolata (L.) G.Don* | Freylinia | Scrophulariaceae | P | EN | bee | bee | UV-Yellow | 0.219 | 214;268 | SP and KL dataset |
| *Fuchsia boliviana CarriÃ¨re* | Fuchsia | Onagraceae | P | N | bird | bird | UV+Red | 0.015 | 52; 2 | SP and KL dataset |
| *Fuchsia loxensis Kunth* | Fuchsia | Onagraceae | SP | N | bird | bird | UV+Pink | 0.101 | 2 | SP and KL dataset |
| *Fuchsia magdalenae Munz* | Fuchsia | Onagraceae | P | N | bird | bird | UV+Red | 0.110 | 2 | SP and KL dataset |
| *Fuchsia microphylla Kunth* | Fuchsia | Onagraceae | P | G | bird | bird | UV+Pink | 0.194 | 114 | SP and KL dataset |
| *Fuchsia paniculata Lindl.* | Fuchsia | Onagraceae | P | G | bird | bird | UV+Pink | 0.043 | 2 | SP and KL dataset |
| *Fuchsia regia (Vand. ex Vell.) Munz* | Fuchsia | Onagraceae | P | N | bird | bird | UV-Red | 0.330 | 253 | SP and KL dataset |
| *Fuchsia vulcanica AndrÃ©* | Fuchsia | Onagraceae | P | N | bird | bird | UV-Red | 0.044 | 2 | SP and KL dataset |
| *Galium verum L.* | Galium | Rubiaceae | P | EN | bee | bee | UV-Yellow | 0.138 | 1 | Coimbra et al. 2020 |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Gardenia jasminoides J.Ellis* | Gardenia | Rubiaceae | P | G | moth | moth | UV+White | 0.086 | 266; 381; 382 | SP and KL dataset |
| *Gasteria pulchra (Aiton) Haw.* | Gasteria | Asphodelaceae | P | EN | bird | bird | UV-Red | 0.131 | 170 | Coimbra et al. 2020 |
| *Gazania heterochaeta DC.* | Gazania | Asteraceae | P | EN | beetle | beetle | UV-Red | 0.142 | 1 | Coimbra et al. 2020 |
| *Gentiana acaulis L.* | Gentiana | Gentianaceae | P | EN | bee | bee | UV+Blue | 0.075 | 112 | SP and KL dataset |
| *Gentiana asclepiadea L.* | Gentiana | Gentianaceae | P | EN | bee | bee | UV+Blue | 0.081 | 218 | SP and KL dataset |
| *Gerbera jamesonii Bolus ex Hook.f.* | Gerbera | Asteraceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV-Red | 0.070 | 134 | SP and KL dataset |
| *Gesneria ventricosa Sw.* | Gesneria | Gesneriaceae | P | N | bird | bird | UV-Red | 0.015 | 17 | SP and KL dataset |
| *Gloriosa superba L.* | Gloriosa | Colchicaceae | P | EN | bird-bee | vertebrate-insects | UV+Red | 0.054 | 234; 350 | SP and KL dataset |
| *Gomphocarpus physocarpus E.Mey.* | Gomphocarpus | Apocynaceae | P | G | wasp | bee | UV+White | 0.007 | 149; 314;315 | SP and KL dataset |
| *Gossypium herbaceum L.* | Gossypium | Malvaceae | P | G | bee | bee | UV+White | 0.011 | 208 | SP and KL dataset |
| *Grevillea banksii R.Br.* | Grevillea | Proteaceae | P | G | bird | bird | UV-Red | 0.178 | 148; 2 | SP and KL dataset |
| *Grevillea rosmarinifolia A.Cunn.* | Grevillea | Proteaceae | P | EN | bird | bird | UV+Pink | 0.171 | 148; 2 | SP and KL dataset |
| *Greyia sutherlandii Hook. & Harv.* | Greyia | Francoaceae | P | EN | bird | bird | UV+Red | 0.058 | 211; 341 | SP and KL dataset |
| *Cleome gynandra L.* | Gynandropsis | Cleomaceae | P | G | bee-butterfly-fly | bee-insects | UV+White | 0.099 | 111 | SP and KL dataset |
| *Gypsophila arabica Barkoudak* | Gypsophila | Caryophyllaceae | P | EN | beetle-fly | insects | UV+White | 0.045 | 1 | Coimbra et al. 2020 |
| *Gypsophila repens L.* | Gypsophila | Caryophyllaceae | P | EN | bee-fly | bee-insects | UV-White | 0.246 | 193 | SP and KL dataset |
| *Hamelia patens Jacq.* | Hamelia | Rubiaceae | P | EN | bird-butterfly | vertebrate-insects | UV+Red | 0.055 | 40; 221; 345 | SP and KL dataset |
| *Handroanthus heptaphyllus (Vell.) Mattos* | Handroanthus | Bignoniaceae | P | G | bee | bee | UV-Pink | 0.246 | 199 | SP and KL dataset |
| *Hedychium coccineum Buch.-Ham. ex Sm.* | Hedychium | Zingiberaceae | P | G | butterfly | butterfly | UV+Red | 0.040 | 153 | SP and KL dataset |
| *Hedychium coronarium J.Koenig* | Hedychium | Zingiberaceae | P | EN | moth | moth | UV+White | 0.063 | 177 | SP and KL dataset |
| *Hedychium gardnerianum Sheppard ex Ker Gawl.* | Hedychium | Zingiberaceae | P | EN | moth | moth | UV+Yellow | 0.121 | 178 | SP and KL dataset |
| *Heliconia angusta Vell.* | Heliconia | Heliconiaceae | B | G | bird | bird | UV+Red | 0.095 | 45 | SP and KL dataset |
| *Heliconia bihai (L.) L.* | Heliconia | Heliconiaceae | B | N | bird | bird | UV+Red | 0.127 | 158 | SP and KL dataset |
| *Heliconia farinosa Raddi* | Heliconia | Heliconiaceae | B | N | bird | bird | UV-Red | 0.029 | 258 | SP and KL dataset |
| *Heliconia metallica Planch. & Linden ex Hook.* | Heliconia | Heliconiaceae | P | G | bird | bird | UV-Red | 0.113 | 246 | Coimbra et al. 2020 |
| *Heliconia rostrata Ruiz & Pav.* | Heliconia | Heliconiaceae | P | G | bird | bird | UV+Red | 0.020 | 45 | SP and KL dataset |
| *Hellenia speciosa (J.Koenig) S.R.Dutta* | Hellenia | Costaceae | P | G | bee | bee | UV+White | 0.250 | 242 | SP and KL dataset |
| *Hesperis pendula DC.* | Hesperis | Brassicaceae | P | EN | bee | bee | UV-Green | 0.066 | 1 | Coimbra et al. 2020 |
| *Heterocentron elegans (Schltdl.) Kuntze* | Heterocentron | Melastomataceae | P | N | bee | bee | UV+Pink | 0.116 | 238 | SP and KL dataset |
| *Hibiscus pedunculatus L. f.* | Hibiscus | Malvaceae | P | EN | butterfly | butterfly | UV-Pink | 0.099 | 273 | SP and KL dataset |
| *Hibiscus sabdariffa L.* | Hibiscus | Malvaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV-White | 0.773 | 216 | SP and KL dataset |
| *Hibiscus schizopetalus (Dyer) Hook.f.* | Hibiscus | Malvaceae | P | G | bird | bird | UV+Red | 0.052 | 51 | SP and KL dataset |
| *Hieracium laevigatum Froel.* | Hieracium | Asteraceae | P | EN | bee-fly | bee-insects | UV+Yellow | 0.074 | 1 | Coimbra et al. 2020 |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Hieracium sabaudum L.* | Hieracium | Asteraceae | P | EN | bee-fly | bee-insects | UV+Yellow | 0.068 | 1 | Coimbra et al. 2020 |
| *Hippobroma longiflora (L.) G.Don* | Hippobroma | Campanulaceae | P | N | fly | fly | UV+White | 0.124 | 240 | SP and KL dataset |
| *Hoffmannia refulgens (Hook.) Hemsl.* | Hoffmannia | Rubiaceae | P | N | bee | bee | UV+Red | 0.016 | 17 | SP and KL dataset |
| *Hypenia reticulata (Mart. ex Benth.) Harley* | Hypenia | Lamiaceae | P | N | bird-bee | vertebrate-insects | UV+Red | 0.210 | 115 | SP and KL dataset |
| *Hypericum balearicum L.* | Hypericum | Hypericaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+Yellow | 0.060 | 262 | SP and KL dataset |
| *Hypericum maculatum Crantz* | Hypericum | Hypericaceae | P | EN | bee | bee | UV+Yellow | 0.018 | 165 | SP and KL dataset |
| *Impatiens burtonii Hook.f.* | Impatiens | Balsamiaceae | P | EN | bee-fly | bee-insects | UV+White | 0.103 | 160; 156 | SP and KL dataset |
| *Impatiens niamniamensis Gilg* | Impatiens | Balsamiaceae | P | EN | bird | bird | UV-Yellow | 0.129 | 52; 2 | SP and KL dataset |
| *Impatiens noli-tangere L.* | Impatiens | Balsamiaceae | P | EN | bird | bird | UV+Yellow | 0.079 | 229; 2 | SP and KL dataset |
| *Impatiens scabrida DC.* | Impatiens | Balsamiaceae | P | EN | bee | bee | UV-Yellow | 0.042 | 229; 2 | SP and KL dataset |
| *Incarvillea delavayi Bureau & Franch.* | Incarvillea | Bignoniaceae | P | EN | bee | bee | UV+Pink | 0.117 | 137 | SP and KL dataset |
| *Inga sessilis (Vell.) Mart.* | Inga | Fabaceae | ST | N | bat | bat | UV-White | 0.797 | 142 | SP and KL dataset |
| *Inga vera Willd.* | Inga | Fabaceae | ST | G | bat-bird-moth | vertebrate-insects | UV+White | 0.218 | 282 | SP and KL dataset |
| *Ipomoea squamosa Choisy* | Ipomoea | Convolvulaceae | P | G | bee-beetle | bee-insects | UV+Pink | 0.228 | 1 | Coimbra et al. 2020 |
| *Iris domestica (L.) Goldblatt & Mabb.* | Iris | Iridaceae | P | EN | bee | bee | UV-Red | 0.069 | 190 | SP and KL dataset |
| *Isatis lusitanica L.* | Isatis | Brassicaceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 0.031 | 1 | Coimbra et al. 2020 |
| *Jasminum polyanthum Franch.* | Jasminum | Oleaceae | P | EN | moth | moth | UV+White | 0.236 | 127 | SP and KL dataset |
| *Jatropha podagrica Hook.* | Jatropha | Euphorbiaceae | P | EN | bird | bird | UV-Red | 0.051 | 2 | SP and KL dataset |
| *Kennedia coccinea Vent.* | Kennedia | Fabaceae | P | EN | bird | bird | UV-Red | 0.080 | 194 | SP and KL dataset |
| *Knautia arvensis (L.) Coult.* | Knautia | Caprifoliaceae | P | EN | bee-butterfly | bee-insects | UV-Pink | 0.028 | 1 | Coimbra et al. 2020 |
| *Knautia dipsacifolia Kreutzer* | Knautia | Caprifoliaceae | P | EN | butterfly | butterfly | UV-Pink | 0.043 | 1 | Coimbra et al. 2020 |
| *Kniphofia uvaria (L.) Oken* | Kniphofia | Asphodelaceae | P | EN | bird | bird | UV-Red | 0.065 | 274; 2 | SP and KL dataset |
| *Kohleria spicata (Kunth) Oerst.* | Kohleria | Gesneriaceae | P | N | bird | bird | UV+Red | 0.297 | 201 | SP and KL dataset |
| *Lamprocapnos spectabilis (L.) Fukuhara* | Lamprocapnos | Papaveraceae | P | EN | bee | bee | UV+Pink | 0.102 | 257; 376; 377 | SP and KL dataset |
| *Lantana camara L.* | Lantana | Verbenaceae | P | N | butterfly | butterfly | UV-Red | 0.073 | 255; 386 | SP and KL dataset |
| *Lapageria rosea Ruiz & Pav.* | Lapageria | Philesiaceae | P | N | bird | bird | UV+Pink | 0.041 | 116 | SP and KL dataset |
| *Lapsana communis L.* | Lapsana | Asteraceae | P | EN | bee-butterfly | bee-insects | UV-Yellow | 0.093 | 1 | Coimbra et al. 2020 |
| *Launaea angustifolia (Desf.) Kuntze* | Launaea | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.022 | 1 | Coimbra et al. 2020 |
| *Leopoldia longipes (Boiss.) Losinsk.* | Leopoldia | Asparagaceae | P | EN | bee | bee | UV-Blue | 0.019 | 1 | Coimbra et al. 2020 |
| *Lessertia frutescens (L.) Goldblatt & J.C. Manning* | Lessertia | Fabaceae | P | EN | bird | bird | UV+Red | 0.043 | 249; 361 | SP and KL dataset |
| *Leucospermum glabrum E. Phillips* | Leucospermum | Proteaceae | ST | EN | bird | bird | UV+Yellow | 0.113 | 205 | SP and KL dataset |
| *Leycesteria formosa Wall.* | Leycesteria | Caprifoliaceae | P | EN | bee | bee | UV-White | 0.124 | 17 | SP and KL dataset |
| *Libertia ixioides (G.Forst.) Spreng.* | Libertia | Iridaceae | P | EN | bee | bee | UV-White | 0.110 | 118 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Linum grandiflorum Desf.* | Linum | Linaceae | P | EN | bee | bee | UV+Red | 0.054 | 2 | SP and KL dataset |
| *Lippia lupulina Cham.* | Lippia | Verbenaceae | P | N | butterfly | butterfly | UV+Pink | 0.128 | 267 | SP and KL dataset |
| *Lobelia anceps L.f.* | Lobelia | Campanulaceae | P | EN | bee | bee | UV-Blue | 0.031 | 17 | Coimbra et al. 2020 |
| *Lobelia siphilitica L.* | Lobelia | Campanulaceae | P | EN | bee | bee | UV+Blue | 0.049 | 172 | SP and KL dataset |
| *Lobelia tupa L.* | Lobelia | Campanulaceae | P | N | bird | bird | UV+Red | 0.048 | 206; 17 | SP and KL dataset |
| *Lonicera fragrantissima Lindl. & J. Paxton* | Lonicera | Caprifoliaceae | P | EN | bee | bee | UV+White | 0.102 | 256 | SP and KL dataset |
| *Lotus berthelotii Masf.* | Lotus | Fabaceae | P | EN | bird | bird | UV-Red | 0.079 | 60 | SP and KL dataset |
| *Lycium shawii Roem. & Schult.* | Lycium | Solanaceae | P | EN | bee | bee | UV-White | 0.035 | 1 | Coimbra et al. 2020 |
