

Biological Colors: The Wisdom of Evolution

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Gu Yueming

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First published in 2026 by Royal Collins Publishing Group Inc. Groupe Publication
Royal Collins Inc. 550-555 boul. Renee-Leevesque O Montreal (Quebec)
H2Z1B1 Canada

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ISBN: 978-1-4878-1402-1

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Preface

As a student, I have always been deeply captivated by the rich and vibrant hues of all living things, both in the biological knowledge taught in class and in my natural observations after school. That sense of wonder lies in every unplanned pause to admire them.

In late autumn, ginkgo trees are heavy with golden leaves, and sunlight filters through them, gilding even the veins with tiny sparkles of gold. Smoke trees on the mountains blaze with a warm orange-tinged red, their leaf edges tinged with pale brown, dispelling the chill of autumn. On campus, purple-leaf peach trees unfurl new leaves of soft purple, their tips blushed with pale pink, glowing beautifully in the sunlight. On the forest meadows, hoopoe birds wear coats of brown and tan streaked with black and white patterns, their bright red crests holding the exquisite wisdom of survival.

These everyday colors are never accidental. They are the answer sheets of growth that all living beings have written to nature over hundreds of millions of years of evolution, holding the most simple wisdom of survival and carrying my purest love and reverence for life.

When I first studied biology, I only memorized the cold definitions of "protective coloration" and "warning coloration" from textbooks, reciting them just to pass exams, never truly understanding the profound meaning behind these colors.

It was not until a late autumn afternoon, when I squatted in a corner of the playground and caught a falling ginkgo leaf, noticing the golden hue was deeper at the edges than in the middle, that I understood this color is a gift of carotenoids. It is the perseverance of the leaf, still striving to capture sunlight and recycle nutrients after losing its chlorophyll at the end of its life, that showed me a life that lives fully right up to its last moment.

As for the hoopoes in the forest, I once stayed to watch them for a long time, seeing how their gorgeous patterns blend them into the plants and trees, and how they spread their bright red crests to send signals. This exquisite survival wisdom of knowing when to hide and when to show oneself filled me with even greater admiration for the adaptability of life.

I write these words out of a deep-seated love for biological colors, and a desire to share this sense of wonder and movedness with others.

This love lies in the dense observation notes in my notebook, and in my perseverance to collect samples by the sea and look up information just to uncover the secret of why laver changes color.

From a student's perspective, I want to use plain and sincere words, avoiding obscure jargon, to share those little-known stories of colors. The poplar trees by the playground have leaves with different shades of green on their upper and lower sides—a simple defense that helps the tree regulate its temperature and adapt to day and night. Laver by the sea is deep purple when dried, pale purple when soaked, and green when cooked: this is the wisdom of phycoerythrin and chlorophyll adapting to the dim light of the deep sea.

I do not want to talk about tedious theories; I only wish to walk with you all through these colorful hues, to feel the magic of nature, and to pass on the love for life.

I have always believed that the colors of nature are the most vivid biology textbook, and also the most touching lyric poem.

Every shade holds the whispers of life, and every color change carries the tenderness of nature.

As a senior high school student, I may not be able to interpret evolutionary mechanisms in professional terms, but I can use a sincere heart to record the wonder of observation and share the movedness of understanding life.

May everyone who opens this book discover the beauty of biological colors in the little moments of daily life, explore the mysteries of all things with a pure curiosity, and hold reverence for every living being that strives to grow.

May we all grow slowly with these wisdom-filled colors, and understand that the most touching power of life is never grand and spectacular, but the perseverance in the ordinary and the love for growing toward the sun.

This book is dedicated to my peers who, like me, love nature, are curious about life, and are willing to grow through exploration.

Here, I would like to express my special gratitude to my biology teacher Yang Pengpeng for her guidance on professional biological knowledge, to my head teacher Zhan Yunxia for her encouragement, and to my English teacher Li Guanghua for her guidance on writing. I am also thankful to my biology enlightenment teachers Mr. Yu Lei and Professor Chunlin Li for their generous help and support.

Gu Yueming

January 2026



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Spring Green of Poplar Branches

Poplar is a deciduous tree belonging to the genus *Populus* in the family *Salicaceae*. It is also known as white poplar or green poplar in some regions. A tall and robust species, it has a long cultivation history in China. Growing extremely fast, it can become a towering tree in just a few years, casting a dense green canopy over urban and rural landscapes.

Every time I look up and watch the layers of bright green poplar leaves fluttering gently in the wind, a curious question always crosses my mind: Why are poplar leaves green?

Poplars are ubiquitous. Like willows by the roadside and crops in the fields, their leaves are mostly green. We often seek shade and cool breezes in poplar groves, taking this for granted.

We talk about afforestation, greening barren mountains, and urban greening, and advocate nationwide tree-planting campaigns. Yet no one ever speaks of cities “turning yellow” or “turning black.” All this is thanks to the selfless gift of green



plants.

But the question remains: Why are plant leaves primarily green, rather than red, yellow, or any other color?

The answer, of course, lies in chlorophyll.

Based on chemical structure, plant pigments can be roughly divided into four categories: chlorophylls (represented by chlorophyll), carotenoids (represented by carotene), flavonoids (represented by anthocyanin), and betalains (represented by



betacyanin).

These pigments reflect different wavelengths of light, resulting in distinct colors.

Chlorophyll gets its name precisely because it does not absorb green light; instead, it reflects most of it, giving it an overall green appearance.

The green color of poplar leaves is exactly the result of chlorophyll working silently.

In colloquial language, green is sometimes referred to as “cyan.” The young leaves of poplars are precisely that vibrant cyan-green, full of life and especially endearing.

Leaves reflecting green light means they actively reject green wavelengths. This is actually quite puzzling: green light carries considerable energy, with photosynthetic efficiency roughly comparable to red light. Yet the vast majority of plants, including poplars, completely reject green light.

What unknown secrets lie behind this choice?

Three theories attempt to explain this plant behavior.

Theory 1:

There is nothing strange about this. Evolution does not always produce the most efficient design; it can only offer relatively reasonable solutions based on existing molecular structures.

To date, plants have not evolved the ability to absorb all wavelengths of light. Chlorophyll's rejection of green light, seemingly wasteful, is actually a highly cost-effective molecular structure. It efficiently captures the most useful light for photosynthesis, discarding less useful green light, this is the optimal solution of natural selection.

Theory 2:

Although red light has a longer wavelength and lower energy, it is abundant in sunlight, making it a plentiful resource. Thus, plants prefer to absorb red light.

Blue light, though less abundant than red light in sunlight, has higher energy, providing sufficient power for photosynthesis and giving plants good reason to favor it.

Only green light, sandwiched between red and blue, is neither outstanding in energy nor abundance, and has low absorption efficiency. It is ultimately "ignored" by plants and actively reflected.

Theory 3:

Atmospheric carbon dioxide concentration is not high. As the most critical raw material for photosynthesis, insufficient CO₂ supply limits chlorophyll efficiency. Even if chlorophyll absorbed all light, it could not produce more nutrients without enough “raw material.”

Under these circumstances, there is no need for chlorophyll to expend energy absorbing all light. It therefore actively discards green light, concentrating energy on absorbing red and blue light to achieve “energy-efficient performance.”

All three theories sound plausible but are not ideal answers. They only explain why chlorophyll can reject green light, not why it must reject it.

“Can” and “must” are two very different things: “can reject” means rejection is optional; “must reject” means failure to do so would cause serious trouble. The world is filled with green plants, indicating that most have chosen to reject green light. This is a “necessary” survival behavior, not an optional choice. It also suggests that green light likely causes significant, non-negligible harm to plants.

Research shows that sunlight is not entirely beneficial to plants. Especially intense summer sunlight not only scorches leaves but also produces two harmful byproducts in plant cells: large amounts of oxygen free radicals and excessive heat energy.

Properly managing these two byproducts is a critical survival task for higher plants like poplars. Without it, they cannot thrive under intense sunlight.

Heat dissipation is a physical problem, and poplars solve it with simple, direct physical strategies.

Their solution is to grow light, thin leaves to maximize heat dissipation efficiency. Additionally, leaf surfaces are covered with tiny stomata that continuously evaporate water, acting like “mini-fans.” Using wind, they constantly carry away excess heat, keeping leaf temperatures within a reasonable range and preventing sunburn.

The coolness we feel in poplar groves in summer comes not only from shade but also from evaporative cooling. In midsummer, a hectare of Canadian white poplars draws 50 tons of water from the soil daily and releases it into the air. As this water evaporates, it carries away massive amounts of heat, making poplar groves natural cool zones.

Dealing with oxygen free radicals, however, is more complicated.

During photosynthesis, when carbon dioxide supply reaches its limit, the photosynthetic saturation point is reached. This means no additional nutrients can be produced, even with more sunlight.

Beyond the saturation point, excessive light actually damages leaves to varying degrees: it significantly inhibits photosynthesis, even destroys the plant's photosynthetic system, and generates massive oxygen free radicals. This causes severe metabolic disorders in plant cells, endangering the entire plant's health. In severe cases, it leads to leaf wilting and plant death.

Free radicals are molecules, ions, or atoms with unpaired electrons. They are “aggressive,” always trying to steal an electron from other molecules to complete their pairing. This directly threatens other molecules and disrupts normal cell structure and function.



Attack !

There are many types of free radicals, but oxygen free radicals are the most common and most harmful.

Since oxygen is essential for plant survival, oxygen free radicals, once produced, are difficult to completely eliminate.

They act like “little ruffians” causing trouble everywhere, ready to attack other molecules, disrupt their charge balance, damage plant proteins and fats, and even threaten genetic integrity.

Notably, chlorophyll also produces free radicals through photo-oxidation under aerobic conditions, further exacerbating cellular damage.

Managing oxygen free radicals is a critical challenge for all living organisms, and poplars are no exception.

Poplar cells respond by continuously producing antioxidants such as vitamin C and carotenoids, acting as “cleaners” to constantly eliminate intracellular oxygen free radicals.

Among these, carotenoids not only scavenge free radicals but also play a vital role in protecting the photosynthetic system from high intensity light damage.

When production and elimination of oxygen free radicals are balanced, poplar cells function normally without major issues.

However, under stress—when the organism is suddenly exposed to harsh conditions such as cold, drought, or excessive light free radical elimination efficiency is severely compromised. Large amounts of oxygen free radicals then accumulate in cells, causing great harm to poplars.

For poplar leaves, eliminating oxygen free radicals is particularly urgent.

Poplars stand rooted in sunlight, unable to move like animals to avoid intense sun. They must continue photosynthesizing, resulting in persistently high oxygen free radical concentrations in leaves.

To grow healthily, poplars must take preventive measures to avoid green light damage in advance.

The truly effective strategy is to proactively reduce light absorption before damage occurs. For this, poplars must reject excess light rather than absorbing everything. Intense green light, with moderate energy but significant harm, naturally becomes the primary target for rejection.

Higher plants like poplars have continuously optimized their light energy utilization strategies through long-term evolution: their leaves reflect most green light to avoid damage from excessive illumination. Meanwhile, carotenoids and other substances

in leaves further eliminate free radicals, protect the photosynthetic system, and prevent sunburn.

This seemingly “wasteful” choice is actually the most suitable survival wisdom poplars have developed through millions of years of evolution.

2

Autumn Gold of Ginkgo Leaves

Ginkgo does not grow the fastest, but it possesses extraordinary vitality. Ancient ginkgo trees hundreds of years old are commonly seen, looking more vigorous than ordinary poplars and pagoda trees. That is why ginkgo is indispensable for both urban greening and classical garden decoration.

Where ginkgos grow in clusters, they turn into a dazzling golden ocean in autumn.

Later, as frost grows heavy and early winter approaches, the shiny golden leaves gradually lose their luster, turn pale withered yellow, and fall gently from the branches. The whole ground is then covered in gold, making a rustling sound when stepped on.

So why do ginkgo leaves turn bright golden yellow in autumn, and later fade into inconspicuous withered yellow?



In fact, poplar leaves also turn yellow in autumn, but they change color too quickly. Besides, poplar leaves are broad and thick, without the translucent, dazzling shine of ginkgo leaves, so they rarely attract people's attention.

Each fan-shaped ginkgo leaf hangs on the branch like a tiny golden fan, shimmering in the sunlight. They leave a deep impression and become the most charming scenery of autumn.

Chinese soapberry (*Sapindus*) is mainly distributed in mountain forests, courtyards, and along roads in southern China. It has strong tolerance to humidity and poor soil, grows in clusters in warm and humid environments, and stands quietly in busy cities, truly a plant spirit decorating autumn.

Every autumn, soapberry leaves turn bright golden yellow early on. This clearly shows the evolutionary value of yellow leaves and becomes an iconic autumn scene in southern China.

Whether in ginkgo or soapberry, leaf yellowing is related to the performance of carotenoids.

What exactly are carotenoids?

Carotenoids are a large group of plant pigments with similar molecular structures. They were first isolated and purified from carrot roots, hence the name “carotene.”

Later, a series of similar pigments were separated from carotene, collectively called carotenoids, including the commonly mentioned lutein.

To date, hundreds of carotenoids have been discovered, including α -carotene, β -carotene, lutein, zeaxanthin, lycopene, and others.

These pigments mainly absorb blue and violet light, while reflecting yellow, orange, and red light. Depending on their type and concentration, they give leaves a range of colors: yellow, orange, red, and more.

The golden yellow of ginkgo leaves in autumn is exactly the effect of abundant carotenoids. Among the colorful mountain forests, under the gentle autumn sun, ginkgo spreads its sturdy branches and sways its golden leaves gracefully in the cool breeze, adding vivid vitality to the quiet autumn.

When the soft autumn wind blows, the golden fan leaves drift down like romantic golden rain, bringing a gentle beauty.

For this reason, ginkgo has become the classic representative of yellow-leaved plants, far more famous than soapberry, and is honored as a “living fossil” golden-leaved tree.

The question is: why do ginkgo leaves turn bright golden yellow, rather than fading into dull withered yellow like ordinary poplar leaves, scattering and turning into soil?

The answer may still be related to green light.

When green light is rejected by chlorophyll, most is reflected back into the air, but some bounces repeatedly inside mesophyll cells like ping-pong balls, potentially damaging internal cell structures.

Plants therefore need a defense mechanism against green light damage, and carotenoids take on this role.



The absorption spectrum of carotenoids complements that of chlorophyll. They capture the “escaped” green light, helping plants use solar energy more fully.

At the same time, by absorbing excess light energy, they effectively protect mesophyll cells from strong light damage.

Even in summer, mesophyll cells contain large amounts of carotenoids. But their concentration is low, and their color is easily masked by chlorophyll, so leaves appear fresh emerald green.

In autumn, however, the situation is completely different.

In northern China, temperatures drop sharply when autumn arrives.

Frost appears and cold intensifies. Leaf temperature can no longer stay within a suitable physiological range. Photosynthetic activity of chlorophyll weakens continuously until it loses function and is rapidly decomposed.

Meanwhile, carotenoids have relatively stable molecular structures and degrade slowly, reversing their ratio with chlorophyll.

When chlorophyll can no longer mask the color of carotenoids, the carotenoid color gradually emerges.

Lutein, in particular, is abundant and plays a key role in leaf color change, directly causing leaves to turn yellow.

However, lutein alone is not enough to produce the bright golden yellow of ginkgo. More carotenoids, especially β -carotene, are required.

Ginkgo faces a different situation from poplar.

Autumn in the north is colder, and ginkgo leaves are thin, tough, and large in surface area, causing continuous loss of heat and water, which is very unfavorable for surviving winter safely.

Many plants therefore choose to shed their leaves early, which is the fundamental reason for autumn leaf fall.

Poplar and soapberry make the same choice, and ginkgo is no exception, only the

timing differs.

Different choices inevitably lead to different results.

Leaves cannot fall randomly; plants must prepare in advance.
One basic rule: maximize nutrient recycling from leaves to avoid waste.

During this process, protective carotenoids (such as lutein) become visible.

Chlorophyll is specifically decomposed, and the released nutrients are transported back through veins to the trunk, roots, and stored for reuse the next year.

But ginkgo's situation is more complex. As an ancient gymnosperm, it values sunlight more than other plants.

Although light weakens in autumn, sufficient diffused light remains, and ginkgo does not want to waste it.

Sunlight is scarce in northern winters, so ginkgo uses every means to exploit autumn light and extend photosynthesis as long as possible. This is when the value of various carotenoids becomes clear.

As light declines in autumn, the proportion of carotenoids in ginkgo increases greatly.

Carotenoids absorb more blue and violet light, helping maintain leaf temperature and metabolic activity, creating better conditions for the remaining chlorophyll to photosynthesize.

That is why ginkgo leaves show a striking bright yellow and stay on the tree for a long time. They are desperately seizing the last sunlight, carrying out faint photosynthesis, and storing energy for sprouting next year.

