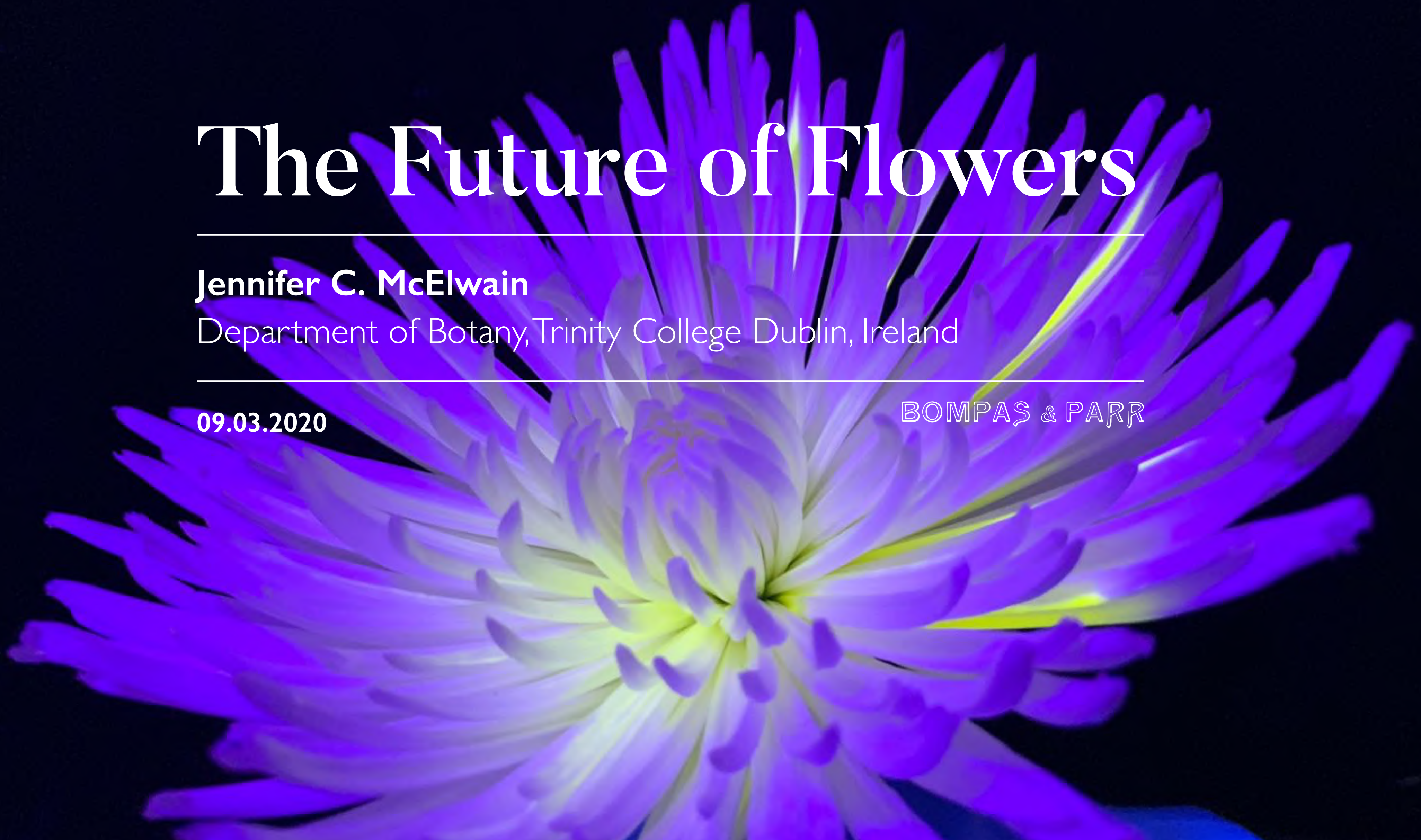

The Future of Flowers

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BOMPAS & PARR

Coreopsis tinctoria in the daisy family photographed by Craig P. Burrows
using ultraviolet-induced visible fluorescence photography

Abstract

There are an estimated 369,400 species of plants which possess flowers (Willis, 2017), representing over 95% of all known land plants. They are collectively known as angiosperms, which means 'vessel seed' because they produce and protect their precious seed more than any other evolutionary group. In this essay I will explore the question 'What is the future of flowers' from both a technological and ecological perspective. In the midst of human-driven environmental and biodiversity crises will our strong cultural symbolism associated with flowers take on greater meaning? Will flowering plants be melded with robots as a novel 'soft' media interface to change human behaviour in a positive way?