| *Macroptilium atropurpureum (DC.) Urb.* | Macroptilium | Fabaceae | P | G | bee | bee | UV+Black | 0.030 | 272 | SP and KL dataset |
| *Magnolia stellata (Siebold & Zucc.) Maxim.* | Magnolia | Magnoliaceae | P | EN | beetle | beetle | UV-White | 0.293 | 166; 323; 324 | SP and KL dataset |
| *Malouetia arborea (Vell.) Miers* | Malouetia | Apocynaceae | P | N | bee | bee | UV-White | 0.246 | 166; 323; 324 | SP and KL dataset |
| *Malva alcea L.* | Malva | Malvaceae | P | EN | bee | bee | UV+Pink | 0.003 | 181 | SP and KL dataset |
| *Mammillaria sheldonii (Britton & Rose) Boed.* | Mammillaria | Cactaceae | P | N | bee | bee | UV+Pink | 0.074 | 2 | SP and KL dataset |
| *Manettia cordifolia Mart.* | Manettia | Rubiaceae | P | N | bird | bird | UV+Red | 0.135 | 132 | SP and KL dataset |
| *Medinilla magnifica Lindl.* | Medinilla | Melastomataceae | P | EN | bee | bee | UV+Pink | 0.053 | 264 | SP and KL dataset |
| *Melaleuca elliptica Labill.* | Melaleuca | Myrtaceae | ST | EN | bird | bird | UV-Red | 0.064 | 2 | SP and KL dataset |
| *Melaleuca hypericifolia Sm.* | Melaleuca | Myrtaceae | P | EN | bird | bird | UV+Red | 0.018 | 226; 2 | SP and KL dataset |
| *Melaleuca pallida (Bonpl.) Craven* | Melaleuca | Myrtaceae | ST | EN | bee-beetle-wasp | bee-insects | UV+White | 0.256 | 54 | SP and KL dataset |
| *Melaleuca quadrifida (R.Br.) Craven & R.D.Edwards* | Melaleuca | Myrtaceae | ST | EN | bird | bird | UV+Red | 0.030 | 129 | SP and KL dataset |
| *Melastoma malabathricum L.* | Melastoma | Melastomataceae | P | EN | bee | bee | UV-White | 0.004 | 195; 333 | SP and KL dataset |
| *Mesembryanthemum nodiflorum L.* | Mesembryanthemum | Azioaceae | P | EN | beetle-fly | insects | UV-White | 0.115 | 1 | Coimbra et al. 2020 |
| *Mimosa polycarpa Kunth* | Mimosa | Fabaceae | ST | N | bee | bee | UV+Pink | 0.139 | 188 | SP and KL dataset |
| *Mimulus cardinalis Douglas ex Benth.* | Mimulus | Phrymaceae | P | EN | bird | bird | UV+Red | 0.245 | 245; 357; 358; 359 | SP and KL dataset |
| *Mirabilis jalapa L.* | Mirabilis | Nyctaginaceae | P | N | moth | moth | UV+Red | 0.118 | 138 | SP and KL dataset |
| *Moehringia trinervia (L.) Clairv.* | Moehringia | Caryophyllaceae | P | EN | bee | bee | UV-White | 0.057 | 1 | Coimbra et al. 2020 |
| *Monolena primuliflora Hook. f.* | Monolena | Melastomataceae | P | N | bee-beetle-butterfly-fly | bee-insects | UV+Pink | 0.105 | 2 | SP and KL dataset |
| *Moricandia nitens (Viv.) E.A.Durand & Barratte* | Moricandia | Brassicaceae | P | EN | bee | bee | UV+Pink | 0.047 | 1 | Coimbra et al. 2020 |
| *Musa paradisiaca L.* | Musa | Musaceae | B | N | bat | bat | UV+Red | 0.132 | 219; 343 | SP and KL dataset |
| *Ensete lasiocarpum (Franch.) Cheesman* | Musella | Musaceae | B | EN | bee | bee | UV+Yellow | 0.011 | 189 | SP and KL dataset |
| *Mussaenda frondosa L.* | Mussaenda | Rubiaceae | B | EN | bee-bird-butterfly | vertebrate-insects | UV-Red | 0.025 | 123 | SP and KL dataset |
| *Mutisia acuminata Ruiz & Pav.* | Mutisia | Asteraceae | P | N | bird | bird | UV+Yellow | 0.043 | 204 | SP and KL dataset |
| *Mutisia acuminata Ruiz & Pav.* | Mutisia | Asteraceae | P | N | bird | bird | UV+Red | 0.097 | 203 | SP and KL dataset |
| *Mutisia coccinea A.St.-Hil.* | Mutisia | Asteraceae | P | N | bird | bird | UV-Red | 0.116 | 244; 356 | SP and KL dataset |
| *Myosotis decumbens Host* | Myosotis | Boraginaceae | P | EN | fly | fly | UV-Blue | 0.021 | 1 | Coimbra et al. 2020 |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Myosotis stricta Link ex Roem. & Schult.* | Myosotis | Boraginaceae | P | EN | bee-fly | bee-insects | UV+Blue | 0.060 | 1 | Coimbra et al. 2020 |
| *Myosotis vestergrenii Stroh* | Myosotis | Boraginaceae | P | EN | fly | fly | UV-Blue | 0.147 | 1 | Coimbra et al. 2020 |
| *Nanorrhinum scoparium* | Nanorrhinum | Plantaginaceae | P | EN | bee | bee | UV-Yellow | 0.144 | 1 | Coimbra et al. 2020 |
| *Napaea dioica L.* | Napaea | Malvaceae | P | EN | bee | bee | UV+White | 0.109 | 169 | SP and KL dataset |
| *Neoregelia cruenta (Graham) L.B.Sm.* | Neoregelia | Bromeliaceae | P | N | bird | bird | UV-Blue | 0.038 | 146 | Coimbra et al. 2020 |
| *Nerine sarniensis (L.) Herb.* | Nerine | Amaryllidaceae | P | EN | bee | bee | UV-Red | 0.078 | 16 | SP and KL dataset |
| *Nicotiana rustica L.* | Nicotiana | Solanaceae | P | G | bee | bee | UV+Yellow | 0.088 | 17 | SP and KL dataset |
| *Nymphoides indica (L.) Kuntze* | Nymphoides | Menyanthaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+White | 0.217 | 250 | SP and KL dataset |
| *Oenothera glazioviana Micheli* | Oenothera | Onagraceae | P | EN | moth | moth | UV+Yellow | 0.042 | 176 | SP and KL dataset |
| *Oenothera lindheimeri Engelm. & A.Gray* | Oenothera | Onagraceae | P | EN | bee | bee | UV+Red | 0.020 | 126 | SP and KL dataset |
| *Oncidium ornithorhynchum Kunth* | Oncidium | Orchidaceae | P | N | bee | bee | UV-Pink | 0.070 | 231; 233 | SP and KL dataset |
| *Opuntia fragilis (Nutt.) Haw.* | Opuntia | Cactaceae | P | EN | bird | bird | UV+Pink | 0.025 | 197 | SP and KL dataset |
| *Ornithogalum candicans (Baker) J.C.Manning & Goldblatt* | Ornithogalum | Asparagaceae | P | EN | bee-bird-fly | vertebrate-insects | UV+White | 0.027 | 133 | SP and KL dataset |
| *Osmanthus delavayi Franch.* | Osmanthus | Oleaceae | P | EN | bee-butterfly-fly-moth | bee-insects | UV+White | 0.037 | 139 | SP and KL dataset |
| *Oxypetalum coccineum Â Griseb* | Oxypetalum | Apocynaceae | P | N | butterfly | butterfly | UV+Red | 0.034 | 26;68 | SP and KL dataset |
| *Pachypodium bispinosum (L.f.) A.DC.* | Pachypodium | Apocynaceae | P | EN | bee | bee | UV+White | 0.057 | 17 | SP and KL dataset |
| *Pachypodium succulentum (L.f.) Sweet* | Pachypodium | Apocynaceae | P | EN | butterfly | butterfly | UV+Pink | 0.100 | 17 | SP and KL dataset |
| *Pandorea jasminoides (Lindl.) K.Schum.* | Pandorea | Bignoniaceae | P | EN | bee | bee | UV+White | 0.243 | 222 | SP and KL dataset |
| *Papaver nudicaule L.* | Papaver | Papaveraceae | P | EN | beetle | beetle | UV-Red | 0.145 | 119 | SP and KL dataset |
| *Papaver orientale L.* | Papaver | Papaveraceae | P | EN | beetle | beetle | UV-Red | 0.042 | 119 | SP and KL dataset |
| *Papaver rhoeas L.* | Papaver | Papaveraceae | P | EN | bee | bee | UV-Red | 0.052 | 1 | Coimbra et al. 2020 |
| *Parnassia palustris L.* | Parnassia | Parnassiaceae | P | EN | butterfly-fly | insects | UV-White | 0.191 | 1 | Coimbra et al. 2020 |
| *Passiflora citrina J.M.MacDougal* | Passiflora | Passifloraceae | P | N | bee | bee | UV+Yellow | 0.059 | 196 | SP and KL dataset |
| *Passiflora edulis Sims* | Passiflora | Passifloraceae | P | N | bee | bee | UV-White | 0.059 | 255; 373 | SP and KL dataset |
| *Paullinia cupana Kunth* | Paullinia | Sapindaceae | P | G | bee | bee | UV-White | 0.047 | 248; 360 | SP and KL dataset |
| *Pavonia multiflora A. St.-Hil.* | Pavonia | Malvaceae | SP | N | bird | bird | UV-Red | 0.063 | 17 | SP and KL dataset |
| *Pelargonium crithmifolium Sm.* | Pelargonium | Geraniaceae | P | EN | bee | bee | UV+White | 0.087 | 259; 2 | SP and KL dataset |
| *Pelargonium echinatum Curtis* | Pelargonium | Geraniaceae | P | EN | bee-moth | bee-insects | UV+White | 0.101 | 213 | SP and KL dataset |
| *Pelargonium oblongatum E. Mey. ex Harv.* | Pelargonium | Geraniaceae | P | EN | bee-butterfly-fly | bee-insects | UV+White | 0.046 | 199 | SP and KL dataset |
| *Pelargonium tetragonum L'HÃ©r.* | Pelargonium | Geraniaceae | P | EN | fly | fly | UV+White | 0.090 | 259; 2 | SP and KL dataset |
| *Penstemon pinifolius Greene* | Penstemon | Plantaginaceae | P | EN | bird | bird | UV+Red | 0.070 | 184 | SP and KL dataset |
| *Pentas lanceolata (Forssk.) Deflers* | Pentas | Rubiaceae | P | EN | bee | bee | UV-Red | 0.055 | 255 | SP and KL dataset |
| *Petunia axillaris (Lam.) Britton, Sterns & Poggenb.* | Petunia | Solanaceae | P | G | moth | moth | UV+White | 0.010 | 167 | SP and KL dataset |
| *Philadelphus coronarius L.* | Philadelphus | Hydrangeaceae | P | EN | bee | bee | UV+White | 0.063 | 231; 233 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Phlomoides tuberosa (L.) Moench* | Phlomoides | Lamiaceae | P | EN | bee | bee | UV+White | 0.038 | 215 | SP and KL dataset |
| *Phlox paniculata L.* | Phlox | Polemoniaceae | P | EN | butterfly-moth | insects | UV-Pink | 0.032 | 159 | SP and KL dataset |
| *Phragmanthera usuiensis (Oliv.) M.G.Gilbert* | Phragmanthera | Loranthaceae | P | EN | bird | bird | UV+Red | 0.084 | 183; 179 | SP and KL dataset |
| *Phygelius capensis E. Mey. ex Benth.* | Phygelius | Scrophulariaceae | P | EN | bird | bird | UV-Pink | 0.092 | 136; 17 | SP and KL dataset |
| *Picris longirostris Sch.Bip.* | Picris | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.134 | 1 | Coimbra et al. 2020 |
| *Pieris japonica (Thunb.) D. Don ex G. Don* | Pieris | Ericaceae | P | EN | bee | bee | UV-White | 0.091 | 261; 229; 287 | SP and KL dataset |
| *Pilosella officinarum Vaill.* | Pilosella | Asteraceae | P | EN | fly | fly | UV+Yellow | 0.056 | 1 | Coimbra et al. 2020 |
| *Pinguicula alpina L.* | Pinguicula | Lentibulariaceae | P | EN | bee | bee | UV-White | 0.099 | 1 | Coimbra et al. 2020 |
| *Pitcairnia heterophylla (Lindl.) Beer* | Pitcairnia | Bromeliaceae | P | N | bird | bird | UV+Red | 0.060 | 16 | SP and KL dataset |
| *Pitcairnia punicea Scheidw.* | Pitcairnia | Bromeliaceae | P | N | bird | bird | UV-Red | 0.104 | 180 | SP and KL dataset |
| *Plectranthus saccatus Benth.* | Plectranthus | Lamiaceae | P | EN | fly | fly | UV+Pink | 0.042 | 43;230; 349 | SP and KL dataset |
| *Plumbago zeylanica L.* | Plumbago | Plumbaginaceae | P | EN | fly | fly | UV+White | 0.070 | 175 | SP and KL dataset |
| *Polygala myrtifolia L.* | Polygala | Polygalaceae | P | EN | bee | bee | UV+Pink | 0.005 | 2 | SP and KL dataset |
| *Potentilla heptaphylla L.* | Potentilla | Rosaceae | P | EN | bee | bee | UV+Yellow | 0.101 | 1 | Coimbra et al. 2020 |
| *Primula vialii Delavay ex Franch.* | Primula | Primulaceae | P | EN | butterfly | butterfly | UV+White | 0.062 | 188 | SP and KL dataset |
| *Proboscidea fragrans (Lindl.) Decne.* | Proboscidea | Martyniaceae | P | G | bee | bee | UV-Pink | 0.027 | 113 | SP and KL dataset |
| *Protea comptonii Beard* | Protea | Proteaceae | ST | EN | bird | bird | UV+White | 0.031 | 124; 296 | SP and KL dataset |
| *Protea nubigena Rourke* | Protea | Proteaceae | P | EN | bird | bird | UV+White | 0.118 | 124 | SP and KL dataset |
| *Prunella grandiflora (L.) Scholler* | Prunella | Lamiaceae | P | EN | bee-butterflu-fly | bee-insects | UV+White | 0.010 | 131 | SP and KL dataset |
| *Prunus laurocerasus L.* | Prunus | Rosaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+White | 0.122 | 2 | SP and KL dataset |
| *Prunus padus L.* | Prunus | Rosaceae | P | EN | bee-butterfly-fly | bee-insects | UV-White | 0.010 | 106;128;185 | SP and KL dataset |