In regions with mild winters and relatively sufficient sunlight,

plants do not need to cling to weak light. They shed leaves quickly to avoid unnecessary damage from sudden cold waves.

Besides ginkgo, many other plants turn golden yellow in autumn, such as the soapberry mentioned earlier.

They share the same evolutionary logic: delay leaf fall and seize the last chance for photosynthesis.

With their bright, charming leaves, these plants are known as golden-leaved plants. They have become important landscape plants in gardening and urban greening, and remain people's favorite autumn scenery.

3

Burning Red of Smoke Tree

The smoke tree (*Cotinus coggygia*) has flexible yet sturdy branches and is a treasure trove of useful materials, serving important roles in daily life and industrial production.

Its wood yields yellow industrial dyes; its bark and leaves can be processed to extract tannins; its tender shoots are edible when fried; and even the natural red pigments in its leaves hold promise as a new raw material for edible colorants.

In ancient times, the smoke tree was a highly esteemed dye material. During the Sui Dynasty, the ochre-yellow hue extracted from its wood was designated as the exclusive color for imperial attire. This tradition even influenced neighboring countries; today, the most formal ceremonial robes of the Japanese Emperor still employ the “Kōrozen” (smoke tree dyeing) technique.

The smoke tree is not overly demanding in its growth requirements, it tolerates drought and poor soil—but it thrives best in well-drained sandy soil. To ensure



robust growth and vibrant leaf color, careful tending is still needed during its growing season.

The color transformation of smoke tree leaves in autumn is truly marvelous. A faint blush first appears along the leaf margins, then gradually spreads toward the center until the entire leaf turns brilliant crimson. Finally, with a hint of reluctance, the leaves drift gently from the branches, unlike willow or poplar leaves, which simply fade from green to withered yellow before falling.

So why do smoke tree leaves turn such a dazzling crimson in autumn?

Leaf reddening is actually a common phenomenon. The red leaves of Fragrant Hills in Beijing, China, are world-famous for this very reason, becoming the most iconic autumn scenery.

Every autumn, the mountains are blanketed with red leaves. Illuminated by the autumn sun, they blaze in vivid crimson, painting the entire range in a magnificent tapestry that draws countless visitors who linger to admire the breathtaking view.

Fragrant Hills is also home to many other plants, such as Oriental arborvitae, pine, pagoda tree, oak, and hawthorn. Their leaves remain green throughout the year or turn yellow and fall like willow leaves in autumn.

Some are evergreen species with minimal leaf drop, forming a lush green backdrop that subtly sets off the brilliant crimson smoke tree leaves, making them stand out even more vividly. This contrast is precisely what makes Fragrant Hills so enchanting.

We tend to fixate on the star-like red leaves, rarely making a special trip to admire green foliage. After all, green leaves are ubiquitous and unremarkable as the background of the ecosystem.

Numerous plant species contribute to Fragrant Hills' crimson hue, including Shantung maple, Japanese maple, and staghorn sumac. Among them, the smoke tree is the most famous and representative.

Statistics show that the smoke tree forest on Fragrant Hills is primarily located in the southwest part of the park, at elevations between 150 and 575 meters. Covering nearly 1,200 mu (about 80 hectares) with over 100,000 trees, it forms the core of the vast red-leaf landscape.

The smoke tree is a deciduous shrub belonging to the genus *Cotinus* in the family Anacardiaceae. It is cold- and drought-tolerant, and its brilliant crimson leaves are its “magic weapon” for coping with cold weather.

In this regard, the smoke tree and red maple share a similar logic for dealing with cold: both use vibrant colors to conceal their wisdom in overcoming adversity.

The physiological mechanisms behind leaf reddening and yellowing are distinct. For both smoke tree and red maple, leaf reddening is primarily the result of anthocyanins, with little involvement from lutein or other carotenoids.



Anthcyanidin basic structure

The smoke tree achieves its intense crimson hue precisely because it synthesizes massive amounts of anthocyanins in its leaves during late autumn, far more than other red-leaf plants. Scientific research shows that smoke tree leaves also contain flavonol glycosides, which enhance the yellow tone and brightness of the leaves, making their red resemble a brilliant sunset and even more striking.

Different types of anthocyanins have varying light-absorbing capabilities, and they are primarily stored in the vacuoles of mesophyll cells.

A vacuole is essentially a small fluid-filled sac within plant cells, enclosed by a membrane and separated from the surrounding cytoplasm. It is the site where anthocyanins reside and function.

Depending on the pH of the vacuole, anthocyanins display different colors, red and purple are the most common. The vacuoles in smoke tree leaves are acidic, which

causes anthocyanins to exhibit their most brilliant red shade.

Anthocyanins are water-soluble natural pigments widely distributed in plants throughout nature.

They are abundant in flowers, also present in large quantities in leaves and fruits, and can display different colors depending on environmental conditions.

Over five to six hundred anthocyanins have been identified to date, making them the primary contributors to autumn leaf reddening. The anthocyanin glycosides in smoke tree leaves further intensify and prolong their red hue: anthocyanins themselves are unstable and easily degraded, but when bound to sugars to form anthocyanin glycosides, the red color becomes more stable and long-lasting.

Curiously, anthocyanins are not abundant in smoke tree leaves during autumn initially; they are synthesized in large quantities just before leaf fall.

The leaves first turn red due to anthocyanins, then fall with the cold wind, a process that seems like a tremendous waste. After all, synthesizing anthocyanins consumes a great deal of the plant's energy, and the leaves will soon wither, making this "effort" appear pointless.

With late autumn upon us and winter approaching, foliage is sparse and soon to wither. Yet the smoke tree synthesizes massive anthocyanins to turn its leaves crimson, what is the meaning of this?

Synthesizing anthocyanins comes at a high cost, so they must serve a vital purpose; otherwise, plants would have no reason to produce them.

Anthocyanins have proven their value through action, they are far from being mere decorative "showpieces."

Their value is also tied to nutrient recycling. Among all nutrients, nitrogen is the plant's top priority for recycling.

Unlike oxygen and carbon dioxide, nitrogen cannot be freely obtained from the air and is a limiting factor for plant growth.

Chlorophyll happens to contain large amounts of nitrogen. Failing to fully

decompose chlorophyll and recover its nitrogen before leaf fall would result in enormous waste.

To reuse nitrogen, it must first be released from chlorophyll, a process that directly causes chloroplast breakdown.

Once chloroplasts break down, various fragments are rapidly released, containing large amounts of photoactive substances.

In the presence of light and oxygen, these substances generate highly reactive oxygen free radicals, which damage plant leaf cells through photo-oxidation, a phenomenon known as photodamage.

For plants to continue growing healthily, they must minimize photodamage.

The smoke tree's solution is to store chloroplast fragments centrally in vacuoles.

The vacuole acts like a waste treatment center, and anthocyanins function as its workers, calmly eliminating oxygen free radicals produced by chloroplast fragments right at the source.

At the same time, anthocyanins have strong absorption capabilities in the blue and ultraviolet light ranges, effectively cutting off the light energy source for chloroplast fragments and further reducing photodamage.

This protective effect is especially critical since smoke trees often grow on sunny slopes where late-autumn sunlight remains intense. This is precisely the "photoprotection hypothesis" proposed by botanists, which perfectly explains the core purpose of anthocyanin synthesis in smoke trees.

This is the signature function of anthocyanins: photoprotection.

Compared to the vibrant spring, autumn smoke tree leaves are like elderly individuals, with greatly diminished resilience to adversity. Even minor damage is keenly sensed by the leaves.

Anthocyanins are the smoke tree's secret weapon. That is why the leaves synthesize massive amounts of anthocyanins in autumn to enhance self-protection, resulting in their extraordinary crimson hue.

Even more uniquely, the pedicels of the smoke tree's sterile flowers elongate after blooming, covered in colorful downy hairs. Contrasting with the brilliant crimson leaves, they resemble wispy smoke or mist from a distance, earning it the poetic name "smoke tree." The ancient verse "Amid layered green and misty veils, I seek old dreams" precisely captures this ethereal, romantic scenery of the smoke tree.

However, a question arises: why should anthocyanins take on this protective role? Leaves already contain large amounts of carotenoids, whose primary function is to defend against excessive light, so why synthesize additional anthocyanins?

This is because anthocyanins are also excellent plant protectants, particularly well-suited to the smoke tree's growing environment.

Biochemical analysis shows that anthocyanins absorb various light wavelengths but reflect most red light, which is precisely why anthocyanin-containing organs (such as leaves and petals) appear red or purple.

Additionally, anthocyanins act as a "sunscreen," absorbing excess light energy harmful to chloroplasts and immediately converting it into heat for dissipation, preventing the plant from being scorched by intense light.

Smoke trees grow on high-altitude sunny slopes with intense late-autumn sunlight and large diurnal temperature fluctuations. Research shows that under a 17/9°C day-night temperature cycle, smoke tree leaves accumulate high concentrations of anthocyanins. The stronger the light and the lower the temperature, the more intense the red hue, making this "sunscreen protection" particularly critical.

The photosynthetic capacity of red leaves has already significantly diminished. Anthocyanins act more like a "protective shield" for these "retiring" leaves, allowing the smoke tree to calmly recycle nutrients and slightly delay leaf fall.

Therefore, autumn leaf reddening is most likely a clever strategy employed by trees under the dual stress of cold and intense light to safely recycle leaf nutrients.

The lower the temperature and the stronger the sunlight, the more urgent this protective need becomes, and the more intensely red the leaves may turn. This explains why smoke tree leaves become even more vividly and movingly crimson after being touched by late-autumn frost.

4

Double Beauty of Purple-Leaf Peach

Purple-leaf peach and common peach both belong to the genus *Prunus* in the family Rosaceae. Apart from their leaf color, they are highly similar in appearance, branch texture, and growth habits: both produce delicate pink blossoms and plump fruits. However, the fruits of purple-leaf peach are mostly for ornamental purposes, and their taste is far less sweet and crisp than those of common peach trees.



Common peach trees show only a faint purple tint on young seedlings and shoots. In contrast, purple-leaf peach retains purple leaves for a long time. From sprouting in spring to defoliation in autumn, purple remains its most distinctive feature. What is the reason behind this?

Purple-leaf peach is native to China and is a typical temperate deciduous small tree. It thrives in warm, humid, and well-lit environments, being cold-tolerant but intolerant to waterlogging. As seasons change and temperatures fluctuate, the leaf color of purple-leaf peach shifts accordingly. In other words, its leaves are not

always pure purple: in early spring, new leaves show a hint of crimson; in late autumn, the color deepens toward purplish red, earning it the nickname “purple-red peach” in some regions. Like the reddening of purple-leaf plum, this change is related to anthocyanins. The usual purple color is simply the result of high anthocyanin concentration masking chlorophyll.

When purple-leaf peach lacks nutrients or raw materials for anthocyanin synthesis, anthocyanin levels drop. If anthocyanin can no longer mask chlorophyll, the leaves turn slightly green, indicating that the tree is enhancing photosynthesis to replenish nutrients. This is especially common after flowering, when the tree bears fruit. It also becomes obvious in hot and rainy summers: some leaves lose their purple hue and turn pale green. Yet people do not call them “green-leaf peaches,” as green is too common to be a defining feature.

In cold weather, especially early spring, purple-leaf peach displays deep purple. In shaded areas, chlorophyll and carotenoid levels decrease, while anthocyanin rises sharply. Low temperatures promote anthocyanin synthesis, which strengthens photoprotection for leaves when photosynthesis is limited. Newly sprouted leaves are fragile in early spring and rely heavily on anthocyanin for protection.

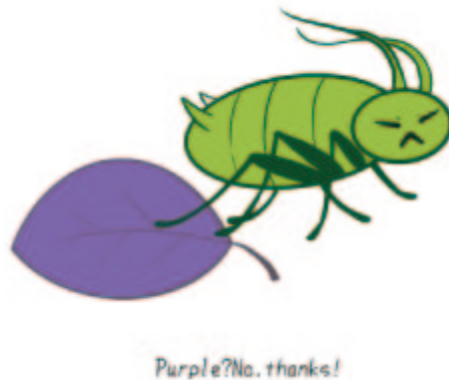
The leaves of purple-leaf peach are very thin and require special protection from anthocyanins. If you compare a purple-leaf peach leaf with a common peach leaf, you will find the former thinner and softer, less than half the thickness of the latter. Such delicate leaves have high light transmittance and can function well even with less chlorophyll. The saved nutrients are used to produce more anthocyanins, providing stronger photoprotection.

Therefore, the vacuoles in purple-leaf peach leaf cells are highly developed, occupying over 90% of the cell volume. Larger vacuoles store more anthocyanins, and higher anthocyanin levels result in deeper purple. If purple deepens further,

it may turn black. However, black leaves are rare because leaves can hardly accumulate such high concentrations of anthocyanins. Excessively high anthocyanin would absorb all light, overheating the leaves, disrupting normal functions, and even burning leaf cells.

The rarity of purple in leaves is worth noting.

Botanists have long observed that the younger the purple-leaf peach leaves, the deeper their purple color. This occurs in many plants: not only young peach shoots but also purple-leaf plum buds may show deep purple. New shoots have weak cell walls and cannot withstand strong light, so they rely heavily on anthocyanins for protection. This defense also helps resist insect infestation and herbivory, supporting healthy shoot growth.



Anthocyanins themselves are non-toxic and cannot directly repel insects. However, high anthocyanin levels are often accompanied by high concentrations of toxic phenolic compounds. Thus, bright purple leaves act as a deterrent to insects.

Leaves rich in anthocyanins are usually nutritionally poor: nutrients are either recycled in autumn or not yet fully produced via photosynthesis in spring. Insects gain little by eating them, making it “a waste of effort.” Anthocyanins thus serve as a clear signal, like a “closed” sign outside a restaurant. Their presence indicates low nutrition and possible mild toxins.

Thus, the purple color associated with anthocyanins carries a clear message: these leaves are unpalatable, low in nutrients, and not worth eating. Insects are advised

to stay away and find better food. Leafcutter ants understand this well. They cut many leaves to grow fungi in their nests but avoid red and purple leaves, which provide no value for fungal growth. Purple-leaf peach leaves are naturally on their “rejection list.”

How do anthocyanins defend against insect infestation and feeding?

Aphids also “know better” and rarely lay eggs on purple leaves. Through hundreds of millions of years of evolution, aphids have learned that purple indicates nutrient depletion. Although soft, purple leaves lack nutrients. Laying eggs on them would starve their offspring or expose them to toxic phenols. This clearly demonstrates the protective value of purple, allowing purple-leaf peach shoots and leaves to grow without excessive insect damage.

Besides purple-leaf peach, many other plants have purple leaves, such as purple lavender and perilla. They readily accumulate anthocyanins to enhance leaf protection and become ornamental highlights with their unique colors.

We now understand why plant leaves can be green, yellow, red, or purple. Plants with varied leaf colors on the same individual are called color-leaf plants or foliage plants, and are important ornamental garden plants. Purple-leaf peach is a typical example, valued for both leaves and flowers: it bears pink blossoms with purple leaves in spring and displays rich leaf colors in autumn, making it a common decorative tree in landscapes.

Color-leaf plants come in various hues: golden yellow, orange, purple, variegated, etc. Most are artificially cultivated to enhance ornamental value. For instance, golden-leaf plants maintain bright yellow leaves for a long time. During off-seasons for flowers, they substitute blooms and enrich monotonous landscape colors.

Golden pothos is one such example: its leaves are rich in carotenoids, showing stable golden yellow. However, its lower leaves remain dark green to carry out

normal photosynthesis, supplying nutrients to the golden leaves and supporting the whole plant. This strategy applies to all color-leaf plants: colored leaves—red, purple, or golden—rely on green leaves for energy.

Purple-leaf peach is no exception. Occasionally, a few green leaves sprout on lower branches. These green leaves quietly perform photosynthesis and provide nutrients to the upper purple leaves, allowing the tree to maintain its beautiful display of flowers and purple foliage year after year.

5

Deep-Sea Purple of Laver

Laver is like purple silk from the sea: thin, soft, and deep purple when dried, hence its name. Although it looks like a delicate leaf, laver is very different from ordinary land plants. It is actually a red alga- as the name suggests, an alga dominated by red pigments. Evolutionarily, it is more advanced than brown algae, yet equally equipped with unique wisdom to adapt to the marine environment. Having long inhabited shallow coastal waters, laver has many distinctive traits that set it far apart from familiar land plants such as Chinese cabbage and spinach.