Will our cities become centres for diverse flowering species with plant-powered street lighting? In a more sustainable future world will we 'see' flowers more like bees and other essential pollinators and appreciate and protect their tremendous diversity?

What are flowers?

Flowers are a marker of Earth's annual journey around the sun (Burger, 2009). Some plants only flower after one such journey – they are called annuals. Many plants repeatedly flower every year at more or less the same time they did the previous year. Flowering marks springtime wherever you are in the world. It postmarks the aftermath of rain in the desert and a time of biological business when so many creatures are getting ready to find a partner for mating season. In a strict biological sense, flowers are the reproductive structures of plants. Many famous botanists have argued that a flower is one of the most difficult structures to define because some flowers are male, others female, others bisexual or a hybrid of the genders. Others have many petals, others none – some are grouped and showy, others are hidden and tiny.

Today there are over 369,400 different types of flowers known to science from catkins to orchids, associated with over 369,400 different species (Willis, 2017). Interestingly, not all the world's plants have flowers. There are approximately 37,511 species of plant which are flowerless (Palmer et al., 2004); these species including mosses, ferns, conifers and cycads have an entirely different way of reproducing.

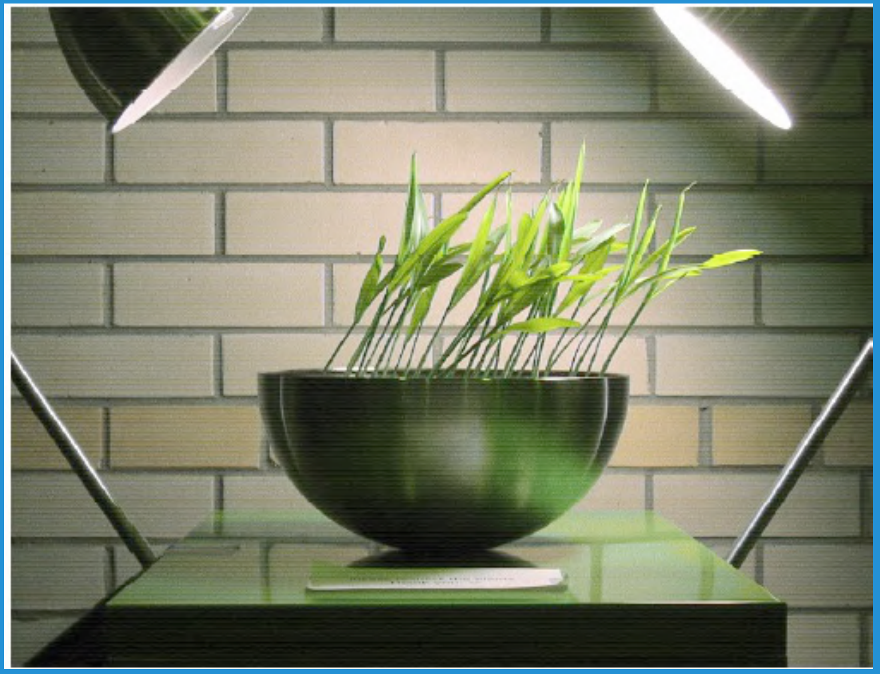
What is the function of flowers?