| *Pseudobombax grandiflorum (Cav.) A.Robyns* | Pseudobombax | Malvaceae | P | N | bat | bat | UV+White | 0.084 | 79;145;311;312 | SP and KL dataset |
| *Psychotria nuda (Cham. & Schltdl.) Wawra* | Psychotria | Rubiaceae | P | N | bird | bird | UV-Yellow | 0.063 | 103; 244 | SP and KL dataset |
| *Pulicaria incisa (Lam.) DC.* | Pulicaria | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV-Yellow | 0.143 | 2 | Coimbra et al. 2020 |
| *Puya santosii Cuatrec.* | Puya | Bromeliaceae | P | EN | bird | bird | UV+Cyan | 0.081 | 16 | SP and KL dataset |
| *Qualea multiflora Mart.* | Qualea | Vochysiaceae | P | N | bee | bee | UV+White | 0.054 | 212;342 | SP and KL dataset |
| *Quesnelia arvensis (Vell.) Mez* | Quesnelia | Bromeliaceae | B | N | bird | bird | UV-Pink | 0.004 | 45 | Coimbra et al. 2020 |
| *Quesnelia liboniana (De Jonghe) Mez* | Quesnelia | Bromeliaceae | P | N | bird | bird | UV+Blue | 0.203 | 202 | Coimbra et al. 2020 |
| *Ranunculus acris L.* | Ranunculus | Ranunculaceae | P | EN | bee-fly | bee-insects | UV-Yellow | 0.064 | 1 | Coimbra et al. 2020 |
| *Ranunculus alpestris L.* | Ranunculus | Ranunculaceae | P | EN | bee-fly | bee-insects | UV-White | 0.250 | 247 | SP and KL dataset |
| *Ranunculus marginatus d'Urv.* | Ranunculus | Ranunculaceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 0.054 | 1 | Coimbra et al. 2020 |
| *Ranunculus millefolius Banks & Sol.* | Ranunculus | Ranunculaceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 0.003 | 1 | Coimbra et al. 2020 |
| *Ratibida columnifera (Nutt.) Wooton & Standl.* | Ratibida | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV-Yellow | 0.075 | 204 | SP and KL dataset |
| *Ravenala madagascariensis Sonn.* | Ravenala | Strelitziaceae | P | EN | bat-bird-mammals | vertebrate | UV+White | 0.027 | 120; 293; 294 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Renealmia petasites Gagnep.* | Renealmia | Zingiberaceae | P | N | bird | bird | UV+White | 0.011 | 142 | SP and KL dataset |
| *Rhagadiolus stellatus (L.) Gaertn.* | Rhagadiolus | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 0.143 | 1 | Coimbra et al. 2020 |
| *Rhipsalis baccifera (J.S.Muell.) Stearn* | Rhipsalis | Cactaceae | P | G | bird | bird | UV+White | 0.259 | 162 | SP and KL dataset |
| *Rhipsalis elliptica G.Lindb. ex K.Schum.* | Rhipsalis | Cactaceae | P | N | bee | bee | UV+White | 0.017 | 122; 295 | SP and KL dataset |
| *Rhododendron lochae F.Muell.* | Rhododendron | Ericaceae | P | EN | bird | bird | UV+Red | 0.110 | 279 | SP and KL dataset |
| *Rivina humilis L.* | Rivina | Phytolaccaceae | P | EN | bee | bee | UV-White | 0.053 | 174; 331 | Coimbra et al. 2020 |
| *Rosa canina L.* | Rosa | Rosaceae | P | EN | bee-fly | bee-insects | UV+Pink | 0.025 | 163 | SP and KL dataset |
| *Rudbeckia fulgida Aiton* | Rudbeckia | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV+Yellow | 0.129 | 281 | SP and KL dataset |
| *Russelia equisetiformis Schltdl. & Cham.* | Russelia | Plantaginaceae | P | EN | bird | bird | UV-Red | 0.151 | 182 | SP and KL dataset |
| *Ruta chalepensis L.* | Ruta | Rutaceae | P | EN | fly | fly | UV-Yellow | 0.046 | 1 | Coimbra et al. 2020 |
| *Salvia cacaliifolia Benth.* | Salvia | Lamiaceae | P | N | bird | bird | UV+Blue | 0.063 | 276 | SP and KL dataset |
| *Salvia canariensis L.* | Salvia | Lamiaceae | P | EN | bee | bee | UV+Pink | 0.052 | 277 | SP and KL dataset |
| *Salvia patens Cav.* | Salvia | Lamiaceae | P | G | bird | bird | UV+Blue | 0.054 | 275 | SP and KL dataset |
| *Salvia splendens Sellow ex Schult.* | Salvia | Lamiaceae | P | EN | bird | bird | UV+Red | 0.060 | 255; 374 | SP and KL dataset |
| *Salvia urica Epling* | Salvia | Lamiaceae | P | N | bee | bee | UV+Blue | 0.047 | 241 | SP and KL dataset |
| *Saraca indica L.* | Saraca | Fabaceae | P | EN | bee-butterfly-fly | bee-insects | UV+Red | 0.141 | 252; 363 | SP and KL dataset |
| *Saxifraga aizoides L.* | Saxifraga | Saxifragaceae | P | EN | fly | fly | UV+Yellow | 0.005 | 141 | SP and KL dataset |
| *Scabiosa columbaria L.* | Scabiosa | Caprifoliaceae | P | EN | bee-butterfly-fly | bee-insects | UV+Blue | 0.045 | 171; 328; 329 | SP and KL dataset |
| *Schizanthus pinnatus Ruiz & Pav.* | Schizanthus | Solanaceae | P | N | bee | bee | UV-White | 0.219 | 4; 17 | SP and KL dataset |
| *Scrophularia xanthoglossa Boiss.* | Scrophularia | Scrophulariaceae | P | EN | bee | bee | UV-Black | 0.111 | 1 | Coimbra et al. 2020 |
| *Scutellaria costaricana H.Wendl.* | Scutellaria | Lamiaceae | P | N | bird | bird | UV-Red | 0.035 | 17 | SP and KL dataset |
| *Seemannia sylvatica (Kunth) Baill.* | Seemannia | Gesneriaceae | P | N | bird-butterfly | vertebrate-insects | UV+Yellow | 0.016 | 201 | SP and KL dataset |
| *Senecio inaequidens DC.* | Senecio | Asteraceae | P | EN | bee | bee | UV+Yellow | 0.085 | 16 | SP and KL dataset |
| *Senna artemisioides Isely* | Senna | Fabaceae | P | EN | bee | bee | UV-Yellow | 0.056 | 200 | SP and KL dataset |
| *Senna bicapsularis (L.) Roxb.* | Senna | Fabaceae | P | G | bee | bee | UV+Yellow | 0.113 | 200; 334; 335 | SP and KL dataset |
| *Sesamum indicum L.* | Sesamum | Pedaliaceae | P | G | bee | bee | UV+White | 0.210 | 164 | SP and KL dataset |
| *Silene aegyptiaca (L.) L.f.* | Silene | Caryophyllaceae | P | EN | bee | bee | UV+Pink | 0.147 | 1 | Coimbra et al. 2020 |
| *Silene flos-cuculi (L.) Greuter & Burdet* | Silene | Caryophyllaceae | P | EN | bee-butterfly | bee-insects | UV+Pink | 0.189 | 269; 383;384 | SP and KL dataset |
| *Silene vulgaris (Moench) Garcke* | Silene | Caryophyllaceae | P | EN | bee-fly-moth | bee-insects | UV-White | 0.057 | 225; 346 | SP and KL dataset |
| *Sinapis arvensis L.* | Sinapis | Brassicaceae | P | EN | bee-beetle-butterfly-fly | bee-insects | UV+Yellow | 0.122 | 1 | Coimbra et al. 2020 |
| *Sinningia aggregata (Ker Gawl.) Wiehler* | Sinningia | Gesneriaceae | P | N | bird | bird | UV+Red | 0.029 | 223; 224 | SP and KL dataset |
| *Sinningia eumorpha H.E. Moore* | Sinningia | Gesneriaceae | P | N | bee | bee | UV+White | 0.037 | 223; 224 | SP and KL dataset |
| *Sinningia macropoda (Sprague) H.E. Moore* | Sinningia | Gesneriaceae | P | N | bird | bird | UV-Red | 0.048 | 223; 224 | SP and KL dataset |
| *Sinningia sellovii (Mart.) Wiehler* | Sinningia | Gesneriaceae | P | N | bird | bird | UV-Red | 0.066 | 223; 224 | SP and KL dataset |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Solanum betaceum Cav.* | Solanum | Solanaceae | P | N | bee | bee | UV-White | 0.047 | 102 | SP and KL dataset |
| *Solidago canadensis L.* | Solidago | Asteraceae | P | EN | bee-fly | bee-insects | UV+Yellow | 0.167 | 161; 1 | SP and KL dataset |
| *Sonchus oleraceus (L.) L.* | Sonchus | Asteraceae | P | EN | bee-beetle-fly | bee-insects | UV+Yellow | 0.054 | 1 | Coimbra et al. 2020 |
| *Sophora macrocarpa Sm.* | Sophora | Fabaceae | P | N | bird | bird | UV+Yellow | 0.187 | 144 | SP and KL dataset |
| *Spathiphyllum cannifolium (Dryand. ex Sims) Schott* | Spathiphyllum | Araceae | B | N | bee | bee | UV+White | 0.050 | 278; 385 | SP and KL dataset |
| *Spathodea campanulata P.Beauv.* | Spathodea | Bignoniaceae | P | EN | bird | bird | UV-Red | 0.071 | 265; 207 | SP and KL dataset |
| *Stifftia chrysantha J.C.Mikan* | Stifftia | Asteraceae | P | N | bird | bird | UV-Yellow | 0.065 | 207; 337 | SP and KL dataset |
| *Strelitzia reginae Banks* | Strelitzia | Strelitziaceae | B | EN | bird | bird | UV+Red | 0.029 | 168 | SP and KL dataset |
| *Streptosolen jamesonii (Benth.) Miers* | Streptosolen | Solanaceae | P | N | bird | bird | UV-Red | 0.187 | 116 | SP and KL dataset |
| *Styrax camporum Pohl* | Styrax | Styracaceae | P | N | bee-fly | bee-insects | UV+White | 0.074 | 243; 354; 355; 386 | SP and KL dataset |
| *Swartzia oblata Cowan* | Swartzia | Fabaceae | P | EN | bee | bee | UV-White | 0.016 | 227 | SP and KL dataset |
| *Swartzia simplex (Sw.) Spreng.* | Swartzia | Fabaceae | P | N | bee | bee | UV+Yellow | 0.045 | 228 | Coimbra et al. 2020 |
| *Symphytum brachycalyx Boiss.* | Symphytum | Boraginaceae | P | EN | bee | bee | UV-White | 0.077 | 1 | Coimbra et al. 2020 |
| *Tacinga palmadora (Britton & Rose) N.P.Taylor & Stuppy* | Tacinga | Cactaceae | P | N | bird | bird | UV-Red | 0.068 | 191 | SP and KL dataset |
| *Tagetes erecta L.* | Tagetes | Asteraceae | P | EN | bee-butterfly-fly | bee-insects | UV-Yellow | 0.060 | 173; 330 | SP and KL dataset |
| *Tanaecium pyramidatum (Rich.) L.G.Lohmann* | Tanaecium | Bignoniaceae | P | EN | bee-wasp | bee | UV-Pink | 0.161 | 155 | SP and KL dataset |
| *Telopea speciosissima (Sm.) R. Br.* | Telopea | Proteaceae | B | EN | bird | bird | UV+Red | 0.153 | 232 | SP and KL dataset |
| *Temnadenia violacea (Vell.) Miers* | Temnadenia | Apocynaceae | P | N | bee-fly | bee-insects | UV+Pink | 0.071 | 157 | SP and KL dataset |
| *Theobroma cacao L.* | Theobroma | Malvaceae | P | N | fly | fly | UV+White | 0.736 | 254 | SP and KL dataset |
| *Theobroma speciosum Willd. ex Spreng.* | Theobroma | Malvaceae | P | EN | fly | fly | UV+Red | 0.084 | 254 | SP and KL dataset |
| *Tilesia baccata (L.) Pruski* | Tilesia | Asteraceae | P | N | bee-butterfly-wasp | bee-insects | UV+Yellow | 0.015 | 147;313 | SP and KL dataset |
| *Tillandsia aeranthos (Loisel.) L.B.Sm.* | Tillandsia | Bromeliaceae | P | G | bird | bird | UV-Blue | 0.068 | 253 | SP and KL dataset |
| *Tillandsia ionantha Planch.* | Tillandsia | Bromeliaceae | B | G | bird | bird | UV+Blue | 0.000 | 154 | SP and KL dataset |
| *Trichostigma peruvianum (Moq.) H. Walter* | Trichostigma | Phytolaccaceae | P | N | bee-beetle-butterfly-fly | bee-insects | UV+Pink | 0.261 | 2 | SP and KL dataset |
| *Tripora divaricata (Maxim.) P.D.Cantino* | Tripora | Lamiaceae | P | EN | bee | bee | UV+Blue | 0.033 | 263 | SP and KL dataset |
| *Trollius chinensis Bunge* | Trollius | Ranunculaceae | P | EN | fly | fly | UV-Yellow | 0.219 | 220 | SP and KL dataset |
| *Uncarina grandidieri (Baill.) Stapf* | Uncarina | Pedaliaceae | P | EN | bee-butterfly-wasp | bee-insects | UV-Yellow | 0.008 | 235 | SP and KL dataset |
| *Vaccinium vitis-idaea L.* | Vaccinium | Ericaceae | P | EN | bee | bee | UV-White | 0.010 | 1 | Coimbra et al. 2020 |
| *Vellozia candida J.C.Mikan* | Vellozia | Velloziaceae | P | N | bee | bee | UV-White | 0.059 | 270 | SP and KL dataset |
| *Verbascum densiflorum Bertol.* | Verbascum | Scrophulariaceae | P | EN | bee-butterfly-fly | bee-insects | UV+Yellow | 0.022 | 1 | Coimbra et al. 2020 |
| *Verbascum lychnitis L.* | Verbascum | Scrophulariaceae | P | EN | bee-butterfly | bee-insects | UV+Yellow | 0.123 | 1 | Coimbra et al. 2020 |
| *Verbena bonariensis L.* | Verbena | Verbenaceae | P | EN | bee | bee | UV+Pink | 0.263 | 255 | SP and KL dataset |
| *Veronica chamaedrys L.* | Veronica | Plantaginaceae | P | EN | bee-fly | bee-insects | UV+Blue | 0.752 | 1 | Coimbra et al. 2020 |
| *Veronica prostrata L.* | Veronica | Plantaginaceae | P | EN | bee-butterfly-fly | bee-insects | UV+Blue | 0.260 | 1 | Coimbra et al. 2020 |