First, the marine and terrestrial environments are completely different, and their effects on plants differ greatly. Laver grows in the intertidal zone, the area submerged at high tide and exposed at low tide. Here, it must withstand wave erosion and alternate between wet and dry conditions day and night. As a result, laver does not need complex stems or roots. It simply attaches to rocks with a disc-shaped holdfast and does not require tough cellulose to strengthen its structure. Laver's thallus (leaf-like body) is extremely

thin, with cells bound mainly by alginate, giving it a soft yet resilient texture, quite unlike the rigid structure of land plants reinforced by cellulose. This explains why laver tastes smooth, tender, and almost melts in the mouth.

Since laver does not need to produce large amounts of cellulose, it can allocate surplus energy to synthesizing phycobiliproteins and algal polysaccharides. In contrast, land plants mainly produce starch and sucrose, leading to major differences in taste and nutrition. For people accustomed to rice, flour and vegetables, the unique umami and rich nutrition of laver are delightful surprises at the dinner table.

The secret to laver's deliciousness lies not in the quantity of protein, but in its quality. Like a wellseasoned dish, the ability to enhance flavor matters more than the amount of seasoning. Laver's protein has exceptional flavorenhancing power, as it is rich in glutamic acid and aspartic acid, both natural umami amino acids. Although laver contains less total protein than soybeans or peanuts, its umami far surpasses many other ingredients. Even simple cooking brings out an intensely fresh flavor.

Yet the factor that most influences laver's overall flavor is indeed its protein.

Why is laver so nutritious? Red algae have strong anabolic metabolism. Seawater provides abundant nitrogen, phosphorus, iodine and other key elements for growth. Furthermore, laver's entire thallus can absorb nutrients directly from seawater, fully meeting its growth needs. This allows extremely fast growth: laver matures from a young seedling in just one to two months.

In addition, laver has another important pathway to ensure nutrient supply: its unique photosynthetic ability.

All red algae contain photosynthetic pigments and perform photosynthesis. As a member of the red algae family, laver is no exception. However, its photosynthesis differs from that of

ordinary land plants and even brown algae like kelp:

- Land plants are rich in chlorophyll and appear green.
- Kelp has complex pigments and appears brown.
- Laver has especially distinctive pigments that combine to give a purple color, closely related to its intertidal habitat and light conditions.

Seawater absorbs sunlight. As light penetrates deeper, more is absorbed. Red, orange and yellow light are nearly exhausted just a few meters below the surface; only green and blue light reach deeper layers. Laver grows in the intertidal zone: exposed to full sunlight at low tide and submerged at high tide. It must adapt to both strong and weak light. This special environment has made laver's photosynthesis highly flexible. Despite its delicate structure, it fixes large amounts of carbon dioxide efficiently. Its productivity per unit area is remarkable, so intertidal zones rich in laver are known as "coastal photosynthetic paradises."



To adapt to the special light conditions of the intertidal zone, laver has evolved a unique set of photosynthetic pigments: mainly chlorophylls, carotenoids, and phycobilins. Chlorophyll includes chlorophyll a (found in all plants) and chlorophyll d (unique to red algae). Chlorophyll d absorbs specific wavelengths, especially blue light and some green light, suited to the weak light underwater. Laver's purple color comes from the combined effect of these multiple pigments.

Among these, phycobilins are the most abundant and the key to laver's purple appearance. They mainly include phycoerythrin and phycocyanin, whose absorption spectra differ greatly from those of common plant pigments. Their strong light absorption largely masks the green of chlorophyll, giving laver a deep purple color. Different laver varieties have different ratios of phycoerythrin to phycocyanin, resulting in shades ranging from purplish red to purplish blue.

Phycobilins have absorption spectra complementary to chlorophyll d, absorbing light wavelengths that chlorophyll d cannot use efficiently, especially blue and green light.

Together, they allow laver to:

- efficiently use weak light underwater during high tide for photosynthesis;
- resist strong light damage when exposed during low tide.

This greatly improves light use efficiency in complex lighting conditions, a unique evolutionary advantage for laver in the intertidal zone. Laver also has strategies to cope with the two main factors affecting photosynthesis: temperature and oxygen free radicals.

First, laver grows in the intertidal zone. When submerged at high tide, seawater acts as a natural coolant, regulating temperature and preventing overheating under strong light. At low tide, laver's thin, large surface area thallus dissipates heat quickly through evaporation. Meanwhile, mucus on the surface reflects strong light and filters harmful wavelengths.

Even so, heat and temperature changes still affect growth. Laver's strategy is to grow only in mild seasons: mainly autumn, winter and spring. When summer temperatures exceed 25°C, growth is inhibited and laver may even die. That is why fresh laver is rarely seen in summer.

Studies show that photosynthetic efficiency rises with increasing seawater temperature, but 20°C is a critical point. Above this temperature, efficiency declines and laver enters a state of photoinhibition. Below 5°C, efficiency also drops significantly. This confirms that laver is adapted to moderate temperatures, where its pigment system works most efficiently to support nutrient synthesis.

Second, laver has a biochemical strategy to deal with oxygen free radicals.

Because laver has high photosynthetic efficiency, it naturally produces large amounts of oxygen free radicals during photosynthesis. Laver, land plants and kelp face similar challenges, but their solutions differ:

- Land plants mainly use carotenoids and anthocyanins to scavenge free radicals.
- Kelp relies mainly on carotenoids and various antioxidant enzyme systems.
- Laver primarily uses antioxidants such as phycobilins and vitamin C. It also reduces freeradical production by regulating intracellular pH.

Laver's purple color comes from its unique pigment combination, especially abundant phycobilins that mask chlorophyll's green. However, phycobilins are very unstable and sensitive to heat and light. When fresh purple laver is placed in boiling water, phycobilins break down rapidly, while chlorophyll remains relatively unaffected in the short term. As a result, heattreated laver often turns pale green, revealing the chlorophyll underneath. This is why laver changes from purple to green in laver egg drop soup: it is not spoilage, but a normal pigment change.

In addition, dried laver stored under strong light, high temperature or humidity may fade gradually from deep purple to pale purple or even whitish, but this does not affect its taste or nutrition.

Importantly, laver never turns brown, the opposite of kelp, which turns green when heated. Laver turns green or pale, revealing fundamental differences in pigment properties between the two.

6

Plain White of Magnolia

In early spring, before the chill fully fades, tall Yulan magnolia trees burst into pure white blossoms. With no green leaves to set them off, large flower buds open one after another, like white pigeons ready to take flight, resting on bare branches. Clusters and single blooms alike resemble fallen snow or carved white jade, standing gracefully.

They spread their petals in the cool spring breeze, showing vitality that breaks through the cold, while sending out a delicate, fresh fragrance.

Its scent is elegant but not weak, refined but not pretentious.

It has no heavy sweetness, only a cool, gentle warmth that refreshes the heart and mind, making people stop to admire and breathe deeply. Yet Yulan magnolia does not bloom and scent for humans but to attract insects.

Yulan magnolia is a typical entomophilous flower, relying on insects to carry pollen



from one flower to another for pollination and fruiting. To attract insects, it secretes sweet nectar as bait and releases its unique fragrance, like a silent invitation calling insects to feed.

When insects follow the scent, move among petals, and feed on nectar, their bodies become covered in pollen. They then carry this pollen to other flowers, unintentionally helping the magnolia complete pollination.

When Yulan magnolias are in full bloom, bees and butterflies gather in numbers, busily collecting nectar among the white petals to store in their hives. Yulan magnolia honey harvested by beekeepers is clear, sweet, and gently scented, one of the finest types of honey.

Besides bees, some beetles active in early spring also visit the flowers. While feeding on nectar, they too become helpful pollinators.

Tasting Yulan magnolia nectar is simple. Gently pluck a fully opened flower, spread its white petals apart, and you will see tiny nectaries among the stamens, where sweet nectar is hidden.

Stick out your tongue, lick lightly, and you will taste wonderful natural sweetness, with a faint magnolia fragrance lingering on your tongue. Though only a tiny amount can be tasted each time, it was enough to fill us children with unique joy in early spring. Little did we know we were stealing food from bees and butterflies.

We used to guess that the magnolia's thick, tough petals existed just to keep thieves like us away. We took nectar without helping pollination, and might even damage the stamens.

Thick petals protect the stamens and nectar, resist early spring cold winds and low temperatures, and reduce nectar loss. This is likely why its petals are so thick and strong.

With this protection, and because most mammals are still inactive in early spring, few animals steal nectar. The magnolia can thus save most nectar for its pollinating insects.

Similarly, since it already has thick petals as physical protection, it does not need to produce toxins for chemical defense. This is why Yulan magnolia nectar is safe to eat directly, and its petals can be used for tea and cooking.

But what does all this have to do
with Yulan magnolia producing white
flowers?

When plants produce pigments, they often create toxic byproducts such as polyphenols. Some plants use this to “defend themselves,” not to kill insects, but to deter nectar-stealing mammals like mice and squirrels.

Insects mostly feed on nectar and rarely chew petals, so toxins in petals affect them little. Mammals, however, bite petals, damage stamens, and destroy the flower’s ability to pollinate and reproduce.

That is why many colorful flowers are beautiful but unpalatable, even slightly toxic, to discourage mammals.

Humans are omnivores, yet we rarely eat flower petals. One important reason is that many colored petals contain such mild toxins.

But Yulan magnolia has white flowers. It does not need to make colored pigments, so it produces no toxic byproducts and is nearly non-toxic. That is why humans can safely eat its nectar and petals.

Also, when it blooms in early spring, leaves have not yet sprouted. Without green foliage blocking the view, the white flowers stand out clearly, making it easy for us to find nectar.

Besides using thick petals for protection, Yulan magnolia blooms high on tall branches. With no leaves in early spring, flowers are fully exposed but out of reach for all but flying insects.

This arrangement protects nectar and stamens from damage. At the same time, white

flowers stand out brightly on bare branches, acting like a visible advertisement so insects can find them easily.

This is part of the evolutionary strategy of entomophilous flowers. Their main task is to attract insects for pollination, and to be found, they must first be seen.

The simplest way is to contrast with green leaves. Otherwise, flowers would be lost in a sea of green and go unnoticed by insects.

Since leaves are mostly green, flowers evolve other colors, any color except green, in theory.

And so it is: insect-pollinated flowers reflect various lights, showing red, yellow, blue, purple, and more, but rarely green. Green would hide them from insects and make pollination nearly impossible.

For this reason, nature has flowers of many colors, inspiring descriptions like “colorful” and “blossoming in a riot of hues.” There are few expressions for green flowers.

Artificially cultivated garden varieties, such as green chrysanthemums and green peonies, are exceptions, carefully bred by gardeners, not products of natural selection.

With so many colors available, why did Yulan magnolia choose white?

Normally, to ensure successful reproduction, different plants bloom at different times with different colors, attracting different insects and avoiding intense pollination competition.

Among all colors, white-flowered plants are the most numerous. Humans simply favor bright colors and often overlook white flowers.

After white come yellow flowers, then blue and purple flowers. Red ranks relatively low.

Yet because people prefer red flowers and plant them widely in parks and gardens, we falsely believe red is the most common. In reality, white flowers are far more numerous in nature.

Yulan magnolia is just one of many white flowered plants, and a representative early spring white bloomer.

So why are white flowered plants the most abundant?



The answer is simple: white flowers reflect most visible light, making them the brightest. Even in dim early spring light, they attract insects most easily.

In addition, white flowers do not need complex pigments, so their flowering cost is lower. It is like building a house without fancy decorations, saving a great deal of energy.

With the same nutrients, white-flowered plants can produce more flowers and more nectar, gaining more pollination chances and higher reproductive success.

Moreover, by saving energy on pigments, white flowers can produce more fragrant compounds to attract even more insects.

Thus, even though white flowers are plain in color, their fragrance is especially charming, clear, and long lasting. This is why Yulan magnolia has such a delicate scent, and why its nectar is sweet and beloved.

Besides, many night blooming plants, such as tuberose, evening primrose, and night

blooming cereus, also have mostly white flowers. White shows incomparably better at night than any other color.

Coincidentally, many insects are nocturnal, especially moths. To them, white flowers in the dark are like bright headlights, guiding their flight and helping them easily find nectar and pollen.

Although Yulan magnolia blooms during the day, early spring light is weak. Its white flowers still act as excellent guides, helping insects find them quickly and complete pollination.

7

Black Magic of Black Beans

Black soybean is an annual herb in the genus *Glycine* (Leguminosae), named for its deep black seeds. The familiar yellow soybeans and mung beans are products of artificial selection. Since yellow soybeans and mung beans do not produce melanin, they save abundant nutrients to accumulate starch and protein, resulting in slightly higher yields than black soybeans. Most wild soybeans have black seeds, indicating that black is the original color of this species.



Some may wonder why black soybean seeds are so small. In fact, they are slightly smaller than yellow soybeans, round and plump. The folk saying “A needlepoint against a wheat awn, a black bean smaller than rice” uses the small size of black soybeans to describe something delicate and slender. The key reason for their small size is that black soybeans rely on ants for seed dispersal.

Many plants depend on ants to spread their seeds; botanists call them myrmecochorous plants. Roughly estimated, there are tens of thousands of such

plants in nature. They use ubiquitous ants to disperse seeds far and wide and expand their range. For ants to willingly carry seeds, the seeds must be small enough to be transported easily. Black soybeans have precisely adopted this evolutionary strategy, hence their petite appearance.

In fact, wild black soybeans have even smaller and rounder seeds. They are not only easy for ants to carry but also avoid excessive nutrient consumption from large volume, better preserving energy for germination and preparing for rooting and sprouting.

To attract ants, small size is not enough and there must be sufficient bait. Most myrmecochorous plants therefore have seeds with an elaiosome, a structure that emits a special fragrance to lure ants. Ants carry these small, fragrant seeds back to their nests, carefully eat the elaiosome, and discard the intact seeds.

These discarded seeds remain highly viable. Carried away from the parent plant by ants, they germinate under suitable soil, moisture, and light, completing population dispersal.

Although black soybeans lack a specialized elaiosome, their seed coat has fine oil glands rich in unsaturated fatty acids, an important reason for their distinctive mellow aroma. Ancient people often called them “black beans,” highlighting both their deep color and high oil content.

Of course, the oil is not meant to please humans or become a delicacy. Its main purpose is to attract ants. Furthermore, to help ants grip and carry them, black soybeans have a finely textured, smooth surface. This texture prevents slipping without damaging antennae, like “carrying handles” designed especially for ants, a masterpiece of natural evolution.

Why are black soybeans predominantly black?

Like black sesame, black soybeans absorb more sunlight, promoting nutrient accumulation and maturation. After ripening, they also dry faster, avoiding rot from rain soaking. However, this is not the most important function. Under its black coat lies great wisdom for seed protection.

The black color comes not from one pigment, but from a combination. Chemical analysis shows that black soybean pigment is mainly anthocyanins, which have strong antioxidant activity. They effectively scavenge oxygen free radicals, resist oxidative damage, protect normal metabolism, and prevent oxidation of proteins, starch, and other nutrients.

At the same time, black soybean pigment strengthens the seed coat, making it harder and thicker for excellent mechanical protection against pressure, abrasion, and invasion by bacteria, fungi, and other microbes.

This may explain why black rice, black soybeans, and black sesame are relatively hard to digest directly: the hard seed coat and melanin provide double protection, stabilizing their structure and resisting breakdown by digestive fluids.

In short, black seeds are stronger and more durable than other colors, maintaining viability for a long time in harsh environments.

For this reason, black seeds generally have strong disease and pest resistance. Even ants rarely eat the seeds directly; they only seek the oil. After consuming the oil, they discard the seeds, accidentally completing dispersal for black soybeans.



Humans also do not eat whole raw black soybeans. This is why we soak them before cooking and grind them for soymilk. Black soybean powder and paste sold in supermarkets are finely milled to break the hard coat, allowing us to enjoy the

rich flavor and fully absorb nutrients.

Furthermore, the color of black soybeans seems closely linked to ants, a wonderful “symbiotic agreement.”

Many ants are black themselves. Like black soybeans, ants use melanin to absorb heat, raise body temperature, boost metabolism, and clear free radicals to protect cells.

Black also helps ants hide in dark environments like soil and leaf litter, avoiding detection by birds, lizards, and other predators.

Even some birds with tetrachromatic vision that can easily spot ants do not prey on them freely. They fear formic acid secreted by ants, which causes extreme sour discomfort and may damage oral mucosa.

Black soybeans depend on ants for dispersal and naturally do not want their carriers eaten. When birds avoid ants, they also avoid similarly colored black soybeans. This indirectly protects the seeds from pecking, supporting dispersal and germination.

More interestingly, many ants have tetrachromatic vision and perceive more colors than humans. What appears deep black to humans may look bright and attractive to ants, standing out sharply against dull soil and leaves.

Thus, ants easily spot conspicuous black soybeans among litter and soil and carry them back to the nest.

It is like a wonderful pact between ants and black soybeans, a win-win symbiosis: ants gain oil as food, while black soybeans achieve seed dispersal and expand their range.