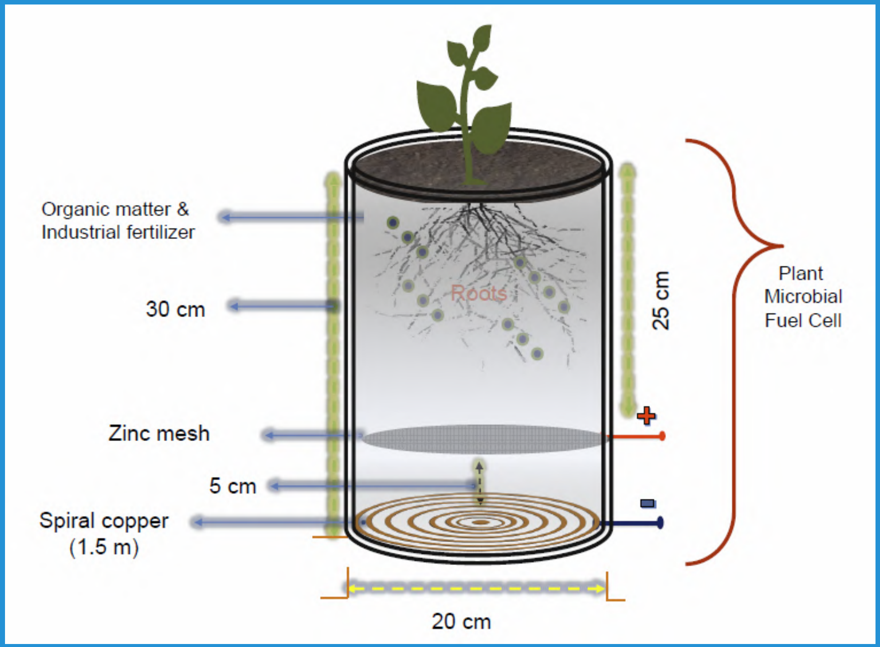
Flowers have multiple functions. Most flowers protect their male and female reproductive parts called the androecium (Greek for male household) and gynoecium (female household) within petals or petal like structures. Some flowers are all about advertising – they are gaudy, showy and exuberant. These encourage their human and bee pollinators to visit them, pick them, explore their insides and pass their pollen from one flower to the receptive female parts of another. Some flowers are inconspicuous and green. They are designed to make little vortices of the wind so that pollen in air currents can be encouraged to deposit on their female parts. These are called wind pollinated flowers. Humans almost exclusively rely on flowering plants for all their plant-based foods.

Non- flowering plant foods are exceptionally rare – these include pine nuts, seaweed, mushroom, ginkgo seeds and some conifer relatives (*Gnetum*), however none of these provide the staple carbohydrates of people's or livestock's diets worldwide. Flowers produce the seeds and stored carbohydrates (wheat, oat, rice, barley, millet, pea, bean seeds etc.) on which entire human civilizations have developed and rely on today. It is evident therefore that there is simply no future *without* flowers.

Future of Flowers – a technological perspective

The future of flowers is high-tech according to some branches of science. In the field of human–computer interactions, designers are exploring the idea of combining plants with robots as living media interfaces to influence human behaviour and human interactions with digital systems. This is the burgeoning discipline of lightweight robotics (Merritt *et al*., 2020). An experiment carried out by Holstius *et al*. (2004) combined living maize seedlings, a recycling station and simple motion detector sensors connected to a directional light source to examine human behaviour in relation to office waste. Living seedlings showed a strong unidirectional response to light via phototropism when people activated the motion detector of the recycling bin. This in turn switched on a light source which the seedlings grew towards within 8 hours. The authors argued that although the human subjects of the experiment did not always understand how the plants were responding to increased recycling they intuitively sensed something positive, and that the plants were signalling increased recycling by strongly leaning in the direction of the recycling bin (Holstius et al 2004). In the future we may see more of these plant-robot interactions to sense the environment, to respond to and act to various stimuli and to influence human behaviour in a positive way.





Plant-computer interactions have also been deployed creatively in London Zoo where a fern plant called Pete, takes its own selfie every 20 seconds. This selfie obsessed plant uses a plant-microbial fuel cell positioned at its roots. Fuel cells generate low quantities of energy – enough to power small internet of things (IoT) devices such as sensors and cameras – by converting chemical energy (protons and electrons released by microbial breakdown of dead roots and root exudates) to electrical energy using microorganisms. The microorganisms live on and around the roots of plants feeding on the exuded carbohydrates – they are the microbiome of the plant – similar to our own gut microbiome. The fuel cell illustrated here (from de la Osorio de la Rosa *et al.* 2019)4 uses C4 plants which produce more root carbohydrates – and more power!