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| *Vicia faba L.* | Vicia | Fabaceae | P | EN | bee | bee | UV+White | 0.247 | 150; 317; 318 | SP and KL dataset |
| *Vriesea neoglutinosa Mez* | Vriesea | Bromeliaceae | B | N | bird | bird | UV-Red | 0.124 | 146; 286 | SP and KL dataset |
| *Zephyranthes candida (Lindl.) Herb.* | Zephyranthes | Amaryllidaceae | P | EN | bee | bee | UV-White | 0.177 | 16 | SP and KL dataset |
| *Zeyheria montana Mart.* | Zeyheria | Bignoniaceae | P | N | bird | bird | UV+Yellow | 0.140 | 121; 386 | SP and KL dataset |
| *Zilla spinosa (L.) Prantl* | Zilla | Brassicaceae | P | EN | bee | bee | UV-Pink | 0.136 | 1 | Coimbra et al. 2020 |

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**Supplementary Table S2.** Spatial autocorrelation statistics (Global Moran's I) calculated at various threshold distances, including 500 km, 1000 km, and 1600 km. The evaluation of these threshold distances was performed at mid-large scales to calculate the spatial matrix. Moran's Index values, Expected Index values, Variances, Z-scores based on the UV chroma variable, and associated p-values are included.

| Threshold distancie | Moran Index | Expected Index | Variance | z-score | p-value |
|---|---|---|---|---|---|
| 500 | 0.33481 | -0.000104 | 0.000012 | 96.191 | < 0.01 |
| 1000 | 0.296467 | -0.000104 | 0.000008 | 103.894 | < 0.01 |
| 1600 | 0.262301 | -0.000104 | 0.000006 | 103.321 | < 0.01 |