Black rice uses a similar dispersal strategy and is also myrmecochorous. Its grains are small, black, oil rich, and nutritious, attracting ants in the same simple, efficient way.

For this reason, farmers must take great care to prevent ants from stealing seeds when sowing black soybeans and black rice for example, by covering seeds with a thin layer of soil or using ant-proof devices.

After all, humans want seeds to grow and bear fruit in their fields, not be carried away and wasted in ant nests.

This evolutionary strategy of “mimicking ant color” gives black soybeans an extra benefit: stronger attraction to ants, allowing seeds to be carried farther and expanding their living range.

With this wisdom, black soybeans have survived and thrived through long periods of natural selection, becoming a common and nutritious food in our lives.



Sun Mark of Sunflowers

Besides sunflowers, there are many other yellow flowered plants in nature, such as sweet osmanthus, ice flowers, winter jasmine, dandelions, as well as familiar chrysanthemums and rape flowers.

Yellow flowered species are second only to white flowered ones, mainly because yellow flowers are rich in carotenoids. These pigments reflect yellow light, giving flowers a bright yellow color.



Sunflowers have large flower heads with golden petals, looking like tiny suns from afar. Behind this striking appearance are carotenoids at work.

Insects pay special attention to sunflower's yellow blooms because their retinas have yellow light receptors specially tuned to receive yellow light. Yellow light carries high energy and is the second brightest color to insects, after white, making it highly noticeable. Insects appear to seek yellow sunflowers, but what they really need is carotenoids. Bees and butterflies, in particular, circle the flower heads,

sipping sweet nectar while gathering carotenoids essential for their survival.

Why do insects seek carotenoids? And why do sunflower flowers contain such high levels of carotenoids? It is closely related to the flower's self-protection.

A sunflower head is essentially a large capitulum, covered with countless tiny tubular florets—the true reproductive organs. The bright ray florets around them (what we usually call petals) act as “bait” to attract insects.

Reproductive organs are the core of a plant's reproduction, and their reproductive cells must be fully protected. In this sense, sunflower's tubular florets might seem to need exceptional toughness. Yet the opposite is true: all flowers are delicate, and sunflower florets are especially soft and fragile, barely resisting wind or rain.

The fundamental reason is that although reproduction is vital, “investment” must be kept within reasonable limits. If sunflowers devoted too many nutrients to building strong reproductive organs, it would severely hinder flower-head growth and seed development, an unsustainable survival strategy.

Most plants complete reproduction quickly within a certain period and return to normal growth, and sunflowers are no exception.

To complete reproduction rapidly and efficiently, sunflowers must maximize reproductive efficiency, relying on two key points:

- release reproductive cells within a short time;
- produce a huge number of reproductive cells.

The logic is simple: only by releasing massive numbers of reproductive cells in a short time can plants maximize pollination success.

Releasing one billion pollen grains in one day produces completely different results from releasing them slowly over a year.

It is like shooting at a target: firing 100 bullets at once is far more effective than firing one bullet 100 times. Denser bullets mean higher hit rates.

The same logic applies to both plant pollination and target shooting. Though sunflowers stand quietly in fields, they have long mastered this strategy, integrating it into their growth rhythm.

Based on this logic, wild sunflowers in nature usually have very short flowering periods, typically about one week, three to four days at shortest, ten days at longest.

Few wild sunflowers bloom for months. Long blooming sunflowers are mostly artificially cultivated ornamental varieties, the result of heavy human intervention, not natural growth.

This rapid pollination strategy means sunflower flowers are only temporary organs. Once pollination finishes, the outer ray florets wither immediately, while tubular florets develop into seeds, avoiding unnecessary nutrient consumption.

Therefore, sunflowers do not need to invest heavily in their flowers. With limited investment, flowers contain little lignin or other supporting structures, making them extremely delicate.

In this sense, sunflower flowers are like temporary shelters: they are “dismantled” once their mission ends, and cannot compare with sturdy stems and heads.

Their bright color serves to quickly attract insects for pollination within the short flowering window. Even a slight delay could mean losing the chance forever, resulting in no plump seeds and endangering the population.

Given this, the fragile sunflower flowers need special protection to successfully complete pollination.

Sunflowers protect their flowers in two main ways:

- shield flowers from strong light damage;
- ensure moderate light to maintain proper temperature and reproductive cell activity.

Sunflowers are famous for heliotropism, as their heads follow the sun.

This is also a clever way to protect flowers: it avoids intense direct sunlight at noon that could burn delicate florets, while absorbing sufficient gentle light in the morning and evening to support reproductive cell activity.

These are conflicting demands, and neglecting either can lead to disaster, putting sunflowers in a dilemma.

They cannot choose their flowering season freely; most bloom in summer and cannot easily avoid intense sunlight. Yet they must prevent high-temperature damage to petals and UV burns. Ultraviolet light is highly destructive; it can directly damage DNA in reproductive cells, block gene transmission, and harm reproduction.

Therefore, protecting sunflower flowers from strong light is more challenging than protecting leaves.

To make matters worse, sunflower ray florets (petals) contain almost no chlorophyll, so they stand out against green leaves. Without chlorophyll, they cannot convert light into chemical energy or consume light through photosynthesis, leaving them fully exposed to sunlight.

Thus, most sunflower flowers rely on chemical protection, most importantly synthesizing large amounts of carotenoids. Carotenoids have strong antioxidant properties, protecting reproductive cells, effectively resisting UV damage, and safeguarding pollination and reproduction.

In sunflower photosynthetic tissues, carotenoids are the second most abundant pigments after chlorophyll. Besides protecting flowers, they also shield leaves from strong light, truly

“one substance, multiple uses.”

Furthermore, synthesizing carotenoids is relatively low-cost: it does not consume excessive nutrients or require extensive genetic information, making it an affordable “biochemical shield.”

Since sunflower petals lack chlorophyll and cannot appear green, carotenoids have full opportunity to display their color.

The most common color of carotenoids is yellow. Higher concentration results in deeper yellow and stronger protection.

Most sunflower petals are bright golden yellow precisely because of extremely high carotenoid levels. These high carotenoids effectively defend against strong summer light and UV radiation, while attracting pollinators with vivid yellow.

Especially at midday in summer, when UV radiation peaks, sunflower flowers depend heavily on carotenoid protection. This is a key reason they can bloom in summer and still achieve successful pollination.

Yellow is undoubtedly the most cost-effective flower color after white: economical, easy to produce, and highly attractive to insects. After all, bees and other pollinators also need

carotenoids to survive.

Carotenoids provide powerful antioxidant functions not only in plants but also in animals.

Bees seek carotenoids from sunflowers to use their antioxidant power to protect their own metabolic systems.

Insects are small but highly active, especially flying ones. Their intense metabolism constantly generates large amounts of oxygen free radicals. If not removed promptly, their metabolic systems quickly collapse, threatening life.

If insects can gain needed antioxidants from sunflower's yellow flowers and receive plenty of nectar as energy reward, why would they not?

This is a major reason bees prefer sunflowers, and the key to sunflowers' successful pollination and reproduction.

Even fungi understand this survival logic.

In North America, there is a close relative of sunflowers called Jerusalem artichoke, which also bears bright golden yellow flowers. A fungus called rust exploits this trait to deceive pollinating insects.

The fungus infects the flower heads and sterilizes the plant, preventing normal pollen and seed production. Instead, the rust produces golden yellow spore masses where seeds should grow. These spores closely resemble the plant's flowers and immature seeds, appearing almost identical.

Bees that normally pollinate Jerusalem artichoke cannot tell the difference. They arrive to pollinate, collect nectar and carotenoids, but end up covered in rust spores. They unwittingly become "volunteers" spreading the fungus. Through this deception, the rust completes its own population dispersal.

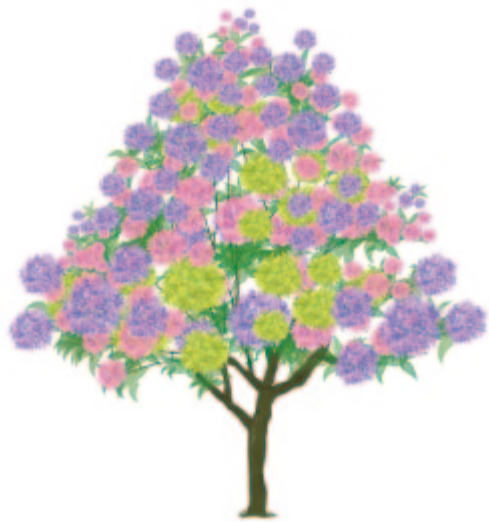


9

Color Switch of Hydrangea

Why do hydrangeas produce blue flowers?
And why do these blue blooms turn pink or
purple in different environments?

In nature, hydrangea is a typical blue-flowered plant. It prefers warm, humid environments and cannot tolerate strong direct sunlight, often growing under tree shade, beside valleys, or in gentle corners of courtyards. If planted in open areas with excessive light, hydrangeas not only grow poorly but also change color distinctly from pure blue to pink. This is the key secret to their “changeable” hues.



Blue flowers seem rare to us. On the one hand, most blue-flowered plants are shade-loving and rarely grow in exposed, bright environments. On the other hand, blue is a cool color and less noticeable to humans than bright red or yellow.

In fact, blue-flowered species are quite numerous, ranking third in the plant kingdom, after white and yellow flowers. As a common blue-flowered plant,

hydrangea is beloved for its large flower heads and variable colors, introducing more people to the unique beauty of blue blooms.

Blue-flowered plants are mainly distributed in temperate regions, a pattern that reveals their evolutionary logic: they are not adapted to strong light, so they rarely grow in bright environments, instead hiding under shade or thriving in milder temperate zones.

For this reason, blue-flowered plants reflect blue light rather than red light—a survival wisdom for regulating flower temperature, since blue and red light have vastly different heating effects.

Few people realize that flowers also need proper temperatures. Only within a suitable range can reproductive cells maintain high physiological activity and ensure successful pollination.

Either too high or too low temperature directly reduces pollination success and affects reproduction. To maintain normal flower temperature, plants must carefully balance sunlight absorption and reflection: they cannot reflect all light (causing insufficient warmth) nor absorb all (causing overheating). Different absorption-reflection strategies result in different flower colors.

Although blue light has a short wavelength and high energy, it is less penetrating and produces less heat than red light. A simple experiment confirms this: shining red light on a thermometer raises the temperature faster and higher than blue light.

This clearly shows that red light is more penetrating and heat-generating.

For flowers, this sends an important message: in hot environments, they must reflect heat-intensive red light to avoid overheating and damaging reproductive cells.

This is one reason tropical flowers are often red or white: white flowers reflect nearly all light waves, keeping them as cool as possible.

Meanwhile, tropical flowers tend to be flat, increasing surface area for better heat dissipation and avoiding heat damage.

Under shade or in mild temperate regions, flowers face the opposite challenge: they need to retain more light to warm themselves and maintain reproductive cell activity.

To achieve this, blue-flowered plants

reflect blue light while absorbing more heat-generating wavelengths. Blue light barely warms flowers internally, so reflecting it does not disrupt temperature maintenance.

For the same reason, hydrangeas have evolved large corymb inflorescences. Dense clusters of small flowers better trap heat from sunlight, efficiently maintaining ideal internal temperatures for pollination and reproduction.

Changes in environmental pH directly affect the acid-base balance of petal cell sap and thus alter petal color. Temperature changes from light intensity also indirectly modify cell sap pH, triggering color shifts in hydrangeas.

Naturally growing hydrangeas display pure blue in cool, humid, and alkaline soil conditions. As light increases and soil becomes acidic, blue fades, gradually turning pink or purple.

This is why hydrangeas bloom in different colors under different conditions: they adapt to both temperature and soil pH changes, always protecting reproductive cell activity, perfectly matching the logic of natural selection.

For example, hydrangea varieties blooming in low temperatures have darker flowers, mostly deep purple or dark blue. This dark color helps capture more heat from sunlight, raising flower temperature above the surroundings.

This natural warming effect also promotes the release and spread of fragrance molecules, effectively attracting insects for pollination even on cold days when insect activity is low, ensuring successful pollination.

Whether reflecting red or blue light, flowers rely on one key pigment: anthocyanin. What secrets lie behind this?



Anthocyanins show different colors under different physiological conditions: blue in alkaline conditions and red in acidic conditions. Plant cell sap is usually acidic, so red flowers are relatively common.

Hydrangea's ability to switch colors flexibly stems from anthocyanin responding to pH changes its unique advantage over single-color flowers.

Another key reason blue-flowered plants successfully attract pollinators is that insects also need anthocyanins

from flowers. Like carotenoids, anthocyanins act as excellent antioxidants in animals, crucial for maintaining metabolic balance and scavenging oxygen free radicals.

To find anthocyanins efficiently, many pollinators have evolved blue-light receptors on their retinas, making them highly sensitive to blue. Thus, they easily spot blue flowers, visit to feed on nectar and obtain anthocyanins, and unintentionally complete pollination.

Take bees as an example: they prefer white flowers most, followed by yellow and blue.

This is another major reason blue-flowered species rank third in the plant kingdom.

Bees likely favor white flowers for more nectar, yellow flowers for more carotenoids, and blue flowers for more anthocyanins.

When blue, hydrangeas usually contain no or very few carotenoids, so they rarely show yellow or mixed yellow-blue hues.

For hydrangeas, one color is enough to attract insects; mixed colors may confuse them and reduce pollination efficiency.

Moreover, complex-colored flowers often appear as simple blended hues to insects, making elaborate colors a disadvantage for pollination.

Hydrangea is a typical blue-flowered plant, and its delphinidin is the key pigment behind its blue color. Many blue-flowered plants contain delphinidin, the essential basis for producing blue blooms.

However, some plants cannot naturally synthesize delphinidin, so they never produce blue flowers no matter how conditions change.

For example, blue roses do not exist in nature precisely because roses lack delphinidin.

Even artificial breeding cannot create natural blue roses, as roses have no genes for delphinidin synthesis.

Many blue flowers sold in the market are actually chemically dyed, not naturally colored.

Many other natural blue-flowered plants exist, such as platycodon, iris, and morning glory, all producing typical blue blooms.

Their color mechanism is similar to hydrangeas in alkaline environments, relying on delphinidin and alkaline cell sap.

Some other plants produce red flowers similar to hydrangeas in acidic conditions. Azalea, for instance, is a typical red-flowered plant; its red color comes from anthocyanins in acidic cell sap.

10

Red Agate of Wolfberries

You read that right: botanically speaking, wolfberry is indeed a fruit. It develops from the ovary of a flower and contains seeds inside.

I once couldn't resist tasting an unripe green wolfberry. Small and entirely green, it hides among lush leaves and is hard to spot unless you look closely.



Unripe wolfberry is hard, neither bitter nor sweet, with only a faint astringent taste. After chewing, it leaves a slight numbing sensation on the tip of the tongue.

When I was little, several wolfberry vines grew by the walls and fields of my hometown. When autumn came, the branches hung heavy with bright red, translucent wolfberries. Pluck one into your mouth: sweet-sour with a light fragrance. It was perhaps the most accessible and unforgettable wild fruit of my childhood.

Plants that produce seeds are called seed plants. A basic task of seed plants is to

disperse their seeds, letting offspring take root and grow elsewhere.

If all seeds piled up together, they would face fierce local competition, even “self-destruction.” Such plants would surely be eliminated in the cruel struggle for survival.

This shows that, for seed plants, seed dispersal is just as important as pollination.

As a typical seed plant, wolfberry has its own unique wisdom for seed dispersal, helping it gain a firm foothold in nature.

Plants use many clever methods to disperse seeds.

Some plants manage to disperse their seeds themselves. For example, when the fruit of the *impatiens* matures, it will suddenly split open, catapult the seeds out, and scatter them onto the surrounding soil.

Some use water currents. Coconuts, for instance, fall into the water when ripe and drift far across the sea, taking root only when they reach suitable shores.

Others rely on wind. The well-known dandelion is a typical example: its seeds drift with the wind and germinate wherever they land.

However, most plants depend on animals for seed dispersal and wolfberry is one of them.

Animals help plants spread seeds in several ways.

Mammals like cats and dogs often pick up spiny seeds (such as cockleburs) as they move, carrying them far away.

But the most common method is for animals to eat the seeds, which pass through the digestive tract and are excreted elsewhere. Birds excel at this.

If insects are the main actors in pollination, birds are the stars of seed dispersal.

Mammals play only a minor role; their presence makes little difference to the overall outcome.

Wolfberry relies almost entirely on birds for seed dispersal. Birds are its key dispersal agents.

During seed dispersal, plants use different color strategies based on seed maturity.

When seeds are unripe, fruits do not want to be eaten, so they stay low-key and hidden.

Once seeds mature, it is time for the fruit to be eaten. It must then stand out and attract birds.