The potential application of plant-microbial fuel cells as energy sources for low-powered devices is far reaching; from wildlife photography powered by trees in remote forests to monitor biodiversity and seasonal change to urban tree sensors powering their own customized pollution monitors. Another potential application of plant powered devices is in house plants which could generate enough root sugars to power small ubiquitous environmental sensors that monitor all aspects of the office environment such as temperature, CO_2 concentration and volatile organic compounds. Plant-microbial fuel-cell powered sensors eliminate the need for conventional batteries that require regular changing and carry environmentally toxic chemicals.

The ultimate environmental sensors of the future are plants themselves. In the future we will understand how to read and quantify their full sensing capacity so that internal green walls and office greenery will sense and signal how healthy the office indoor environment is for workers via their movements or digitally interfaced read outs. It is unlikely that a bouquet of flowers will be able to take its own selfie in the future, however the idea of receiving a digital photograph of a rare tropical tree in full bloom that has been taken and emailed by the tree itself is already technically feasible.

Other examples of augmented plant-computer interactions take advantage of their qualities to enable different forms of interaction between humans and digital systems. The aim with these plant-based media interfaces is that they are less obtrusive for the user and generate feelings of empathy.

'Overgrown' for example is a moveable plant endoskeleton on which a plant can grow. The skeleton structure is accentuated so that it has a capacity to control plant movements in an exaggerated way thereby signalling to the human user to take medicine or keep hydrated (Degraen et al., 2019). There is a concept in botany called 'plant blindness' which renders most people completely blind to plants (except when in flower) because of their dominant greenness and ubiquitous presence. Perhaps a computer-plant interface with exaggerated and unnatural movements would make people stop and see plants as individual living organisms?

Perhaps one of the most exciting future technological applications of plants is in a newly emerging field called plant nanobionics (fusion of plants and nanotechnology). This field has given rise to the concept of living streetlights (reviewed in Lew et al., 2019). These glowing plants have been artificially enhanced to produce a light without a conventional source of electricity by the incorporation of nanomaterials into and between the cells of leaves (see glowing plant below from Kwak et al. 2017; Lew et al., 2019). This relatively new technology does not use genetic modification of the plant cells to produce a glow. Instead light emitting chemicals such as luciferin and luciferase (Kwak et al. 2017) are packaged within a nanoparticle composed of silica, chitosan (from shrimp cells) and PGLA and 'fed' into the plant via its tiny breathing pores called stomata or via its roots. The light emitting compounds react with ATP within the plant to produce a glow which is plant powered! The technology is exciting because it has the potential to reduce energy use by street lighting and thus help us to reduce our reliance on fossil fuels. It is however still in early stages of development because the plants it has been applied to so far are of the salad rather than tree variety, and the light they emit is still a long way off what is needed to light up whole streets. However, serious consideration must be given to how newly bioluminescent trees and plants could influence the behaviour and physiology of other species such as insects and birds.

Future of Flowers – an ecological perspective

One of the most exciting and impactful future technological developments involving plants and people is urban greening – making cities biodiverse, with more plant species, more species interactions, more habitat and ecosystems types, more trees, more flowers, more green biomass on walls, rooves and roadways with urban forests, urban meadows and an abundance of informal green spaces. This new field which examines the human-biodiversity interface aims to greatly enhance the bio-cultural diversity of future cities for human wellbeing and social cohesion, and for conservation of biodiversity (reviewed in Botzar et al. 2016). Globally biodiversity is in crisis with increased pressure from development, land use change for agriculture and climate change. Urban areas are expected to triple up to the year 2030 (Seto et al. 2012) further increasing pressure on biodiversity loss. As the global population becomes increasingly urbanized there is also a concern that we are rapidly undergoing an "extinction of nature experience" (Miller, 2005) in parallel with extinction of biodiversity, which may make us value nature less. Increasing urban biodiversity will therefore bring both ecological and cultural benefits.