**Supplementary Table S3.** Variance Inflation Factor (VIF) calculated to a multiple linear regression model fitted with all independent variables to examine multicollinearity among them. The Generalized Variance Inflation Factor (GVIF) is a measure of multicollinearity in regression analysis considering the logit of UV chroma as dependent variable and altitude, annual mean temperature (AMT), log of annual mean precipitation (AMP), log of annual mean UV-B irradiance (AMR), pollination system, and species color category as independent variables. The Df represent the degrees of freedom associated with each variable in the regression model, while the $GVIF^{(1/(2*Df))}$ represent the adjusted GVIF, a transformed measure of multicollinearity that considers the degrees of freedom associated with each variable. Values closer to 1 indicate lower multicollinearity.

| **Variable** | **GVIF** | **Df** | **$GVIF^{(1/(2*Df))}$** |
|---|---|---|---|
| AMT | 1.521 | 1 | 1.233 |
| AMP | 1.325 | 1 | 1.151 |
| AMR | 1.104 | 1 | 1.050 |
| Altitude | 1.384 | 1 | 1.176 |
| Pollination system | 3.690 | 12 | 1.055 |
| Color category | 4.110 | 15 | 1.048 |

**Supplementary Table S4.** – Correlation matrix examining the correlations between the numerical studied variables, including UV chroma, altitude, annual mean temperature (AMT), annual mean precipitation (AMP) and annual mean UV-B irradiance (AMR). The matrix displays the Pearson correlation coefficients. The correlation coefficients range from -1 to 1, with positive values indicating positive correlations, negative values indicating negative correlations, and 0 indicating no linear correlation.

| Variable | UV Chroma | AMT | AMP | AMR | Altitude |
|---|---|---|---|---|---|
| UV Chroma | 1 | 0.1545945 | 0.250870212 | 0.1074097 | -0.021952269 |
| AMT | 0.15459448 | 1 | 0.328845315 | 0.4872440 | -0.377977168 |
| AMP | 0.25087021 | 0.3288453 | 1 | 0.1713824 | 0.009653057 |
| AMR | 0.10740968 | 0.4872440 | 0.171382416 | 1 | 0.136867945 |
| Altitude | -0.02195227 | -0.3779772 | 0.009653057 | 0.1368679 | 1 |

**Supplementary Table S5.** Results from Local Indicator of Spatial Autocorrelation (LISA) analysis, including the type of cluster, the frequency of each cluster type, the Local Moran's (LM) Index values with standard deviation (sd), the mean UV chroma values with standard deviation (sd), and the associated p-values.Cluster type indicates the type of spatial cluster, with categories "Not significant," "HH" (high-high), "HL" (high-low), "LH" (low-high), and "LL" (low-low). Cluster frequency shows the number of occurrences for each cluster type.LM Index ± sd represents the Local Moran's Index along with its standard deviation, which measures spatial autocorrelation.UV chroma ± sd indicates the mean UV chroma values along with their standard deviation, describing a specific attribute related to each cluster type. P- values denote the significance levels across different cluster types.

| Cluster type | Cluster frequency | LM Index ± sd | UV chroma ± sd | p-value |
|---|---|---|---|---|
| **Not significant** | 3088 | 0,021755819 ± 0,14945854 | 0,100593 ± 0,083024 | 0,228709197 |
| **HH** | 1148 | 1,959657244 ± 3,762793925 | 0,339465 ± 0,220558 | 0,008845819 |
| **HL** | 724 | -0,066948452 ± 0,100608119 | 0,138817 ± 0,054991 | 0,005772099 |
| **LH** | 1049 | -0,236648758 ± 0,269277903 | 0,051087 ± 0,026115 | 0,009152526 |
| **LL** | 3624 | 0,161277712 ± 0,111195608 | 0,043623 ± 0,028357 | 0,005359823 |

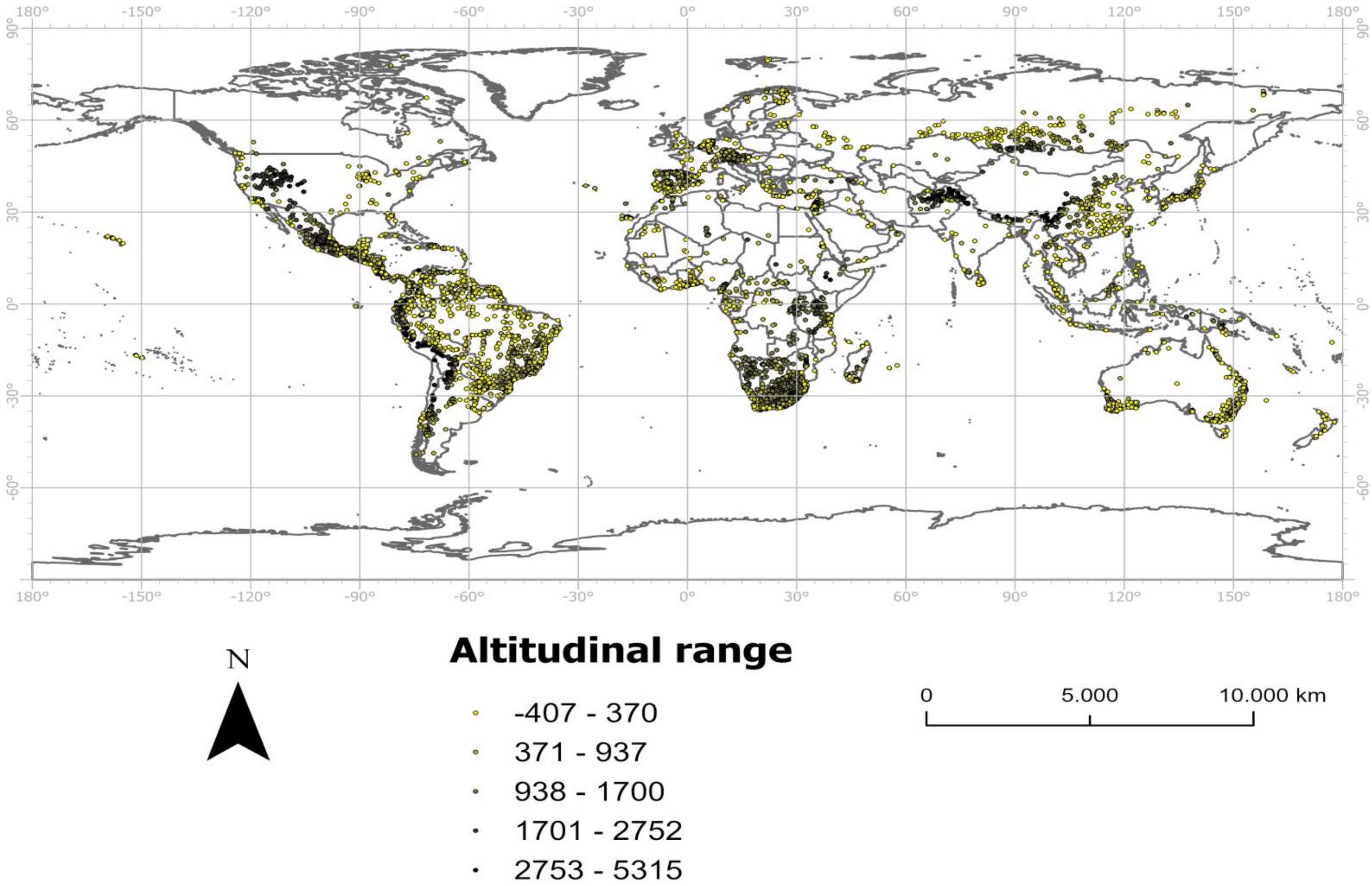
**Supplementary Table S6-** Tukey's test results conducted to compare the differences between the different color categories of the studied species. The Difference column indicates the estimated mean difference between the compared categories. The Inferior IC (lwr) and Superior IC represent the lower and upper limits of the confidence interval for the difference. The the p-value column indicating the significance of the observed differences associated with each comparison. In bold are highlighted the comparisons for which the difference is statistically significant.

| Categories comparation | Difference | Inferior IC (lwr) | Superior IC (upr) | p-value |
|---|---|---|---|---|
| **Blue vs. Black** | 0.4116116262 | 0.051712614 | 0.77151064 | **0.0123717** |
| **Cyan vs. Black** | -0.7329957988 | -1.435365221 | -0.03062638 | **0.0335691** |
| **Green vs. Black** | 0.5183704249 | -0.031096643 | 1.06783749 | 0.0810184 |
| **Pink vs. Black** | -0.1051269000 | -0.447427682 | 0.23717388 | 0.9830917 |
| **Red vs. Black** | 0.0243683053 | -0.307320665 | 0.35605728 | 0.9999986 |
| **White vs. Black** | -0.0003765623 | -0.330355733 | 0.32960261 | 1.0000000 |
| **Yellow vs. Black** | -0.1686570344 | -0.500449239 | 0.16313517 | 0.7850620 |
| **Cyan vs. Blue** | -1.1446074250 | -1.789209267 | -0.50000558 | **0.0000021** |
| **Green vs. Blue** | 0.1067587987 | -0.366636161 | 0.58015376 | 0.9974278 |
| **Pink vs. Blue** | -0.5167385263 | -0.715128430 | -0.31834862 | **0.0000000** |
| **Red vs. Blue** | -0.3872433209 | -0.566704463 | -0.20778218 | **0.0000000** |
| **White vs. Blue** | -0.4119881885 | -0.588269162 | -0.23570721 | **0.0000000** |
| **Yellow vs. Blue** | -0.5802686606 | -0.759920533 | -0.40061679 | **0.0000000** |
| **Green vs. Cyan** | 1.2513662237 | 0.484620963 | 2.01811148 | **0.0000211** |
| **Pink vs. Cyan** | 0.6278688988 | -0.007075241 | 1.26281304 | **0.0551562** |
| **Red vs. Cyan** | 0.7573641041 | 0.128077358 | 1.38665085 | **0.0064563** |
| **White vs. Cyan** | 0.7326192365 | 0.104232024 | 1.36100645 | **0.0097656** |
| **Yellow vs. Cyan** | 0.5643387644 | -0.065002401 | 1.19367993 | 0.1170525 |
| **Pink vs. Green** | -0.6234973250 | -1.083655248 | -0.16333940 | **0.0010512** |
| **Red vs. Green** | -0.4940021196 | -0.946321765 | -0.04168247 | **0.0209826** |
| **White vs. Green** | -0.5187469872 | -0.969814323 | -0.06767965 | **0.0115674** |
| **Yellow vs. Green** | -0.6870274593 | -1.139422812 | -0.23463211 | **0.0001141** |
| **Red vs. Pink** | 0.1294952054 | -0.011390663 | 0.27038107 | 0.0984251 |
| **White vs. Pink** | 0.1047503378 | -0.032061606 | 0.24156228 | 0.2819184 |
| **Yellow vs. Pink** | -0.0635301343 | -0.204658875 | 0.07759861 | 0.8732275 |
| **White vs. Red** | -0.0247448676 | -0.132286745 | 0.08279701 | 0.9970792 |
| **Yellow vs. Red** | -0.1930253397 | -0.306007945 | -0.08004273 | **0.0000063** |
| **Yellow vs. White** | -0.1682804721 | -0.276140331 | -0.06042061 | **0.0000623** |