These two survival strategies correspond to different coloring plans.

Unripe fruits are almost always green. Bananas, apples, grapes, and wolfberries all contain large amounts of chlorophyll in their green skin, blending with leaves to hide from birds and foragers.

After all, for a plant, being eaten before seeds mature is reproductively meaningless, it only wastes the chance to reproduce.

To foragers, green is a silent statement: I am not ripe yet. I am not tasty or pleasant to eat. Please return later, when I turn red and fully mature.

Before ripening, a fruit's main task is to protect itself and its seeds, not to advertise.

Many fruits invest heavily before ripening to repel “unwanted eaters,” especially insects. Insects are highly destructive to developing seeds; if seeds are damaged, the plant cannot reproduce.

Although insects are heroes for pollination, helping plants bear fruit, they only cause trouble for seed dispersal and are often seen as pests by farmers.

That is why fruits treat insects very differently from flowers. Insects once warmly welcomed as honored guests by flowers become thieves to be guarded against by fruits.

To repel insects and protect seeds, fruits use a completely new tactic.

They change their taste: making flesh sour, astringent, and unpalatable to insects. Some even contain mild toxins that kill insects that feed on them.

This is the main reason unripe wolfberries taste terrible.

Unripe wolfberries contain small amounts of wolfberry alkaloid, a mild plant toxin that acts as a biochemical weapon against insects. Though not highly toxic to humans, eating too many raw can cause stomach discomfort, nausea and bloating.

That is why almost no one eats green wolfberries directly. People wait until they fully ripen: toxin levels drop, and the taste turns sweet sour.

Once seeds are fully mature, the fruit’s priority immediately shifts to attracting eaters.

Color contrast becomes critical.

Birds rely heavily on color to find fruits. Ripe fruits must stand out from the green background, otherwise they will be hidden by leaves and dispersal efficiency will drop sharply.

As soon as they ripen, fruits carefully “dress up”: turning bright red, fragrant, sweet, and tempting, making mouths water to attract birds.

Wolfberry uses this color strategy perfectly:

- green and low-key before ripening, hiding among leaves for protection;

- bright red once seeds mature, actively drawing birds' attention.

The pigment that gives wolfberry its bright red color is mainly wolfberry red, a carotenoid brighter than lycopene. It makes wolfberries stand out sharply among green leaves, easily spotted by birds.

Birds have evolved red-light receptors, making them highly sensitive to red flowers and fruits. They easily find red wolfberries among green leaves.

This is classic coevolution: birds prefer red fruits, and fruits evolve red appearances. They form a perfect, mutually beneficial partnership, each fulfilling its survival role and continuing life.

Wolfberry simply follows this evolutionary strategy, using its color to successfully attract birds for seed dispersal.

The plump, fleshy wolfberries we eat today are partly products of artificial cultivation.

Wild wolfberries are native to arid regions of northwest China. They are very small, similar to sesame seeds, with thin flesh perfect for birds to swallow whole.



Win-win-cooperation!

The tiny seeds inside have hard coats. When eaten by birds, they are not fully digested and are excreted elsewhere.

In this way, wolfberries complete dispersal and reproduce. Birds gain rich nutrition, especially wolfberry red, creating a win-win relationship.

Clearly, wolfberry and birds share a mutually beneficial symbiosis: wolfberry uses sweet sour fruit to attract birds, which spread its seeds.

This successful partnership allowed wolfberry to spread widely across the arid northwest and gradually expand to other regions.

In fact, many plants use strategies similar to wolfberry to attract bird dispersers, and many birds obtain nutrition from fruits while serving plants.

That is why so many fruits turn red when ripe, most contain carotenoids.

Tomato, a fellow member of the nightshade family like wolfberry, contains large amounts of lycopene, which also gives ripe tomatoes a bright red color.

Tomatoes have a long cultivation history and have been greatly improved to be much larger than wild varieties.

Wolfberry has been cultivated for a relatively short time, and many varieties still retain small, wild type fruit, perfect for birds to swallow whole strong evidence they rely on birds for dispersal.

Peppers, like wolfberries, belong to the nightshade family and use a similar bird-attracting dispersal strategy.

Before seeds ripen, peppers avoid being eaten and stay green. When mature, they turn bright red to attract birds.

Peppers use an even more advanced tactic: they produce large amounts of capsaicin when ripe.

However, capsaicin does not target birds. Birds lack capsaicin receptors in their mouths and are completely unaffected, so they swallow peppers and spread seeds normally.

Capsaicin's real role is to repel mammals, which it strongly irritates and discourages.

Mammals chew food thoroughly and may crush peppers and seeds, destroying reproductive ability. Peppers naturally avoid being eaten by mammals.

Unexpectedly, humans evolved the ability to enjoy capsaicin and widely cultivate peppers for their flavor, an unexpected reward for the pepper's defensive strategy.

Finally, it is worth noting that wolfberry red, like carotenoids and lycopene, has strong antioxidant properties.

It not only nourishes birds and supports health but also helps synthesize feather pigments, making plumage brighter and more attractive for mating and reproduction.

11

Gorgeous Mystery of Beetles

We dare not catch bees, for they sting, and their colors are rather plain. Beetles are different: they have a hard shell, move slowly, and boast striking colors and patterns. They stand out clearly in grass or on tree bark, like tiny ornaments carefully crafted by nature.



We catch beetles with our bare hands, no tools needed. Once we spot a beautiful one, we keep our eyes fixed on it. When it rests on a leaf or stone, we approach quietly from the side.

Sometimes we crouch down, hold our breath, stretch out our thumb and forefinger, and slowly move toward both sides of the beetle. At just the right moment, we gently pinch its shell and hold it in our palm.

After turning to show off to our friends, we gently open our hand and let the beetle crawl away. A faint, fine sheen remains on our fingers, sometimes with a tiny dusting of powder.

Now I know: these are the tiny pits and waxy powder from the beetle's forewings. These fine structures give its shell its distinctive texture.

A beetle's shell is actually its modified forewing, called an elytron. It is hard and protects the delicate hindwings and body beneath. This is why beetles belong to the order Coleoptera.

If the waxy and pigment layers are wiped off, the elytron is a translucent, horn-like structure.

The elytra serve to color the beetle with bright hues and unique patterns, making it look like a moving tiny jewel, hence the name "colorful beetles."

The question is: why do beetles need such brilliant colors and diverse patterns?

To understand beetle colors, we must first understand the structure of the elytra. They contain two key substances: One is chitin, the same material as our fingernails and hair. In beetle elytra, it provides support and protection, making the elytra hard and durable, a typical structural protein.

The other is pigments. All elytra have different types and concentrations of pigments, which produce different colors. Combined with pits and textures on the surface, they form countless unique patterns.



Common pigments in beetle elytra include melanin, carotenoids, and flavonoids. Different combinations and concentrations create black, yellow, red, blue, green, and many other colors.

For example, the common chafer displays dazzling golden yellow thanks to abundant carotenoids in its elytra. The white-spotted longhorn beetle has a black base from melanin, and its striking white spots come from missing pigment or overlapping layers.

Besides pigments, beetles produce color through special elytron structures known as structural colors. These arise from complex microstructures on the elytra, involving optical effects such as reflection, diffraction, and interference.

These colors change with the viewing angle, so they are also called iridescent colors.

The rainbow in dewdrops and the colorful sheen on soap bubbles form by similar principles.

Iridescence on beetle elytra comes from tiny bumps, grooves, or scales. These features are known as iridescent structures.

When pigments and iridescent structures combine, they produce even more stunning mixed colors.

For instance, jewel beetles have a bright green base color from pigments, plus a metallic sheen. As the viewing angle changes, blue, purple, and gold appear, special effects from iridescent structures.

The two effects complement and blend together, dazzling in sunlight as if the elytra are studded with glittering jewels.

Beetles seem dedicated to producing varied colors and patterns through different mechanisms, making them among the most spectacular insects in nature.

For beetles, these colors and patterns are not just for beauty or useless decoration; they have great practical value, falling into these categories:

First: nuptial colors.

This is a vivid term, not meaning beetles “dress up for marriage.” Rather, certain colors and patterns help males and females mate successfully. They are also called mating colors, common in the animal kingdom.

During courtship, males usually seek females. A male’s choice depends largely on the female’s brightness and pattern uniqueness.

Females also judge males by their colors and patterns when choosing a mate.

Beetle elytra display bright colors and patterns in sunlight, signaling health and genetic quality to the opposite sex, with strong attractive power.

In addition, males and females of some species differ greatly in color and pattern, helping them quickly tell each other apart.

For example, male stag beetles have deeper, brighter metallic elytra, while females are duller with simpler patterns.

The logic is simple: quick gender recognition improves mating efficiency. Chasing a same sex partner wastes time and energy.

Thus, patterns can also be a key part of nuptial coloration.

Second: cryptic colors (camouflage).

Some beetles closely match their surroundings in color and pattern, providing excellent camouflage and avoiding predators.

Weevils, for example, are mostly grayish brown with tiny dark spots, nearly identical to bark. When still on a tree, they are hard for birds and lizards to spot.

However, many beetles use colorful elytra and patterns for camouflage. They live among flowers, leaves, and rotting wood, where bright colors and patterns blend in better. The closer the match, the better the camouflage.

This explains why almost no pure black beetles live in flowers: black stands out sharply, making them easy prey.

Some beetles even change color with weather.

In sunny weather, elytra are brighter and patterns sharper. On cloudy, rainy days, colors fade and patterns blur.

These changes help them blend in and avoid detection, also a form of camouflage.

Third: thermoregulatory colors.

Beetles are ectotherms; they cannot maintain a constant body temperature. Higher temperatures boost activity: crawling, flying, and feeding.

To warm up quickly, they absorb heat from sunlight. Different colors absorb light differently: dark colors absorb more heat, light colors reflect more.

Using these differences, beetles flexibly adjust their body temperature to suit the environment.

For example, black velvet chafers lie in the sun on cold mornings, spreading elytra to absorb heat and become active faster.

On hot middays, they hide in shade to avoid overheating.

Some beetles change color with seasons: lighter in summer to reflect heat, darker in winter to absorb it, a classic thermoregulatory strategy.

Fourth: aposematic colors (warning colors).

Many beetles use bright, striking colors and patterns to warn predators: they are toxic or unpalatable. Eating them may cause vomiting, coma, or even death.

Warning colors are usually red, yellow, black, and white, in high-contrast combinations that immediately catch predators' attention.

Some combine colors for extra boldness, like rove beetles: black elytra, bright red abdomen and legs. They do contain toxins that irritate human skin and threaten predators.

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Fifth: mimicry colors.

This strategy is similar to that of toxic mushrooms: beetles mimic the colors and patterns of poisonous species to protect themselves, a smart “borrowed defense.”

For example, harmless darkling beetles mimic toxic rove beetles: black elytra, red abdominal markings. Birds and lizards avoid them, letting the beetles survive.

Sixth: masquerade colors.

Some beetles disguise themselves as other objects, a form of mimicry, like butterflies that imitate objects to hide.

Dung beetles are dark brown, rough, and matte, almost identical to animal dung. When resting on dung, predators barely notice them.

Other beetles look and feel like small pebbles. When still among stones, they blend perfectly and avoid being seen.

Elytron patterns can also be considered masquerade, with some mimicry features.

Mimicry and masquerade often overlap, and beetle patterns are a typical example.

Many beetles have spots or stripes that help camouflage them and also deter predators.

At rest, they tightly close their elytra, fully enclose their body, and blend into the background.

When disturbed, they suddenly open their elytra, revealing bright colors or bold patterns underneath, startling predators and escaping.

Ground beetles, for example, are dark and camouflaged at rest. When alarmed, they quickly open their elytra to show bright red hindwings, scaring predators and buying time to flee.

Some beetles have tiny patterns along the edges of their elytra, with a very different function from central markings.

These small spots do not scare predators, but distract them, protecting vital body parts, like sacrificing a chariot to save the general.

These edge patterns often show damage from birds or ants. The more worn they are, the better they work: they successfully draw attacks to non-vital edges, protecting the core body and helping the beetle survive.

Clearly, beetles are masters of insect color. Nearly every use of color and pattern can be seen in them. Every hue, every stripe, holds wisdom for survival.

This is closely related to their daytime activity, feeding, and mating habits.

If beetles' lifestyle changed, their coloration would change completely.

Moths, for example, use a completely different strategy: they are mostly nocturnal and do not need bright colors to attract mates or warn predators, so they are duller.

Beetles are active during the day and use colors for mating, camouflage, warning, and more. That is why they are brighter, more varied, and more intricately patterned.

12

Metamorphosis of Silkworm Babies

People often call silkworms “caterpillars.” Caterpillars are simply the larvae of insects, some are butterfly larvae, others moth larvae. There are countless kinds, and I have never counted exactly how many.



Not all caterpillars are scary. Often found on mulberry leaves is a plump “caterpillar,” about as thick as a little finger, snow-white and soft. Locally we call it “silkworm baby,” and its scientific name is domestic silkworm (*Bombyx mori*).

Besides being soft and tempting to touch, silkworms are completely harmless. When they grow up, they spin silk and form cocoons. Humans raise them specially to produce the smooth, beautiful silk woven from their threads.

Like other caterpillars, silkworms come in various colors. Snow-white ones are the most common. Colorful silkworms with pale yellow or light green spots are mostly artificially bred varieties and are not poisonous.

The different colors mainly come from their breeding environment and variety, not from toxicity. Almost all silkworms are non-toxic, which is fundamentally different from the bright-colored, poisonous stinging caterpillars.

Overall, insects rely on a “fast-growth” strategy for survival and reproduction. They generally have short lifespans and must produce many offspring quickly, so they win by quantity, laying large numbers of eggs at once.

Although the survival rate of these eggs is very low, probability ensures enough offspring survive to continue the species.

As a result, their eggs are usually tiny and lack enough nutrition for the embryo to develop directly into an adult. A larval stage is necessary for growth.

This is why many insects undergo metamorphosis: from egg to larva, larva to pupa, and finally pupa to adult.

The silkworms we commonly see are simply the larval stage of the domestic silkmoth. It is an essential step in becoming a moth.

Since the larva is only a transitional stage, its main job is simple: eat constantly to gain enough nutrition in the shortest time, laying a solid foundation for later spinning cocoons and developing into an adult. This survival strategy means silkworms cannot grow too large or

take too long to develop. Otherwise, they would become food for other animals before completing metamorphosis.

That is why silkworms are somewhat “picky eaters.” They mainly eat mulberry leaves, and occasionally silkworm bush or elm leaves, which are rich in nutrients and support rapid growth.

Their weight increases extremely quickly. In just half a month, they grow from ant-sized newly hatched silkworms into plump larvae, gaining over a thousand times their original weight, truly the champion “eaters” of the animal world.

Such a heavy body is not suited for flying or fast movement, so silkworms have essentially given up speed as an advantage.

Like adults, they have six true legs. Although they look soft and have many small prolegs on their abdomen, these are false legs. Their main role

is to support the heavy body and grip mulberry leaves; otherwise, silkworms would drag their bellies and crawl very slowly.

Silkworms move in a special way. Their legs are not strong enough to fully support their bodies, so they stay low on leaves, contracting abdominal muscles to move prolegs forward little by little, slowly and gently.

This is a side effect of overeating and being heavy. Such movement cannot be fast, and this directly shapes other behaviors of silkworms.

Limited by speed, silkworms can hardly escape predators and must rely on other self-protection methods.

Newly hatched silkworms are black and tiny like ants. They usually rest on the underside of mulberry leaves, avoiding detection by birds, ladybugs, and other predators. This is an inborn trick to survive their fragile early stage.

Another method is camouflage. Some wild silkworms are light green, almost identical to mulberry leaves. When resting on leaves, predators struggle to tell them apart. They use camouflage to avoid being eaten.

Another common self-protection strategy for silkworms is relying on a protected environment.

Most domestic silkworms are raised by humans in clean, safe trays, far from natural predators. They do not need to avoid danger on their own.

Wild silkworms live in dense mulberry forests. Layers of leaves effectively hide them, lowering the chance of being spotted and creating a relatively safe habitat.

Clearly, hiding and seeking safety are common choices for most silkworms.

Some silkworms upgrade this strategy. As wild silkworms grow, their color gradually changes from light green to yellowish green, always matching mulberry leaves to hide as much as possible.

But in their final stage, just before spinning cocoons, they become fatter and paler, eventually turning milky white. They no longer mimic leaves, because they will soon enclose themselves in cocoons and enter the pupal stage, no longer needing camouflage.

Most domestic silkworms are snow-white. Feeding mainly on mulberry leaves and living in safe, human-raised environments, they do not need camouflage. Their white bodies make it easier for people to observe growth and monitor health.

Furthermore, white silkworms do not need to produce special colored pigments. The saved nutrients go entirely into growth and silk spinning. This simple coloration suits artificial rearing and large scale breeding.