Studies have found that people prefer urban greenspaces that are not too dense and not too open, providing a means of being seen (prospect) and a place to hide (refuge) (Lefortezza et al., 2008). In another study, people increased their attention restoration, which is a measure of wellbeing when looking at green rather than grey rooftops (Lee et al 2004). Office workers reported higher wellbeing with truly wild green roofscapes planted with native species rather than non-native neat sedum plant carpets (Loder, 2014).

Untapped Cities by Augustin Pasquet

Wildness in an urban environment harbours greater biodiversity than managed greenspaces (see vacant lots planted with wildflowers below) yet people tend to prefer neater more designed spaces (right) unless there is some minimal maintenance and care evident to enable access (Ozguner and Kendle, 2006). People value high plant and bird diversity in cities, but not always high insect biodiversity (Botzat et al. 2016). Yet it is imperative that we conserve all diversity - including the species that bite us. Urban park planners prefer to design species rich environments but local users tend to value lower species diversity spaces more. In the future therefore we need to educate urban dwellers on the positive benefits to wellbeing and climate resilience that biodiversity brings (Hoffmann et al., 2012; Diaz et al., 2006). Floral abundance in urban meadow settings with a high diversity of flower colour is highly valued by people however there is a tendency for people to prefer non-native showy flowers that bring few benefits to bees and other pollinators as these require native species that some argue are 'weeds'.

The annual value of pollinators for the agriculture and horticulture sectors in the UK alone is estimated to be around £603 million per annum. Around 78% of our wild flowering plants require pollinators. Without native pollinators, our crops and major food sources and native flowering plants species will fail to set seed or disappear (All Island Pollinator Plan). Whole streetscapes packed with dandelion, Ox-eye daisy, Spear thistle, buttercup and cow parsley would be more beneficial to native pollinators than horticultural exotics (see full Pollinator Guide for recommended species to promote pollinators). Clearly there is some distance to travel in terms of public perception before people will start to love and cherish their weeds. The cities of our future should include managed messiness with a profusion of diverse native wildflowers and flowering trees. Interestingly, London is among the top 5 cities of the world in terms of the incorporation of biodiversity and ecosystem attributes into its urban planning (Nilon *et al*. 2017). It is also the world's first 'National Park City' and has an ambition to increase the city's tree cover by 12% and greenspace from 47 to 50% by 2050. As part of this initiative, the city has also identified a need to halt the loss of biodiversity in the city's gardens which has occurred because of an increase in hard landscaping by over 26% in the last decade (reviewed in Moxon, 2019).

In the non-urban environment, whole farms and portions of farmland should be repurposed for wildflowers and wilding to promote biodiversity conservation and to grow the population of native pollinators. Climate change will drive shifts in flowering plant and non-flowering plant distribution and cause miss-matched timing of important biological events such as flowering times, seed set, pollination and seed dispersal (Parmesan, 2006). Nature will need our help to come back into synchronicity by meeting our obligations under the Paris Climate agreement. We will have to engineer great wildlife corridors to enable migration of species so that they can maintain the climate envelope which they are adapted to after millions of years of evolution.

Bouquets of the Future

What will bouquets of the future look like? Based on current environmental pressures such as climate change (Masson-Delmotte et al., 2018), biodiversity loss (Diaz et al. 2020) and a need for sustainability (UN Sustainability Goals) it is likely that gifting flowers in the future will take on an even greater and more precious symbolism. I predict that future bouquets will be either ecological or technological. Both types of bouquet will symbolize how human societies are meeting climate and biodiversity goals (I am eternally hopeful). The ecological bouquet will be predominantly native wildflowers and the receiver will be educated to appreciate their wild beauty and the ecosystem services they provide to other organisms. If they are non-native, they will have been grown in highly sustainable, robot-facilitated horticultural settings with recycled grey water, solar glazed glasshouses and self-watering systems through plant-sensor feedbacks and perhaps plant-computer interfaces.