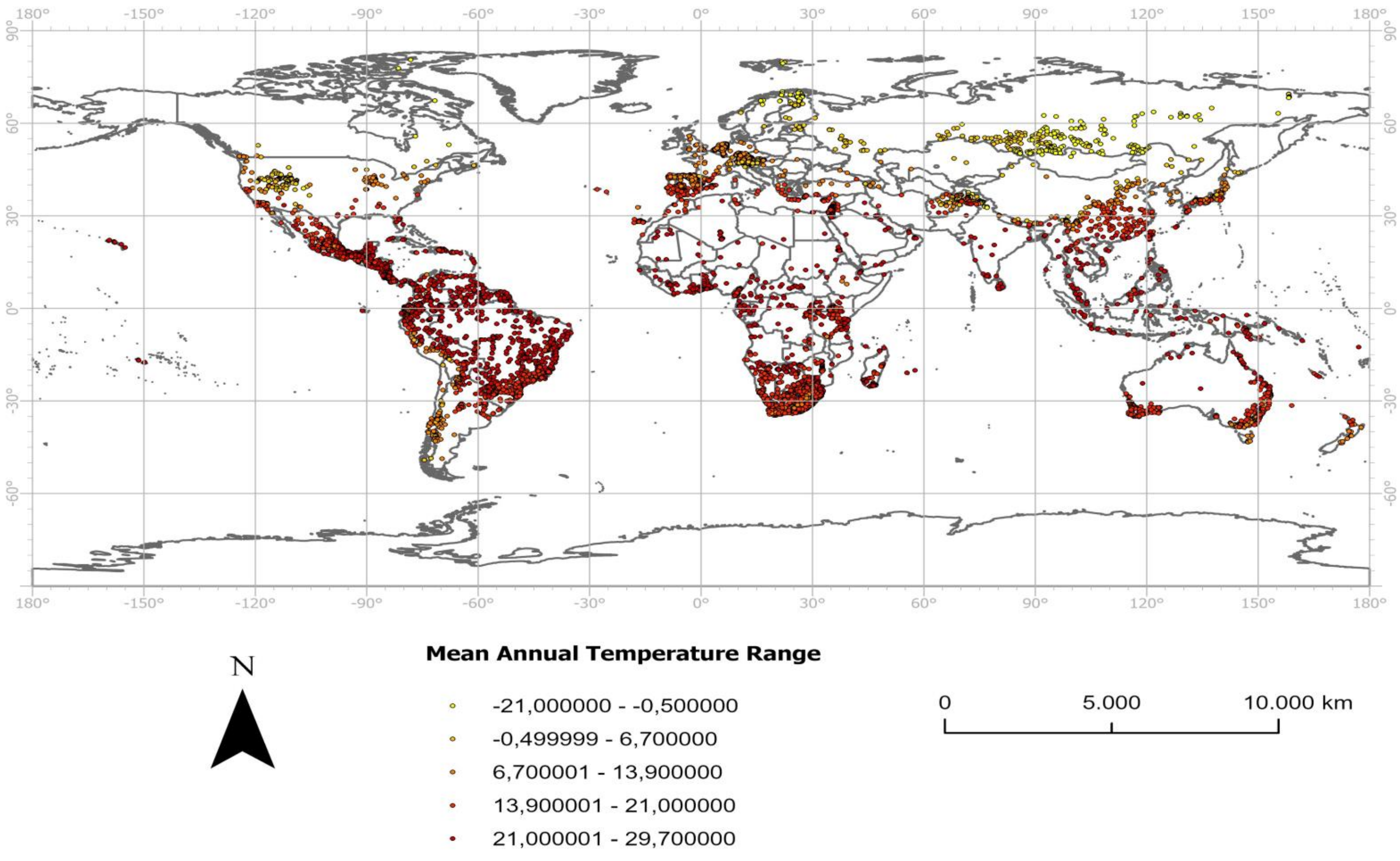
**Supplementary Table S7-** Tukey's test results conducted to compare the differences between the different categories of pollination system of the studied species. The Difference column indicates the estimated mean difference between the compared categories. The Inferior IC (lwr) and Superior IC represent the lower and upper limits of the confidence interval for the difference. The the p-value column indicating the significance of the observed differences associated with each comparison. In bold are highlighted the comparisons for which the difference is statistically significant.

| Categories Comparation | Difference | Inferior Ic (Lwr) | Superior Ic (Upr) | p-value |
|---|---|---|---|---|
| **Bee vs. Bat** | 0.020810418 | -0.381487968 | 0.42310880 | 1.0000000 |
| **Bee+Insects vs. Bat** | -0.589621365 | -0.995978128 | -0.18326460 | **0.0001602** |
| **Beetle vs. Bat** | -1.318745025 | -1.851207493 | -0.78628256 | **0.0000000** |
| **Bird vs. Bat** | -0.295699129 | -0.701344666 | 0.10994641 | 0.4016405 |
| **Butterfly vs. Bat** | 0.017049231 | -0.478154847 | 0.51225331 | 1.0000000 |
| **Fly vs. Bat** | -0.147763637 | -0.647448862 | 0.35192159 | 0.9972074 |
| **Insects vs. Bat** | 0.105291345 | -0.416387372 | 0.62697006 | 0.9999032 |
| **Moth vs. Bat** | -0.462307580 | -0.997158379 | 0.07254322 | 0.1646463 |
| **Vertebrate vs. Bat** | -0.158699590 | -0.888196498 | 0.57079732 | 0.9998081 |
| **Vertebrate+Insects vs. Bat** | 0.289162633 | -0.170303368 | 0.74862863 | 0.6303948 |
| **Bee+Insects vs. Bee** | -0.610431783 | -0.721327658 | -0.49953591 | **0.0000000** |
| **Beetle vs. Bee** | -1.339555443 | -1.701063889 | -0.97804700 | **0.0000000** |
| **Bird vs. Bee** | -0.316509547 | -0.424770244 | -0.20824885 | **0.0000000** |
| **Butterfly vs. Bee** | -0.003761187 | -0.307733481 | 0.30021111 | 1.0000000 |
| **Fly vs. Bee** | -0.168574055 | -0.479793272 | 0.14264516 | 0.8126001 |
| **Insects vs. Bee** | 0.084480927 | -0.260947445 | 0.42990930 | 0.9994530 |
| **Moth vs. Bee** | -0.483117998 | -0.848135058 | -0.11810094 | **0.0010418** |
| **Vertebrate vs. Bee** | -0.179510008 | -0.795414071 | 0.43639406 | 0.9975253 |
| **Vertebrate+Insects vs. Bee** | 0.268352215 | 0.026937462 | 0.50976697 | **0.0153370** |
| **Beetle vs. Bee+Insects** | -0.729123660 | -1095143035 | -0.36310428 | **0.0000000** |
| **Bird vs. Bee+Insects** | 0.293922237 | 0.171438746 | 0.41640573 | **0.0000000** |
| **Butterfly vs. Bee+Insects** | 0.606670596 | 0.297347170 | 0.91599402 | **0.0000000** |
| **Fly vs. Bee+Insects** | 0.441857728 | 0.125409901 | 0.75830556 | **0.0003658** |
| **Insects vs. Bee+Insects** | 0.694912710 | 0.344766188 | 1.04505923 | **0.0000000** |
| **Moth vs. Bee+Insects** | 0.127313785 | -0.242171371 | 0.49679894 | 0.9904366 |
| **Vertebrate vs. Bee+Insects** | 0.430921775 | -0.187640786 | 1.04948434 | 0.4739718 |
| **Vertebrate+Insects vs. Bee+Insects** | 0.878783998 | 0.630665257 | 1.12690274 | **0.0000000** |
| **Bird vs. Beetle** | 1.023045896 | 0.657816288 | 1.38827550 | **0.0000000** |
| **Butterfly vs. Beetle** | 1.335794256 | 0.873115703 | 1.79847281 | **0.0000000** |
| **Fly vs. Beetle** | 1.170981387 | 0.703509796 | 1.63845298 | **0.0000000** |
| **Insects vs. Beetle** | 1.424036370 | 0.933125942 | 1.91494680 | **0.0000000** |
| **Moth vs. Beetle** | 0.856437445 | 0.351551574 | 1.36132331 | **0.0000027** |
| **Vertebrate vs. Beetle** | 1.160045435 | 0.452224763 | 1.86786611 | **0.0000073** |
| **Vertebrate+Insects vs. Beetle** | 1.607907658 | 1.183698545 | 2.03211677 | **0.0000000** |
| **Butterfly vs. Bird** | 0.312748360 | 0.004359862 | 0.62113686 | **0.0434636** |
| **Fly vs. Bird** | 0.147935491 | -0.167598518 | 0.46346950 | 0.9170716 |
| **Insects vs. Bird** | 0.400990473 | 0.051669604 | 0.75031134 | **0.0100664** |
| **Moth vs. Bird** | -0.166608452 | -0.535311264 | 0.20209436 | 0.9341599 |
| **Vertebrate vs.. Bird** | 0.136999539 | -0.481096025 | 0.75509510 | 0.9997728 |
| **Vertebrate+Insects vs. Bird** | 0.584861762 | 0.337909553 | 0.83181397 | **0.0000000** |
| **Fly vs. Butterfly** | -0.164812868 | -0.589360260 | 0.25973452 | 0.9766105 |
| **Insects vs. Butterfly** | 0.088242114 | -0.361984326 | 0.53846855 | 0.9999261 |
| **Moth vs. Butterfly** | -0.479356811 | -0.944781930 | -0.01393169 | 0.0370406 |
| **Vertebrate vs. Butterfly** | -0.175748821 | -0.855984737 | 0.50448710 | 0.9991152 |