However, some silkworms take a different path, using soft colors to stand out.

Most are artificially bred, non-toxic varieties. Their colors are created by selective breeding for ornamentation, pale yellow, light pink, light green.

Their behavior is almost the same as white silkworms; only their color is special, satisfying human appreciation.

Some plants produce mild toxins to deter plant-eating animals. Silkworms have adapted to these plant juices: they do not get poisoned and instead convert nutrients into energy for growth.

For example, wild silkworms eat slightly toxic silkworm bush leaves and absorb plant pigments for camouflage, including both carotenoids and chlorophyll.

This makes their body color closer to leaves, improving camouflage and survival rate.

Stinging caterpillars are completely different from silkworms. They are typically bright-colored, poisonous, and dangerous to touch.

Snow-white or light-green silkworms are completely non-toxic. Protected either by human care or camouflage, they do not need poison for defense. Saved nutrients support better growth and development.

Generally, wild silkworms living on tall mulberry trees in nature rely more on camouflage.

Those on mountain mulberry trees are mostly light green or yellowish green, blending perfectly with leaves, and they have very low toxicity.



Mulberry branches have dense foliage. After eating one leaf, silkworms do not need to crawl far to another. Thick leaves hide them well from predators.

Since pigments provide full-time protection, silkworms can survive without poison. That is why most wild silkworms are non-toxic.

In sharp contrast, domestic silkworms live in comfortable, safe trays under careful human care. They need no camouflage and no effort to avoid predators.

That is why they are snow-white. They produce no camouflage pigments or toxins. They only need to focus on eating mulberry leaves, growing, spinning silk, and completing their life mission.

13

Seabed Spots of Damselfish

Bright colors are actually common among marine fish, but the relatively plain colors of familiar freshwater fish have obscured this truth.



As a group, coral-reef fish like tropical damselfish are even more colorful than many freshwater species, making them some of the most magnificent small vertebrates in the ocean. They dart among corals like moving colored gems, lighting up the entire underwater world.

Studies show that tropical damselfish have many types of pigment cells: melanophores (black), xanthophores (yellow), erythrophores (red), iridophores (iridescent), as well as leucophores (white) and a few cyanophores (blue).

All these pigment cells attach to the surface of scales and can be freely combined and concentrated according to the environment and physiological state. This allows damselfish to easily display stunning colors: bright red, vivid yellow, deep blue, emerald green, and even mixed patterns, each unique.

Among all pigment cells, melanophores are the most common, containing large amounts of melanin. As a result, many damselfish species are entirely black or have black markings.

Nearly all damselfish have melanophores. Anyone who has observed reef fish will notice that black patterns are a common “decoration.”

Both yellow and red pigment cells are rich in carotenoids, which produce different colors depending on concentration: higher carotenoid levels appear red, lower levels appear yellow.

Fish cannot synthesize carotenoids; they can only obtain them from food.

Tropical damselfish mostly feed on carotenoid-rich plankton and algae, so they readily accumulate carotenoids and display bright red and yellow colors.

Blue pigment cells are relatively rare. Most blue colors in damselfish do not come from blue cells, but from a combination of iridophores and other pigments. This blue is a perfect adaptation to the light environment of coral reefs.

The iridophores of tropical damselfish contain large amounts of guanine crystals.

Guanine is abundant in bird droppings, so it is also called “bird dung pigment.” It refracts and reflects scattered underwater light, giving damselfish a silvery-white luster, and some species even have a faint metallic sheen.

Leucophores are similar to iridophores in using purine crystals for color, but they only produce white or silvery-white, without the iridescent sparkle. They are mostly used to contrast with other pigments and create sharp body color patterns.

The body color of the common clown damselfish results from the combined action of pigment cells: black markings, white stripes, and a bright red or yellow base. Some individuals also have an iridescent sheen.

We tend to focus on its bright base and distinctive patterns, so it always strikes us as strikingly colorful.

In fact, different damselfish species have different color combinations, all masterpieces of random pigment cell arrangement.

Why are most tropical damselfish so brightly colored?

Without question, their coloration is the result of both natural selection and sexual selection: to adapt to their environment and to attract mates.

Damselfish are common in tropical coral reefs, and their ancestors were likely small marine fish with simple patterns.

Coral reefs are complex and food-rich, so brightly colored individuals stand out and succeed in courtship. Over time, vivid colors became strengthened and fixed.

However, no matter how damselfish colors change, they only come from random combinations and concentration adjustments of a few cell types. Natural selection did not create new pigment cells, only optimized existing combinations.

Many brightly colored damselfish species still live in tropical coral reefs today. The most famous include the blue devil damselfish, yellowtail damselfish, and red spot damselfish.

The blue devil damselfish is deep blue all over with a pale silvery belly, one of the most common reef damselfish, living in groups among coral branches.

The yellowtail damselfish has a dark gray back, silvery belly, and a striking orange-yellow tail that looks like a streak of sunlight as it swims.

The red-spot damselfish has irregular red patches over a silvery-white base, matching the colors of corals beautifully.

These damselfish maintain bright colors because coral reefs have clean water, abundant light, and plentiful plankton and algae, providing ample food and a relatively safe habitat.

Damselfish are omnivorous, feeding mainly on plankton and algae, as well as small aquatic insects and coral larvae.

These habits make the brilliant colors of tropical damselfish possible.

Damselfish usually live in shallow coral reefs with abundant light. All wavelengths penetrate the water, especially blue and green, which travel widely in shallow zones.

If damselfish reflect specific wavelengths and show bright colors, they can signal effectively and attract mates.



For this reason, damselfish evolved bright colors as nuptial colors. The brighter the body and sharper the patterns, the higher the carotenoid level, indicating better health, stronger foraging ability, and higher quality offspring.

Both males and females use bright colors to show off their physical condition. Genes for vivid color spread through the population and became fixed in the reef environment.

Some damselfish do not need to produce excess melanin or consume large amounts of tyrosine, saving nutrients and growing faster. This gives them a local competitive advantage in the small coral reef ecosystem.

However, while using bright colors to attract mates, damselfish must solve two key problems: avoiding being eaten, and not startling their prey.

Coincidentally, both issues are perfectly solved in their habitat: coral reefs.

Coral reefs have a complex terrain with intertwined branches, creating countless

natural hiding places.

Although damselfish are brightly colored and active in shallow water, dense corals provide excellent cover. When in danger, they quickly dart into branches to escape predators.

Moreover, most reef predators (such as groupers and moray eels) hunt by ambush and are not sensitive to bright colors, so damselfish rarely worry about being preyed upon.

The chance of startling prey is tiny. Damselfish feed mainly on plankton, algae, and small invertebrates, most of which lack advanced vision and cannot respond quickly to bright colors. This favors the evolution of vivid coloration.

Besides tropical damselfish, many other colorful marine fish exist, especially in shallow coral reefs. The underwater “colorful forest” of corals provides a fantastic ecological backdrop.

These colorful fish are like butterflies on land. They evolved stunning colors for camouflage, mimicry, warning, and mating. Examples include clownfish, butterflyfish, and angelfish, all captivating humans and kept as popular aquarium pets.

In the deep sea, however, brightly colored fish are rare.

Most deep sea fish evolved plain colors for safety. The deep sea cod, which we occasionally encounter, is a typical example.

Although it is a bony fish like tropical damselfish, it is dull gray and well-hidden in the dark deep sea.

This low-key survival strategy is common among deep sea fish and may be one reason they can survive long in the dangerous depths.

14

Gorgeous Plumage of Roosters

Why are roosters' feathers so beautiful?

In fact, this is a profound question that puzzled zoologists for a very long time.

With their bright, elaborate feathers, roosters look like stars on stage in fancy costumes. Don't they fear danger because of this?

Even if not hunted by humans, they could become prey for wild animals. Yet they still strut about proudly every day, showing off their splendid plumage.

This is not unique to chickens. Many other birds behave similarly, such as peacocks and golden pheasants: males are usually brightly colored and showy, while females are plain and low-key. This striking difference in appearance between males and females is called sexual dimorphism.



The main reason is closely related to their mating system, which reveals the unique survival and reproductive wisdom of birds.

The term “mating system” is not exclusive to humans; it also describes the mating habits and family structures of animals.

Zoologists long ago discovered a pattern: generally, brightly colored males only mate with females. They do not incubate eggs or care for their young, they are classic “playboys.”

They do not form stable pairs. For this reason, these “playboys” have only one core task: to attract females and win as many mating opportunities as possible.

Roosters use this typical playboy strategy and face intense male competition every day.

There are many forms of competition; the most direct and fierce is fighting.

To gain an advantage and win fights, roosters evolved sharp claws and beaks. Almost any time two roosters meet, they will fight to establish dominance.

This is why cockfighting was once popular: roosters are naturally aggressive, and fighting is deeply rooted in their survival instinct.

Besides this, roosters have a prominent comb.

Few birds have such a large, prominent comb. This relates to their ancestors: chickens descended from tropical jungle fowl that lived in warm forests. The comb is an important heat-loss organ, helping them cool down. Without it, high body temperature could weaken them or even be fatal.

The comb is rich in capillaries and often bright red from blood flow. Over time, it became a male symbol and a key tool for attracting females.

When a rooster matures, male hormones make its comb larger and brighter. It is like a “health advertisement” to other roosters and hens.

After all, only a strong, well-nourished rooster can grow such a large, bright comb. Weak roosters usually have small, pale combs.

During fights, the comb also confuses opponents, who may mistake it for a red worm.

Once the rival focuses on the comb, the rooster can counterattack and turn the fight around.

In this way, the comb became a “hidden weapon” for roosters in male competition: practical and impressive.

Besides the comb and fighting, roosters have another special way to compete. Do you know what it is?

It is crowing.

Roosters love to crow. In fact, they are declaring their strength and defending their territory. The louder and longer the crow, the stronger and healthier the rooster, and the more attractive it is to hens.

That is why roosters love to crow early in the morning: the air is quiet, and sound travels farther and clearer.

The earlier they crow, the less noise interference, and the better they show off and attract mates.

This creates a vicious cycle among roosters: if you crow earlier than me, I will crow even earlier and louder.

This is why roosters in the countryside often start crowing one after another around 4 a.m., breaking the morning silence.

Luckily, we are used to this sound. Otherwise, roosters would not crow so “arrogantly.”

However, fighting is costly: it can leave both sides injured or even dead. Frequent fighting is clearly not sustainable.

Crowing is limited by time: during the noisy day, sound is easily drowned out. A rooster might try hard but attract almost no hens.

So roosters gradually evolved a safer, more efficient, long-lasting way to compete: showing off their gorgeous feathers.

Unlike fish, birds do not have many types of pigment cells, they only have melanophores.

To produce colors other than black or brown, birds had to develop another way besides simple pigment.

One solution was to “learn from plants” and deposit pigments in feathers through biochemical processes. Among these, carotenoids produce the brightest, most vivid colors.

With the right concentration of carotenoids, feathers turn bright red, yellow, or purple.

The better nourished a bird is, the more carotenoids it stores in its feathers, and the brighter its colors. This indirectly shows how healthy and strong it is.

To some extent, the brightness of feathers serves as an important clue for females to judge a male’s health.

Another way birds produce color is through structural colors from tiny feather structures, similar to the iridophores in fish.

The difference is that in birds, these structures are on the feather surface, not inside cells. They create brilliant colors through reflection and diffraction of light. This is why some birds shine so brightly and it is also why rooster feathers are so magnificent.



By combining pigment deposition and structural iridescence, roosters display stunning, unique feathers and patterns.

The biggest advantage of splendid feathers is that once grown, they can be worn all the time. No risky fighting, no tiring crowing, they constantly show strength and compete with other males.

Furthermore, feather color cannot be faked. It is an “honest signal” that does not deceive hens, making it a key factor for judging a rooster’s quality.

Notably, producing bright pigments uses a lot of nutrients. Hens evolved plain feathers because they need to save nutrients for laying eggs and raising chicks, rather than wasting them on fancy plumage like roosters.

Besides, after laying eggs, hens must sit quietly on the nest for long periods.

In the wild, bright, conspicuous feathers would make them easy prey. The result would be “both hen and eggs lost”, they would die, and so would their offspring.

Therefore, hens must be plain and low-key, never showy like roosters. This is their survival and reproductive strategy.

Roosters have none of these worries. They do not incubate eggs or care for chicks.

After mating with one hen, a rooster immediately turns around, uses its bright feathers to attract other hens, and seeks more chances to reproduce.

This strategy has worked for thousands of years and remains the key to roosters' success in male competition.

Many birds, like roosters, use body color to show strength and attract mates. The most impressive example is the male peacock.

Its magnificent tail does not keep it warm, help it fly, or even move well. Its only function is to show physical and genetic superiority to other peacocks and peahens.

It displays to both males and females. To other males, the message is: "Look how splendid my feathers are, I am stronger and have better genes. Do not compete with me, or you will be humiliated."

To females, it says: "Look how striking I am. I am the best male. Mating with me is the right choice, we will have healthy, brilliant offspring."

And this is exactly what roosters want to tell hens: to prove their excellence with gorgeous feathers, win mating opportunities in the most direct way, and pass on their genes.

15

Crest Secret of Hoopoes

Unlike woodpeckers that drum on tree trunks or sparrows that chirp nonstop, hoopoes communicate mainly with sharp, short “coo-coo” calls.

Their calls are clear and pleasant, with even intervals, carrying far through woods or grasslands, loud enough for other hoopoes to hear clearly.

If both sides are willing, they will meet in secret deep in grass or beside tree trunks.

When foraging on the ground, hoopoes move softly and slowly, pausing now and then to listen and peer closely at the soil.

This behavior frightens earthworms and mole crickets underground, which either burrow deeper or freeze completely.

They avoid making noise to hide, but it is also a helpless resignation to fate.



This raises a question: since hoopoes feed mainly on the ground, often in open grass and fields where they are easily seen, why do they dare to have such bright feathers?

Wouldn't that make them even more noticeable?

After all, hoopoes are not large, similar in size to woodpeckers and have many predators: sparrowhawks, goshawks, stealthy weasels, and snakes. Aren't they afraid of being eaten?

First, a foraging hoopoe already reveals its position, so its bright feathers do not add much extra risk.

Danger still exists, but hoopoes have their own solutions.

They do not stay long in one spot. They peck and search as they walk, moving on immediately if no food is found.

Even if predators are drawn by their movement or sound, they usually find nothing.

Once they find insects, hoopoes finish feeding within minutes, then fly quickly to nearby branches to rest and watch, leaving only disturbed soil for disappointed predators.

A hoopoe's second strategy is cooperation with sparrows.

Sparrows are common small birds. Though sometimes annoying, they are extremely alert. They feed on branches or the ground and love to "scavenge" behind hoopoes.

When hoopoes peck at soil for insects, they uncover tiny eggs, larvae, and disturb other bugs to the surface, all favorite foods of sparrows.

Since food comes easily, sparrows are happy to follow.

Moreover, when hoopoes nest in tree hollows, sparrows build nests nearby. They fly together inseparably, forming a wonderful symbiotic relationship.

Hoopoes rarely call for long, but sparrows are constant chatterboxes.

Yet one thing silences them instantly: the appearance of a sparrowhawk or other predator nearby.

When sparrows fall silent and hide in thick branches, they send a silent warning to hoopoes.

Sensing something wrong, hoopoes become alert at once, flying quickly to high branches or darting into nearby hollows to escape.

A flock of sparrows acts like noisy but highly sensitive bodyguards, greatly reducing the hoopoe's risk.

The hoopoe's third defense is its unique self-defense weapon.

Hoopoes look gentle and beautiful, but they are not easy targets. Their most powerful defense is spraying foul smelling feces.

When disturbed by predators or people approaching their nest, hoopoes shoot black, rotten smelling feces from their rear. The stench is so strong it drives predators and humans away.

In some regions, they are called "stinky hoopoe" for this reason and this gives them the confidence to have bright colors.

Even against fierce predators like sparrowhawks, hoopoes spray foul feces to fight back, rather than surrender.

Combined with their quick, agile movements, few predators risk attacking a hoopoe unless desperate.

In short, hoopoes can keep themselves fairly safe while active outside.

More importantly, they nest mainly in tree hollow ,often old abandoned woodpecker holes or natural hollows,much safer than nests on branches.

Even if predators find the nest, hoopoes guard the entrance and spray feces to defend themselves. Thus, hoopoes are fully confident in showing off their beautiful feathers.

Confidence is one thing; the motivation to display bright feathers is another.

And hoopoes do have this motivation. What is the secret behind it?

Like woodpeckers, hoopoes practice serial monogamy: they stay with one partner during a breeding season, building nests, incubating eggs, and raising young together.

But in the next season, they usually change partners and form new families.