The technological bouquets of the future will be enhanced through augmented perception of their attributes – such as colour- so that the user can appreciate their technicoloured splendour as pollinators do. Human perception of colour is unreliable and irrelevant in an ecological sense as humans perceive flower colour very differently than bees. A team of electronic engineers in Queen Mary College London and botanists in Kew Gardens have developed a database of flower colour as perceived by bees versus humans, based on their actual reflectance spectrum (Arnold et al. 2010). The team have quantified the effectiveness of flower surfaces (petals, stamens etc.) at reflecting radiant energy from the sun. The analysis reveals that so many flowers that we perceive as pink, purple, and yellow are perceived by bees as UV-blue, UV-green or blue (Arnold et al. 2010)!

This process is known as fluorescence where light is absorbed by a flower and then emitted in a different wavelength (usually longer). It is the same process where your white T-shirt looks bright blue under UV lights in a club. We can only see in the visible light spectrum but bees can see in the UV spectrum. Pollen, which is a tasty carbohydrate snack for bees fluoresces bright yellow and bright blue guiding bees to their reward deep in the flower and ensuring that the flower deposits pollen on the bee for cross pollination with another flower. One of the compounds responsible for blue fluorescence in flower pollen and pollen-producing structures (anthers) is hydroxycinnamoyl (Mori et al., 2018). This compound is shown to have UV- protective function for the pollen grains protecting the genes of the male sperm held inside each pollen grain (every pollen grain contains two sperm!). It seems therefore that bright blue fluorescence in the male 'household' of many flowers not only serves as an attractant to bees in full sunlight but originally may have evolved to protect the genes of the next generation from sunburn and genetically damaging UV radiation.

Many flowers that cannot manufacture fluorescing chemicals produce the blue and UV colours that attract bees by structurally altering their petal surfaces (Moyraud et al. 2017). They do so at a nanoscale resolution so that light is reflected in short blue and UV wavelengths that bees love (Moyraud et al. 2017). Flowers are visually stunning when viewed as bees see them in UV light (see above). Perhaps therefore that the technological floral bouquets of the future will be delivered with 'bee goggles' that allow the human user to experience flowers as bees do - with full UV vision.

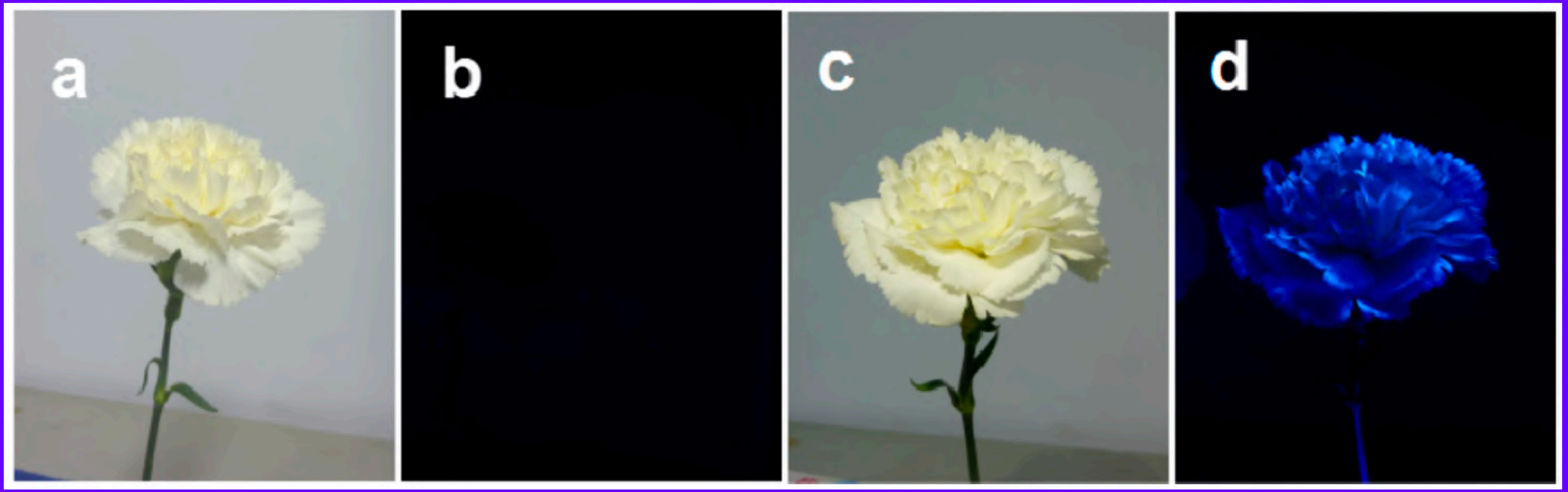
Photographs by Craig P. Burrows using ultraviolet-induced visible fluorescence photography, or UVIVF for short. Cereus flower comparison on left photographed in visible light and UV light.