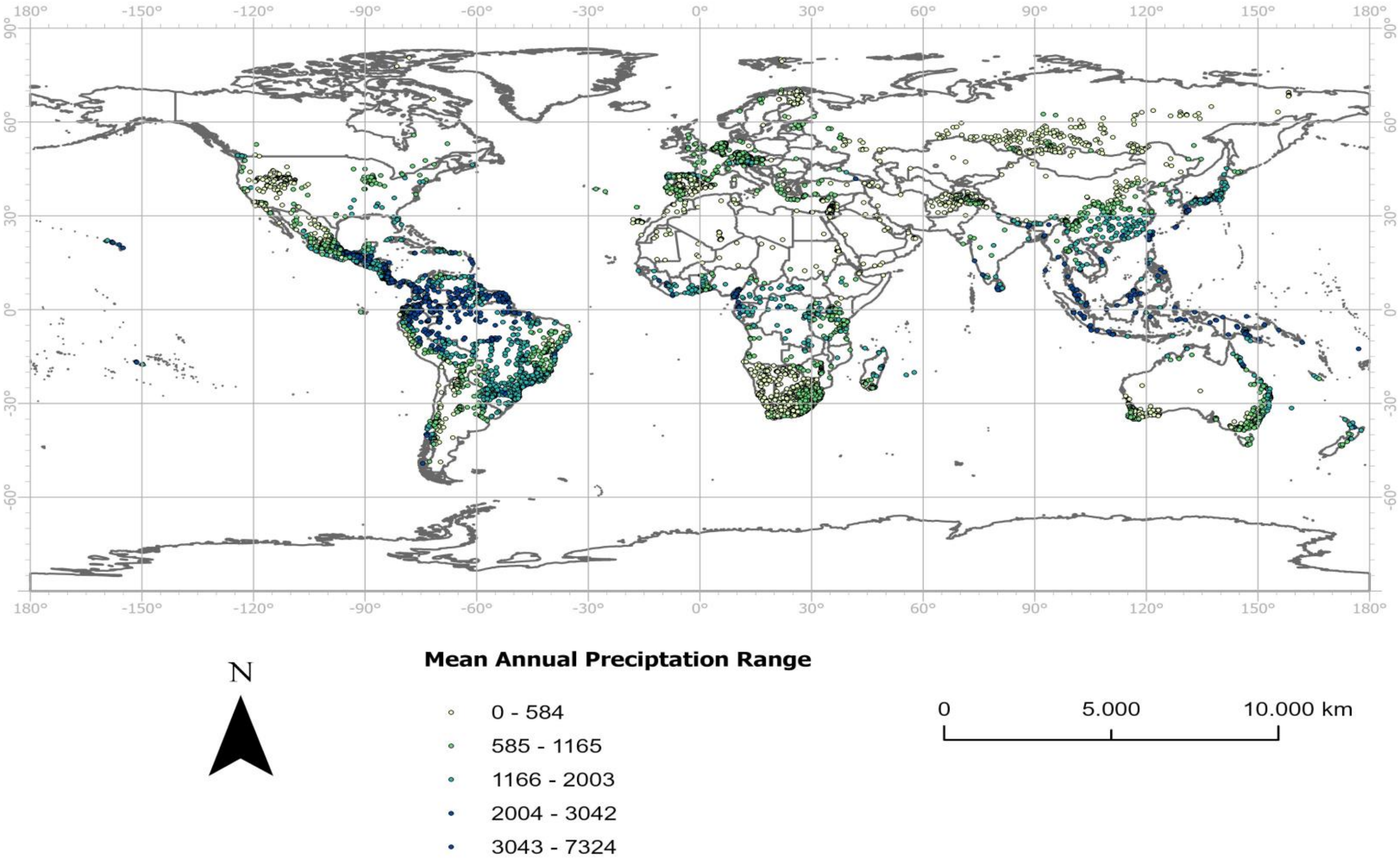
| | | | | |
|---|---|---|---|---|
| **Vertebrate+Insects vs. Butterfly** | 0.272113402 | -0.104269608 | 0.64849641 | 0.4147433 |
| **Insects vs. Fly** | 0.253054982 | -0.202095644 | 0.70820561 | 0.7863483 |
| **Moth vs. Fly** | -0.314543943 | -0.784734102 | 0.15564622 | 0.5381805 |
| **Vertebrate vs. Fly** | -0.010935952 | -0.694440998 | 0.67256909 | 1.0000000 |
| **Vertebrate+Insects vs. Fly** | 0.436926270 | 0.054666653 | 0.81918589 | **0.0106659** |
| **Moth vs. Insects** | -0.567598925 | -1.061098819 | -0.07409903 | **0.0098034** |
| **Vertebrate vs. Insects** | -0.263990935 | -0.963735536 | 0.43575367 | 0.9810115 |
| **Vertebrate-Insects-Insects** | 0.183871288 | -0.226720692 | 0.59446327 | 0.9378555 |
| **Vertebrate vs. Moth** | 0.303607990 | -0.406011063 | 1.01322704 | 0.9539488 |
| **Vertebrate+Insects vs. Moth** | 0.751470213 | 0.324267137 | 1.17867329 | **0.0000008** |
| **Vertebrate+Insects vs. Vertebrate** | 0.447862223 | -0.206815431 | 1.10253988 | 0.5029391 |



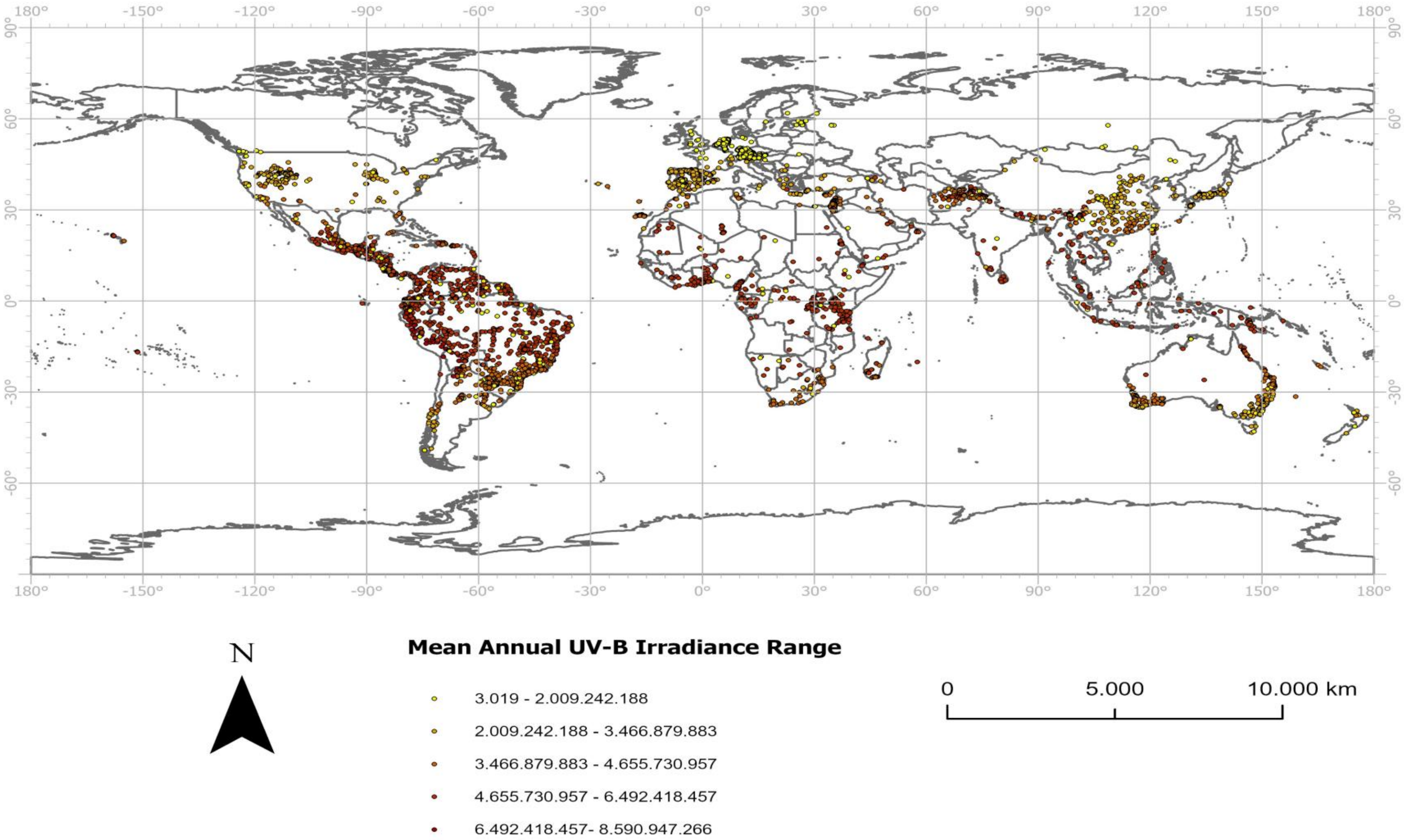

**Supplementary Figure S1**. Spatial distribution of altitude data collected monthly between 1970 and 2000 at a 10-minute (~340 km²) resolution, obtained from the WorldClim database. The altitude data is associated with georeferenced species occurrences.



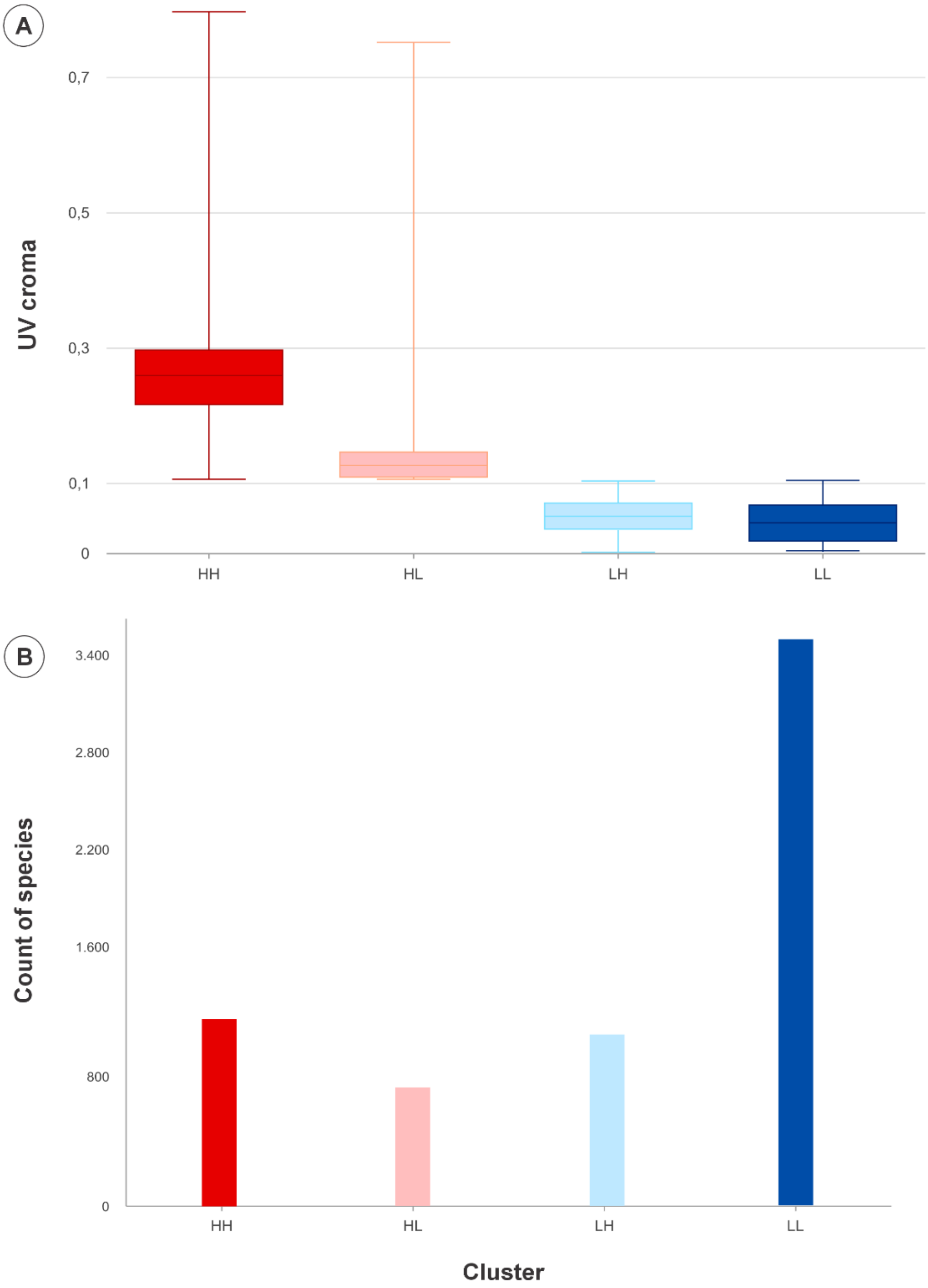

**Supplementary Figure S2**. Spatial distribution of annual mean temperature data collected monthly between 1970 and 2000 at a 10-minute (~340 km²) resolution, obtained from the WorldClim database. The temperature data is associated with georeferenced species occurrences.