Because of this, both male and female hoopoes need to attract mates, so both have reason to evolve bright plumage.

Unlike woodpeckers, hoopoes feed on the ground and are less powerful. So their feathers, though beautiful, are slightly more understated.

There are not many species of hoopoe, but each has distinctive feather colors and similar behavior.

All have a characteristic crest, which opens into a lovely fan shape.

The crest is not just decoration; it shows their mood. It fully opens when excited or alert, and gently closes when relaxed.

The common hoopoe in my hometown is mostly tan, with black-and-white patterns on its back and wings. Its crest is reddish-brown with black tips, very eye-catching.

The hoopoe's beak is long, thin, and curved, adapted for digging on the ground. It easily reaches into soil and stone cracks to catch prey.

Their eyesight and hearing are sharp; they can accurately detect small insects several centimeters underground.

All hoopoes have bright feathers, and the evolutionary logic behind them is much the same.

Some scholars believe that birds with safer nests tend to evolve brighter colors.

Take the woodpecker: similar in shape to the hoopoe, also brightly colored, serially monogamous, and nesting in tree hollows.



Woodpeckers often excavate their own hollows, making their nests even safer than hoopoes'.

Thus, woodpeckers can safely evolve beautiful colors, even more brilliant than hoopoes’.

This is because woodpeckers feed mainly on tree trunks, rarely going to the ground, so they are less likely to be spotted by predators.

They are also stronger fighters, defending themselves with powerful neck muscles and sharp beaks.

For these reasons, woodpeckers’ colors, though equally bright, are bolder than hoopoes’, making them among the most noticeable birds in the woods.

16

Night Glow of Fireflies

How did fireflies get their name?

Fireflies are small and delicate, mostly dark brown. Their most special feature is the soft glow from the tip of their abdomen, which can be yellow, green, or pale yellow. Flying at night, they look like lively little lanterns, hence the name “firefly.”



Of course, some fireflies glow brighter or dimmer, and some have light-colored spots on their elytra (wing covers). They come in many different forms.

The brightness of their light also varies: some glow brightly and stand out in the dark, while others glow softly and are barely visible even in daylight.

“Firefly” is a general name, used for all insects that commonly produce light.

Because their light is unique and beautiful to watch at night, fireflies are easily remembered. They have become the most iconic little insect of childhood summer nights, holding precious memories for many people.

Fireflies are not only beautiful but also fun to observe.

We often gently hold a firefly in our palm and watch its abdomen flash on and off, as if holding a tiny twinkling star.

If we blow gently, the firefly immediately stops glowing and may even crawl quickly away, as if frightened by the sudden airflow.

This is probably because fireflies have sensitive touch and sight. They react instinctively to sudden air movement and outside disturbance to protect themselves.

We often chase fireflies at night but rarely keep them trapped. Watching them fly and glow freely in the night sky is more enjoyable than holding them tightly, and lets us feel the beauty of nature.

Besides avoiding disturbance, fireflies also track prey by following scent clues.

Their main food is snails and slugs, which are pests that damage crops and plants by eating roots, stems, and leaves, causing poor growth, wilting, and rot.

Where snails and slugs appear in grass or near walls, nearby plants usually show damaged leaves and rotting roots.

Firefly larvae follow these traces to find prey, feeding on their body fluids and helping eliminate pests. For this reason, fireflies have long been considered beneficial insects.

That is why we only chase and watch them at night, rarely harming these lovely “little lanterns.”

Unlike butterflies, fireflies, like ladybugs, belong to the order Coleoptera. They have a hard outer shell covering their wings, protecting the delicate flight wings like a case. So fireflies are actually beetles.

Because of these hard wing covers, fireflies do not display color on their flight

wings, but on their elytra and abdomen.

Compared to soft wings, elytra are harder and better protect the body from harm. The abdomen is responsible for glowing and auxiliary coloration. This is the biggest difference between fireflies and ladybugs: ladybugs mainly show colors on their wing covers, while fireflies' main feature is the glow from their abdomen.

Firefly elytra usually contain a lot of melanin, which is why they appear dark brown or blackish-brown.

The glow from the abdomen comes from a chemical reaction between luciferin and luciferase inside their bodies, not from pigments. This is what makes firefly light unique.

Different firefly species have different colors and light patterns. Generally, their elytra are dark, and their abdominal glows vary in color. These distinct features are important for identifying different firefly species.

This is another important function of animal coloration (including light production): species recognition.

Animals that look similar can tell if another is the same species by different wing-cover patterns and glow colors.

Mating between different species is risky: they cannot produce offspring, and may even fight.

For short-lived fireflies (adults live only a few days), such waste is completely pointless.

Therefore, species recognition plays an irreplaceable role in both the survival competition and reproduction of fireflies.

Besides this, the color of fireflies' elytra and their abdominal glow are affected by many factors. The most important is that fireflies use their unique light as a warning color and signal color.

Yes, this small, lovely glowing creature uses its light to scare predators and send messages.

Otherwise, dark brown fireflies resting on grass or leaves would be inconspicuous to nocturnal predators, but their glow would give away their position and increase the risk of attack.

But fireflies have a special trick against predators: they produce mild toxins to protect themselves.

These toxins are stored in their body fluids and have a faint unpleasant smell, acting as a “biochemical weapon” against birds, spiders, and other predators.

There is a clear pattern: the brighter and more unique a firefly’s glow, the higher the level of toxins in its body.

Any predator thinking of attacking such a firefly must think twice to avoid being poisoned.

In late spring and early summer, more fireflies glow dimly.

As temperatures rise and nights grow darker, the number of brightly glowing fireflies gradually increases.

In autumn, as temperatures drop and nights shorten, dimly glowing fireflies become more numerous again.

This does not mean glow brightness simply corresponds to temperature. After all, fireflies are mainly active at night and hide under grass or leaves during the day, rarely exposed directly to sunlight.

Changes in their color and glow actually strengthen self-protection and the efficiency of signaling.

Night brightness and grass density differ by season. Fireflies adjust their glow brightness and elytra color accordingly to adapt to the environment and stay safe.

For example, on brighter autumn nights when grass withers, fireflies glow dimmer to avoid standing out and being spotted by predators.

On dark summer nights with thick grass, a bright glow confuses predators and helps

others of the same species find each other quickly, improving mating and survival efficiency.

Because color and glow are so important, fireflies pay close attention to each other's glow color and brightness when mating.

In this sense, firefly glow also acts as a nuptial color. It replaces the color-based mating choice used by ladybugs, becoming the key to attracting mates and reproducing.

Generally, in spring, males with yellowish glows are more popular with females.

In summer, however, males with greenish glows are preferred.

This matches the seasonal changes in firefly glow. Only individuals with glow traits favored by their own species get more mating opportunities and become more numerous.

Fireflies with glow colors and brightness no one likes will be eliminated by natural selection, unable to reproduce, and gradually disappear from the population.

Few people notice that fireflies have a famous relative: the seven-spot ladybug.

Both belong to the order Coleoptera and the suborder Polyphaga.

This means most fireflies, like ladybugs, are carnivorous. The difference is that fireflies are active at night, while ladybugs are active during the day. Their behaviors are very different, and each has developed its own unique way of living.

The seven-spot ladybug is also a beneficial insect. Both adults and larvae feed only on aphids and other crop-damaging pests, making them very helpful for agriculture.

Adult flying ladybugs live much longer than fireflies, usually

several months. Their main tasks are feeding, mating, and reproducing.

Since they are active during the day, ladybugs rely heavily on body color. They use bright colors and distinctive spots for species recognition, warning predators, and mating, unlike fireflies, which send signals through light.



Most of us only remember the bright wing covers and spots of ladybugs, and rarely think about whether they can glow.

In fact, they cannot glow. Their wing covers are brightly colored, typically red with black spots or yellow with black spots. These bright colors help them attract mates and scare predators effectively in daylight.

Their bright wing covers also let others of their kind recognize them quickly on green leaves, helping them win mates, mate successfully, and continue their species.

When it comes to color expression, fish are just as impressive as insects, or even more so. Goldfish are a brilliant example of this.

In addition, fireflies' color and glow have other supplementary functions.

For example, as seasons change, their glow brightness shifts with temperature and night light levels. This helps them adapt better to the environment and improve survival and reproduction efficiency, an ability developed by fireflies through long-term natural selection.

17

Color Change of Tree Frogs

Tree frogs are completely different from their larval form, tadpoles.

Tadpoles rely on color differences between their belly and back to hide in water.

But tree frogs, which live in trees their entire lives, usually climb or crouch on leaves, with their bellies pressed tightly against the surface, almost never exposed.



From an energy allocation perspective, producing pigments on the belly is simply a waste. Keeping the belly pale white or light yellow is a more economical and efficient evolutionary strategy.

This raises a question: why do their backs come in so many colors and change flexibly?

Tree frogs are amphibians. Like ordinary frogs, they can lay eggs and reproduce in

water and live on land (mainly in trees).

When active in water, tree frogs breathe partly through their skin. Their skin is therefore thinner and smoother than that of ordinary frogs, with no hair or scales, and can even secrete a thin layer of mucus.

This mucus keeps the skin moist for breathing and improves grip while climbing, allowing them to stick firmly to leaves and branches.

Because of this, pigment cells in their skin can show colors directly without obstruction, efficiently forming protective coloration that blends with leaves and branches.

They can even adjust body color rapidly according to the environment, giving them better camouflage than ordinary frogs.

Tree frog skin also has three layers of pigment cells, with distribution and function basically the same as in ordinary frogs.

The bottom layer consists of melanophores, which make the skin black or dark brown.

The middle layer has iridophores, which produce complex colors using purine crystals inside the cells, especially bright green and sky blue.

The top layer has xanthophores, which filter blue light reflected by iridophores and mix it with their own yellow pigment, creating various shades of green.

This is the most common and classic body color of tree frogs.

Therefore, the green color of tree frogs is not from chlorophyll, but a combined effect of iridophores and xanthophores.

If a tree frog lacks the upper xanthophores, it becomes transparent blue-green, like a delicate, see through leaf, very distinctive.

Tree frogs come in many colors, but green is the main tone: bright green, light green, dark green, etc. They often have brown or yellow patterns.

They live their entire lives on branches and leaves in tropical or subtropical forests

and must closely match the surrounding colors to survive.

For better concealment, their backs have irregular patterns, some like leaf veins, some like branch textures, as if wearing a custom camouflage suit.

Hidden among leaves, they are hard for humans to see, and even harder for insect prey to notice. This helps with both hunting and avoiding danger.

A tree frog's "camouflage suit" serves two main purposes: to deceive prey and to deceive predators.

Tree frog predators include snakes, birds, and small mammals; humans are not currently a major threat.



Can't see me!

These predators have color vision and can see the tree frogs' bright colors.

But when a tree frog presses tightly against a green leaf and even adjusts its color to match perfectly, it achieves excellent concealment.

This fools insects, letting it approach quietly to hunt, and also fools predators to avoid attack, two advantages at once.

This is the fundamental reason green is their main color.

The red-eyed tree frog is a typical tree frog with two famous biological features.

First, it is strikingly colorful: bright green body, pale yellow belly, bright red eyes, and orange webbing between toes, making it highly visible in the forest.

Second, its skin contains mild toxins that defend against predators.

The perfect combination provides a strong warning to predators, and its bright colors are classic aposematism (warning coloration).

Tropical rainforests are home to birds and snakes. Tree frogs moving among branches face higher exposure risk than ground dwelling frogs.

If red-eyed tree frogs could not deter predators, they would have gone extinct long ago.

Today, red-eyed tree frogs remain common in rainforests, proving their warning strategy is an unprecedented success.

Meanwhile, tree frogs do not only hide passively. Some take a bold approach and use powerful toxins to protect themselves.

Many toxic tree frogs live in rainforests. Besides the red-eyed tree frog, the most famous is the blue poison dart frog (a type of tree frog). It is extremely toxic, even dangerous to humans, and one of the most dangerous amphibians in nature.

Why do these tree frogs need toxins for self-defense, while ordinary tree frogs do not?

This is closely related to the special ecological environment of tropical rainforests.

In rainforests, most tree frogs live high up on branches and leaves. Though leaves are dense, gaps between branches are large, making tree frogs easily exposed when moving.

Leaves also vary in color and shade of green. Camouflage alone cannot hide them all the time, so its protective effect is limited.

Under these conditions, they no longer rely only on hiding, but actively announce themselves with warning colors.

“I am here, but I am highly poisonous. Come eat me if you dare.” This directly deters predators.

Studies show that the toxicity of poisonous tree frogs is directly related to how bright their colors are: the stronger the poison, the more brilliant the colors.

The blue poison dart frog, for example, is bright blue with black patterns, easily recognizable, and its venom can kill predators quickly.

Predators must stay highly alert to these bright frogs, remember their appearance, and avoid attacking them.

Reckless predators that attack blindly out of hunger have long been eliminated by natural selection, becoming dust in the forest, unremembered.

Some tree frogs are not poisonous at all, yet have equally bright skin. They are mimicking poisonous tree frogs to deceive predators and protect themselves.

This is a dangerous survival game. If predators see through the disguise, the frogs face certain death.

For example, some non-toxic tree frogs mimic the red-eyed tree frog: bright green body, bright red eyes. This disguise confuses predators into thinking they are poisonous and keeps them away.

However, predators face a dilemma: they cannot tell if a brightly colored tree frog is poisonous.

If it is harmless, eating it fills the stomach; but if it is poisonous, there is no second chance.

Predators also have no interest in trial and error. They cannot taste every kind of tree frog to pick out non-toxic ones.

The safest strategy is to avoid all tree frogs with dangerous (bright, striking) colors.

This is the main reason non-toxic tree frogs can survive by mimicking poisonous ones.

Besides camouflage and warning, tree frog skin also regulates body temperature, more effectively than ordinary frogs, another key adaptation for living in trees.

The cytoplasm in tree frog pigment cells flows rapidly. This flow can spread pigment granules throughout the cell or concentrate them in the center.

Depending on how concentrated the pigments are, the cells show different shades.

If pigments spread under the cell membrane, the cell appears dark.

If pigments cluster in the center, the cell looks pale from outside.

These changes in pigment distribution cause obvious, rapid color shifts in the frog's skin.

This color change is faster and more obvious than in ordinary frogs, giving tree frogs stronger environmental adaptability.

Furthermore, pigment distribution is easily affected by external light and temperature.

When outside temperature rises, tree frog skin becomes lighter, reflecting more sunlight and preventing overheating.

When temperature drops, skin darkens to absorb more sunlight, warming the body quickly to maintain normal activity.

Therefore, tree frog body color is always changing. They are cold-blooded (ectothermic) animals and cannot regulate body temperature on their own.

Heat from sunlight is precious survival energy and must not be wasted.

Tree frogs change color more noticeably than ordinary frogs: for example, from bright green to pale yellow, or dark green to brown.

They can even adjust pattern shades to match leaves, earning them the title “masters of camouflage in nature.”

This interesting color-changing mechanism is similar to that of chameleons.

Chameleons simply have more pigment types, allowing more dramatic changes.

Tree frog color change, however, is more focused on blending into the environment, with the core goal of hiding and surviving.

Strangely, toads close relatives of tree frogs, survive well in nature without changing color.

This is because they have their own unique way of surviving.

Toads have rough, thick skin that secretes large amounts of toxic mucus, enough to deter predators.

Their body color is mostly dull brown, which already hides them well among soil and rocks. They do not need color changes to adapt.

This survival strategy has earned them a stable place in nature.

18

Camouflage of Nightjars

The most obvious biological characteristic of nightjars is that they are nocturnal birds, feeding mainly on small nocturnal insects such as flying bugs and moths.

This unique lifestyle directly shaped their other physical traits and largely determined their feather colors and patterns, as a result of long-term adaptation to the natural environment.



To adapt to hunting at night, nightjars must minimize the noise produced during flight.

Their main prey are flying insects and moths, have extremely sensitive hearing. Even the slightest airflow noise is enough to make them flee quickly, causing the nightjar to fail.

To achieve silent flight, nightjar feathers have evolved to be soft and dense, with

fine, thread like tips, feeling like fluffy cotton.

This structure greatly reduces airflow friction, allowing nightjars to glide silently through the night sky and steadily track flying prey without frequent wing flapping.

Nightjars also have very special wings: long, narrow, and pointed, with neatly arranged feathers and serrated edges.

This special wing structure effectively breaks up airflow during flight, further reducing noise and making their flight more concealed.

The sound frequency produced by flying nightjars is extremely low—too low for most insects and small mammals to detect.

This is how nightjars can approach prey silently, launch surprise attacks, and strike successfully.

To achieve a lethal strike, nightjars must also enhance their visual positioning ability.

Their eyes are highly sensitive to light. Even faint moonlight or starlight allows them to clearly see small flying prey and accurately track their paths.