Photographs by Craig P. Burrows using ultraviolet-induced visible fluorescence photography, or UVIVF for short. Bottle brush flower comparison on right photographed in visible and UV light.

Future Flowers and Medicine

28,187 plant species have recorded medicinal use according to Kew's State of the World Plants Report (Willis, 2017). Of these the majority are flowering plants. Medicinally active compounds with antimicrobial, anticancer and anti-oxidant (anti-aging) properties occur in all plant parts including flowers. The UV-protective and fluorescing compounds in flowers have medicinal properties for humans. Flower teas and edible flowers are commonly used as traditional medicines in many cultures, as they are rich in tannins and phenolics. Prickly pear, camomile, sweet chestnut, rose and bougainvillea flowers are some familiar examples which all have medicinal properties. "Fifteen of the 56 natural drugs registered for the treatment of cancer since 1980 are derived from medicinal plants with a long history of traditional use" (Willis, 2017).

The fact that many flowers have fluorescent properties is of interest to nanomaterials scientists. Auto fluorescing nanomaterials have huge potential to be used in medicine for bio-imaging. Currently most synthetic fluorescent nano-materials are highly toxic. In future, flowers may be used as a crop to synthesize and harvest non-toxic fluorescing nanomaterials for a wide range of potential applications from surgery to solar panels.



An example is provided by Han et al (2017) who produced UV fluorescent carnations in the lab by feeding the cut flowers a solution of calcium hydroxide. Naturally occurring carbon dots within the carnation petals became highly luminescent following the procedure when viewed under UV light (d) compared with control flowers (b). Non-toxic fluorescent dyes are increasingly being used in surgery to precisely distinguish cancerous cells from non-cancerous cells to improve patient outcomes.

Concluding Points

25% of the world's species are under immediate threat of extinction (Diaz et al., 2020). Nearly half of Earth's natural ecosystems have been altered by humans (Brondizio *et al.*, 2019; Diaz et al. 2020). The global climate is changing at a faster pace than ever before in human history due to human activity (Masson-Delmotte *et al.*, 2018). These are stark sobering statistics. We are in the midst of a climate and biodiversity emergency. We do not value nature sufficiently but there are seeds of hope. We are calmed by urban greenspace and woodlands. Energy generating plant-microbial fuel cells are advancing and we use flowers to mark the most important and transformational moments in our lives. Cities, not countries are driving climate action and increasingly adopting planning policies that will increase urban biodiversity and enhance ecosystem services (Moxon, 2019).

We do therefore have a deep cultural connection to nature (Coscieme et al 2020). This connection just needs to be awakened further, and urgently, so that we can save our pollinators, save our species and this planet. Perhaps this awakening will come through augmented nature, plant nanobionics or plant-robot interfaces? I think it is more likely that it will come by bringing wild nature into the places where we work and live, by allocating truly wild areas in our farms and gardens. We need re-educating to what is important – the value of nature not money. We need this transformational change to happen now before we cross irreversible thresholds. The future of flowers has to be hopeful because without flowering plants and the food, medicine and ecological networks they provide to us and so many other species, there is no future.

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Protection of flowering diversity

- Diversity ensures resilient against climate change – this is called the insurance hypothesis.
- Diversity provides a source of untapped and undiscovered medicines. Consider that only about one tenth of the world's species have been medicinally characterized.
- Diversity of flowering plants goes hand in hand with diverse pollinators which are essential to pollinate all the cereal, vegetable and fruit crops that we rely on the world over.
- Diversity can be conserved by protecting species, ecosystems, genetic varieties and habitats in situ by halting the destruction of natural landscapes for human development and through habitat restoration.

Thank You

For further details please contact:
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