**Supplementary Figure S3**. Spatial distribution of annual mean precipitation data collected monthly between 1970 and 2000 at a 10-minute (~340 km²) resolution, obtained from the WorldClim database. The precipitation data is associated with georeferenced species occurrences.




**Supplementary Figure S4.** Spatial distribution of annual mean UV-B irradiance data collected monthly between 1970 and 2000 at a 10-minute (~340 km²) resolution, obtained from the WorldClim database. The radiation data is associated with georeferenced species occurrences.




**Supplementary Figure S5.** A- Variation in UV chroma values of species across different clusters and B- number of species occurrences associated with each cluster identified by the Local Indicator of Spatial Autocorrelation (LISA) analysis. Each boxplot and bar is associated with a specific cluster type, with distinctive colors representing the clusters:Red: HH (High-High) Cluster, Blue: LL (Low-Low) Cluster, Light Pink: HL (High-Low) Cluster and Light Blue: LH (Low-High) Cluster. These boxplots provide a visual comparison of UV chroma distributions within each cluster type.

## CONCLUSÕES GERAIS

A presente tese teve como objetivo explorar e analisar as dinâmicas das cores, com ênfase no croma ultravioleta, das flores de angiospermas em escalas macroevolutivas e macroecológicas. Os principais achados, discussões e contribuições são apresentados ao longo dos três capítulos que compõem este trabalho. Cada seção apresentou um papel significativo para a compreensão de fatores e processos complexos e relevantes que moldam esse importante atributo floral nas espécies estudadas. Coletivamente, os três capítulos também apresentam importantes contribuições para o avanço no campo da biologia cognitiva e da polinização. Além das descobertas específicas, as abordagens metodológicas adotadas nesta tese como a curadoria global de dados, análises evolutivas detalhadas e investigações explicitamente espaciais podem atuar como referencial para futuros estudos que buscam explorar questões semelhantes em diferentes contextos e ambientes. Abaixo, apresento as conclusões gerais derivadas destes trabalhos:

### *Capítulo 1- A global dataset on flower colors for macroevolutive and macroecological perspectives*

No primeiro capítulo, realizamos a curadoria de um amplo conjunto de dados que inclui informações sobre reflectâncias espectrais, categorias de cor, visitantes florais, tipos de sistema de polinização, distribuição geográfica, variáveis altitudinais e climáticas, e filogenia de 464 espécies de angiospermas, das quais 367 não tinham dados compilados ou publicados anteriormente. A análise desse conjunto de dados evidenciou a diversidade de cores e visitantes florais associados às espécies incluídas, destacando as cores brancas e vermelhas com sistemas de polinização por abelhas e aves. As espécies também exibiram ampla distribuição geográfica e gradientes altitudinais e climáticos associados, com as áreas neotropicais concentrando a maior diversidade de cores e sistemas de polinização. Em suma, ao apresentar um amplo conjunto de dados global sobre cores florais, este capítulo não apenas revela padrões intrigantes na distribuição geográfica dessas cores, mas também lança luz sobre a complexidade das interações entre plantas e polinizadores em diferentes regiões do mundo. Esse conjunto de dados pioneiro não só enriquece nosso entendimento sobre as dinâmicas coevolutivas entre plantas, polinizadores e fatores abióticos, mas também proporciona insights valiosos para pesquisadores que buscam compreender mais a ecologia e evolução das cores florais em escalas macroevolutivas e macroecológicas.

### *Capítulo 2- Evolution of UV reflectance in bee- and bird-pollinated flowers*

O segundo capítulo oferece insights sobre alguns dos processos ecológicos e evolutivos envolvidos na origem da marcante diversidade de cores florais das angiospermas ao longo de grandes escalas temporais. Focamos na investigação da evolução do croma UV, um atributo-chave que modula a atração e exclusão de visitantes florais em espécies polinizadas por abelhas e aves. Realizamos análises de reconstruções de estado ancestral e modelos evolutivos usando uma lista de espécies com flores vermelhas, brancas e amarelas polinizadas por esses animais, exibindo ampla variação no croma UV. Nossas análises revelaram que: I. Os diferentes estados do croma UV tiveram uma trajetória evolutiva com muitas mudanças entre si; II. A evolução de maior croma UV estava associada a flores vermelhas e brancas polinizadas por abelhas e flores amarelas polinizadas por aves; e III. Durante sua história evolutiva, as flores brancas e amarelas polinizadas por abelhas apresentaram grandes variações no croma UV e uma alta taxa de mudança evolutiva. Esses resultados sustentam que tanto a atração de polinizadores efetivos quanto a exclusão sensorial de antagonistas florais são processos importantes na evolução do croma UV de flores vermelhas de abelhas e aves, enquanto nas flores brancas e amarelas, essa evidência é menos pronunciada. Neste capítulo, a análise detalhada das mudanças evolutivas no croma UV revela padrões complexos e nuances nas estratégias adaptativas das plantas cuja a evolução das cores florais é influenciada pela relação entre polinizadores e antagonistas florais em níveis macroevolutivos. Essas descobertas não apenas fornecem insights importantes para entender a seleção de cores em flores polinizadas por diferentes agentes, mas também estabelecem um marco para futuras investigações de bases moleculares e genéticas subjacente a essas adaptações, proporcionando uma visão abrangente da evolução das interações planta-polinizador.

***Capítulo 3- Spatial dynamics of ultraviolet chroma in flowers: A comprehensive analysis of biotic and abiotic impacts on global floral color variation***

O terceiro capítulo examinou a presença de padrões espaciais no croma UV, e como condições bióticas e abióticas podem influenciar e estar relacionadas à expressão desse atributo em larga escala espacial. Realizamos análises estatísticas espacialmente explícitas para verificar a presença de autocorrelação espacial neste atributo e explorar a relação espacial entre o croma UV das espécies estudadas e diferentes fatores abióticos (altitude, médias anuais de temperatura, precipitação e radiação) e bióticos (categorias de cor e tipo de sistema de polinização). Os resultados destacaram padrões de agrupamento geográfico no croma UV das espécies estudadas, com maior croma UV ocorrendo nas áreas neotropicais e menor croma UV nas extra-neotropicais. Além disso, fatores abióticos como precipitação anual e temperatura média anual mostraram uma relação positiva com o aumento do croma UV, assim como fatores bióticos relacionados à categoria de cor e sistema de polinização das flores dessas espécies. Este capítulo amplia a perspectiva da ecologia e evolução das cores florais ao examinar padrões espaciais do croma UV em larga escala. Este conhecimento é crucial para revelar os processos ecológicos que moldam a evolução e diversidade das cores florais, especialmente diante das mudanças globais do clima. Ao analisar a autocorrelação espacial deste atributo e suas relações com fatores bióticos e abióticos, esse capítulo fornece uma visão única das adaptações locais das plantas em resposta ao ambiente. Essa abordagem espacial não apenas aprimora nossa compreensão da ecologia das cores florais, mas também oferece importantes implicações para estudos e estratégias de conservação e preservação da biodiversidade.

*Considerações Finais*

Esta tese destaca a complexidade e a importância do croma UV como atributo envolvido na diversidade de cores florais. Nela, os capítulos convergem na busca por compreender as dinâmicas evolutivas e ecológicas das cores florais em angiospermas. No primeiro capítulo, a análise global do conjunto de dados revela padrões de distribuição de cores e sistemas de polinização, fornecendo um panorama abrangente das relações entre plantas e polinizadores em diferentes regiões do mundo. O segundo capítulo, por sua vez, aprofunda-se na evolução do croma UV, destacando a importância desse atributo em flores polinizadas por abelhas e aves. Por fim, o terceiro capítulo expande a análise para padrões espaciais do croma UV, explorando suas relações com fatores bióticos e abióticos em larga escala espacial. O ponto em comum entre essas abordagens é a compreensão de que as cores florais não tem apenas um papel atrativo, mas representam adaptações cruciais das plantas ao ambiente ecológico em constante transformação. A interligação entre a distribuição global de cores, a evolução do croma UV e seus padrões espaciais destaca a importância fundamental desses atributos na sobrevivência e reprodução das angiospermas. Isto deixa claro que a pesquisa desses diferentes aspectos não apenas enriquece nosso entendimento teórico, mas também contribui para uma compreensão mais holística das estratégias adaptativas das plantas. Essa perspectiva integrada, que permeia os três capítulos, fortalece a base conceitual para futuras investigações, destacando a necessidade de uma abordagem abrangente para desvendar os mistérios por trás da evolução das cores florais em escalas macroevolutivas e macroecológicas.

*Perspectivas Futuras*

Os resultados desta tese sugerem diversas direções para pesquisas futuras na área da biologia da polinização, especialmente no contexto de gestão de ecossistemas e conservação da biodiversidade face às mudanças ambientais em curso. A adaptação das cores florais, especialmente aquelas relacionadas ao croma UV, pode servir como indicador sensível das respostas das plantas às mudanças ambientais. Com base nessa premissa, estudos interdisciplinares podem unir conhecimentos em ecologia, biologia molecular e conservação para aprofundar ainda mais o entendimento e a compreensão científica sobre o tema.

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# ANEXOS

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## DECLARAÇÃO

Em observância ao **§5º do Artigo 1º da Informação CCPG-UNICAMP/001/15**, referente a Bioética e Biossegurança, declaro que o conteúdo de minhaTese de Doutorado, intitulada "***PERSPECTIVAS MACROEVOLUTIVAS E MACROECOLÓGICAS DA COLORAÇÃO DAS FLORES DE ANGIOSPERMAS***", desenvolvida no Programa de Pós-Graduação em Biologia Vegetal do Instituto deBiologia da Unicamp, não versa sobre pesquisa envolvendo seres humanos, animais ou temas afetos a Biossegurança.

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Data: 11 de Abril de 2024

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