To improve precision, their eyes are not on the sides of the head like most birds, but face slightly forward.

Although not as forward facing as owls' eyes, this arrangement still provides some stereoscopic vision, helping to lock onto fast-flying insects and ensure hunting success.

Furthermore, nightjars have greatly strengthened their auditory system to suit hunting in dark nighttime conditions.

Biologically, nightjars belong to the order Caprimulgiformes, family Caprimulgidae. Their specialized auditory system is a classic example of adaptive evolution, with every structure designed for nocturnal life.



To collect more sound waves in darkness, nightjars' ears are hidden under thick feathers. They lack owl-like ear tufts, but have wide ear openings that are slightly asymmetrical on the left and right.

This special ear structure uses the time difference of sound reaching both ears to quickly determine direction and distance, a typical auditory adaptation in nocturnal birds.

In addition, many fine soft feathers on their face form a small facial disc that helps absorb sound waves and further improve hearing.

Their ear ossicles are well-developed and amplify faint airborne sounds, allowing them to clearly detect the tiny wingbeats of insects and greatly increase auditory sensitivity.

Combined, these traits make nightjars look somewhat like owls, especially their small facial disc and nocturnal habits. This is a typical case of convergent evolution.

Different organisms gradually evolve similar structures to adapt to similar environments.

In fact, although both are nocturnal, nightjars and owls belong to different orders and are not closely related. Their similar forms are only a result of environmental adaptation.

To adjust their head flexibly, collect sound from all directions, and detect prey and predators in time, nightjars can rotate their heads about 180 degrees.

Though less flexible than owls' 270 degree rotation, this allows full surveillance of air and ground without missing potential signals.

Even more remarkably, their auditory system can automatically filter out their own wing noise and wind during flight, focusing only on the faint sounds of insect wings.

This "filtering" function greatly improves their nocturnal hunting efficiency by reducing irrelevant interference.

While strengthening hearing and night vision for nocturnal life, nightjars have had to give up some other abilities.

Because night light is too dim to distinguish colors, nightjars have lost color vision over time. Like owls, they are color-blind.

Their world consists only of black, white, and shades of gray.

Since they cannot see colors, they cannot notice color differences in the feathers of potential mates.

Although nightjars are monogamous and need mates to reproduce, neither males nor females have evolved bright, showy feathers.

Bright colors would not be recognized and would only increase the risk of being spotted by predators.

Biologically, nightjar feathers are rich in barbules, lack prominent shafts, and are soft and fluffy. This structure aids silent flight and provides good insulation.

Their brown markings are formed by melanin and brown pigments, a classic biological example of cryptic coloration.

Nightjars are overall dull brown, covered with varying black and gray patterns—all for better concealment.

Their belly patterns are finer, helping conceal them both while hunting and resting, serving two purposes at once.

Because nightjars fly swiftly and are rarely attacked by predators, their nests are usually very simple. Many do not build nests at all.

They lay eggs directly on leaf litter, in rock crevices, or on horizontal tree branches.

After laying eggs, both parents share incubation and care, raising chicks until they can fly and hunt independently.

There are many species of nightjars, but most share a similar lifestyle, feeding mainly on nocturnal flying insects.

Although their colors and patterns differ slightly, all follow the core principle of concealment. No nightjar has bright, showy plumage.

For these nocturnal birds, hiding and hunting successfully are the essential needs for survival.

From the nightjar's habits, we can see that many birds are monogamous, or at least serially monogamous, closely related to their reproductive style.

This is especially true for altricial birds, whose hatchlings are very weak, unable to open their eyes or move, and only beg for food.

They require joint care from both parents to grow healthily and survive.

In addition, safety, food, and environment all affect bird coloration. These factors interact, resulting in the rich, diverse colors and patterns of birds.

Unlike birds, most mammals are not monogamous. Many are polygynous: one male mates with multiple females to reproduce.

Others are promiscuous, with multiple males and females mating randomly.

Logically, such complex mating systems might seem to require complex colors and patterns to attract mates and recognize peers.

Yet mammal coloration is relatively plain, cannot compare with birds, fish, or insects like butterflies.

This phenomenon is closely linked to their evolutionary path and lifestyle.

Plain Fur of Hamsters

The reason hamsters are cute is quite simple.

They are small rodents, smaller than rabbits, with round bodies, round eyes, and short ears, all features that hit humans' "cute buttons" and easily arouse a desire to protect them.



Yet although they look gentle, lovely, and suitable as pets, they are actually hard to keep healthy in the long term and the reason is simple.

Cats and dogs are popular because they took part in human evolution, interacting closely with people early on and gradually forming an interdependent, companionable relationship.

Hamsters are different. The essential difference is that hamsters are typical herbivorous rodents, feeding mainly on grains, seeds, and nuts. This trait fundamentally determines their habits and even indirectly shapes their fur color.

Naturally, the more grains and nuts hamsters eat, the more waste their metabolism produces.

To lighten their body weight and move or escape easily in narrow burrows, hamsters have developed a habit of storing food and defecating while eating.

Their cheek pouches are highly developed and can store up to half their body weight in food, but this also makes them defecate frequently and very hard to clean, the key reason they are difficult to keep healthily long-term.

In addition, hamster urine has a strong odor, and they are highly territorial, marking their area with urine. Even diligent owners struggle to completely remove the smell.

In contrast, carnivores need little food to meet their needs, and their waste is less problematic. Humans as “poop-scoopers” can live with them easily with a little effort.

Another difficulty for hamsters is that they are at the bottom of the food chain with many predators. Weasels, owls, snakes, cats, and dogs could all kill them at any time, so their survival risk is extremely high.

Plant seeds and grains have relatively low nutrient density, so hamsters must eat a lot every day to maintain normal metabolism.

They also store large amounts of food to survive possible shortages in the wild. This is the main reason their cheek pouches evolved to be so large, a result of long-term adaptation to wild life.

To fight off predators and improve survival, hamsters must strengthen their self-protection.

What practical self-defense strategies do they have?
There are roughly five.

First: the timidity strategy.

They stay in their burrows or hiding places as much as possible, rarely going out voluntarily, especially avoiding exposure during the day, when light is strong and predators are active.

Second: the alertness strategy.

Although hamsters have small ears, their hearing is very sharp, and their sense of smell is strong. They sense danger through smells and faint sounds, and are ready to run or hide at once if something feels wrong.

Third: the speed strategy.

Hamsters have short legs but strong explosive power and quick reflexes. When in danger, they dart into nearby burrows or cracks and escape predators with their agile bodies.

Fourth: the stable hiding strategy.

For safety, hamsters mainly live underground or in hidden crevices. Their burrows usually have multiple exits, which improves safety, stabilizes temperature, and helps store food.

As the saying goes: “A hamster that stores food worries not about winter.” This is their survival wisdom for danger and hunger, preparing in advance to live better.

Fifth strategy: improve cryptic coloration, blending into the environment to reduce the chance of being spotted.

The white and golden hamsters we commonly see are actually human-bred varieties (such as golden hamsters and silver fox hamsters).

White fur saves metabolic cost by not making extra pigments. Colorful coats are bred by humans to match our aesthetic preferences, making these hamsters popular pets.

But in the wild, bright or pure white fur is extremely dangerous for hamsters, as they are easily seen.

Except for a few in high-altitude cold areas, almost no wild hamsters are white. They need colors similar to their surroundings to hide and survive.

Wild hamsters have a very wide distribution and can live in deserts, grasslands, farmland edges, shrubs, and other ecosystems.

In different environments, they evolve different body colors to hide.

Besides human-bred patterns, wild hamsters come in gray, light brown, tan, dark brown, and more.

All these colors come from melanin, mammals have only one type of melanin cell in their skin, which is why their fur colors are relatively plain.

(Fact: Hamster melanin cells are mainly at the base of hair follicles. They secrete pigment as hair grows, determining how light or dark the fur is.)

Mammals evolved from a nocturnal, mouse-like ancestor that was not sensitive to color.

Over time, only primates regained color vision. Most other mammals still have dichromatic vision and cannot see rich colors.

For this reason, like owls, they have no reason to evolve bright colors, as such colors would not be recognized by their own kind and would only increase the risk from predators.

Furthermore, mammal fur is fine and soft, unlike bird feathers, which support complex structures and iridescence. Mammals can only evolve limited colors based on melanin and hamsters are no exception.

Fortunately for hamsters, melanin cells fully meet their survival needs and help them hide effectively.

Melanin cells are abundant in hamster skin and follicles. They produce not only black but many other fur colors.

This is due to two basic pigments: eumelanin and pheomelanin.

(Fact: Eumelanin is resistant to light and UV rays; pheomelanin breaks down easily. So wild hamsters have mostly eumelanin on their backs, making them darker, better protected from sunlight, and better hidden.)

When eumelanin is high, fur is black; when low, tan or yellowish-brown.

If both pigments are missing, fur is white.

This rule shapes nearly all mammal fur colors: black, brown, white, or mixed shades.

Examples: white polar bears, orange tabby cats, reddish-brown red pandas.

When different colors mix randomly, they form patterned fur, like calico cats.

When pigment is distributed in clear patterns, it forms distinct stripes, like on zebras.

During embryonic development, hamster melanin cells line up along the spine.

As the embryo matures, melanoblasts migrate gradually from the back toward the belly.

During migration, their number decreases, so pigment on the belly becomes lighter.

This is the physiological reason mammals have lighter bellies—another form of dorsoventral color difference.

(Fact: Hamsters have a more obvious back-belly difference than rabbits: dark gray or brown-black on the back, pure white or pale yellow on the belly. This difference helps them hide in both burrows and on the ground.)

Dorsoventral color difference is extremely important for hamsters. All color types have a clear dark-back, light-belly pattern.

The optical principle behind it is: under natural light, the dark back absorbs light and appears dim.

The light belly reflects more light and brightens the shadow.

This dark-top, light-bottom pattern creates a wonderful visual flattening effect, helping hamsters camouflage and avoid being recognized.

We can do a simple simulation:

Place a white ping-pong ball on a table and shine light on it. The top is bright, the bottom dark.

This contrast creates a strong 3D effect, so we clearly see a round ball.

Now simulate an animal's dorsoventral color difference: paint the top half black, leave the bottom white, then shine light on it.

The black top absorbs much light and appears dark.

The white bottom reflects light in the shadow. The contrast is greatly reduced, the 3D effect weakened, and the outline much less distinct and hard to recognize quickly.

Thus, dorsoventral color difference is a crucial camouflage strategy for mammals.

Hamsters use this principle to hide successfully in the wild, blending into their surroundings and even “disappearing” from predators' sight.

Otherwise, under constant threat from so many predators, they might disappear from nature entirely.

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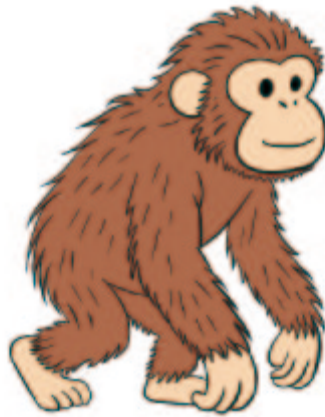
Evolutionary Skin Color of Humans

Why are monkeys' butts red?

In fact, not all monkeys have red bottoms, only adult monkeys in estrus do.

It is a signal to the opposite sex indicating they are in heat, a form of nuptial coloration.

This reddish area is therefore called sexual skin.



Monkeys have their sexual skin on their buttocks because they spend most of their time in trees. A bright red bottom acts like a signal light in the trees, easily seen by mates.

Monkeys are primates, a branch of mammals.

Different primates have different habits and fur colors.

For example, chimpanzees have black hair, orangutans dark reddish hair, golden snub-nosed monkeys golden hair, and rhesus macaques mostly gray hair.

Fur color is related to their environment, and the way they display sexual skin also differs.

Take baboons: their sexual skin is in a completely different place from monkeys'.

Baboons' sexual skin is not on their buttocks, but on their face.

This is because baboons live mainly on the ground and often sit, so a "signal board" on the bottom would be hidden.

A face signal is much more convenient. When sitting and eating, baboons only need to look up to send their message.

The red on a monkey's bottom comes from capillary congestion.

In contrast, baboons' facial color changes are more complex: besides blood, they also have iridescent coloration, making them rare mammals with iridescent skin.

Under different conditions, a baboon's face can be red, white, blue, and other colors.

This unpredictable mix makes baboons look like clowns, very strange and striking.

For this reason, they are sometimes called "ghost-faced baboons". In ancient China, they were known as *shānxiāo* (mountain demons).

These ghostly names came about because their facial colors were so unusual they exceeded ancient people's understanding of animal coloration.

Humans are also primates and live mainly on the ground, so we cannot display sexual skin on our buttocks or face.

In fact, humans do not have distinct sexual skin.

Other primates are covered in fur, so only a patch of bare skin stands out.

But humans lost most body hair long ago, leaving most skin exposed. Sexual skin thus became unnecessary.

So why did humans lose their fur?

It likely relates to early humans' evolution in the African savanna.

The savanna favors long-distance running, and early humans evolved strong endurance.

Long running requires excellent heat dissipation; overheating causes heatstroke. This is why humans lost their fur.

Losing fur triggered a chain reaction. The most direct change was that we revealed smooth skin and distinct skin color.

After losing fur, early humans' exposed skin needed better sun protection to avoid burning.

So humans evolved dark skin. Melanin absorbs ultraviolet (UV) rays and protects DNA in skin cells.

Later, as humans spread out of Africa, melanin in skin gradually decreased, making skin lighter.

Western Europeans generally have lighter skin than East Asians.

All humans belong to the species *Homo sapiens*. Small differences reflect biodiversity and adaptation to different environments.

For example, sunlight in Europe is weaker than in Africa, so less melanin is needed.

UV intensity in Asia is between Europe and Africa, so Asian skin has moderate melanin, neither very dark nor very light.

But why must skin become lighter where UV is weaker?

Wouldn't keeping melanin to prevent sunburn be better?

The reason is that while too much UV is harmful, too little UV is also harmful.

It has to do with our need for vitamin D.



Vitamin D is a group of vitamins highly sensitive to UV light.

The human body cannot make vitamin D on its own. It can only convert cholesterol into vitamin D when exposed to UV rays.

Vitamin D supports many metabolic processes, especially calcium absorption and bone strength.

Simply put, vitamin D makes bones stronger.

Without enough vitamin D, people easily develop rickets.

For this reason, vitamin D was once called the “anti-rickets vitamin”.

The cheapest way to get vitamin D is sunlight.

A healthy person only needs about 10 minutes of sun a day to make enough.

When sunlight is scarce, the body cannot make enough vitamin D, harming health.

Thus, groups that moved to low-sunlight regions evolved less melanin to let enough UV through for vitamin D.

Vitamin D also explains why women generally have lighter skin than men.

During pregnancy and breastfeeding, women need much more calcium-for themselves and their babies.They therefore need more vitamin D, meaning more UV exposure.

So they must reduce their UV “blocker”-melanin-making their skin lighter.

Yet women’s skin cannot be infinitely light; it is limited by other factors.

The most important is folate.

Folate is an essential B-vitamin. The body cannot make it; it must come from food like green vegetables and liver.

Omnivorous humans usually get enough.

But folate has a weakness: it is easily destroyed by long wave UV.

Worse, sunlight contains long wave UV that penetrates deep into blood vessels and breaks down folate in the blood.

The problem is that folate is essential for making DNA.All cell division requires it.

Here, women’s light skin becomes a double edged sword.

Light skin allows more UV for vitamin D, but also destroys more folate.

Estrogen also affects folate metabolism, making pregnant women especially likely to lack folate.Their need is far higher.

Folate deficiency can cause severe birth defects, including anencephaly.

Folate thus became a key factor in natural selection.

To protect folate and ensure healthy offspring, women evolved a moderately darker skin tone as an adaptation.

In ancient times, people had few choices. Under natural selection, they could only adapt passively. Skin color was finely tuned by evolution,not too dark, not too light.

Today's global skin colors strongly support this idea.

To match different sunlight levels, ideal skin is neither extremely dark nor pure white.

It lets just enough UV through to protect folate and make enough vitamin D.

Skin color directly affects hair color, because hair color is also determined by melanocytes.

The more melanin in skin, the darker the hair.

Black hair blocks UV from damaging the brain. That is why native Africans have dark skin and black hair, and most Asians also have black hair.

Less melanin in skin means lighter hair. This is why many Europeans have blond or light hair.

Lighter hair lets in more sunlight, helping retain head heat and resist cold, especially important in cold European regions.

Human coloration is not fundamentally different from other mammals. We too are products of evolution and natural selection. We use color to protect, signal, and adorn ourselves.

This may be why humans love cosmetics. Makeup enhances beauty and adds color to the world.

So we should appreciate the brilliant colors of all living things. They make the world beautiful, life bright, and the future full of hope.