THE world is like a colour box with waves of colours everywhere. The radiance of colour we see in and around our mundane life is bestowed on us mostly by the magnanimity of plants. The greenery of leaves and tender stems soothe our eyes. The withered yellow and red leaves fallen on the ground mark the onset of autumn. Come spring and the surroundings are bedecked with flowers of various shades. Colourful strawberries and apples are visually appealing. But pigments in plants do much more than just help plants perform aesthetic functions.

We all know that photosynthesis is the first step in the food chain that connects all living organisms. Plants use chlorophyll to convert sunlight into energy they can store in simple sugar during photosynthesis. The concocted food is later utilized by plants to run different life processes.

Pigments also play a significant role in pollination as well as propagation. A flower may be rendered conspicuous by the bright colour of its petals or perianth (floral parts not differentiated into sepals and petals) and thus attracts certain insects. However, majority of the compound-eye insects are bichromatic and they have just two types of colour pigment receptors. Their colour spectrum is limited and blue shifted compared to ours. Honeybees are trichromatic—they have three types of pigment receptors like us. They can distinguish a wider spectrum and that is why honeybees visit various coloured flowers to fetch honey and are mostly involved in pollination. Red colour is invisible to insects while they can see ultraviolet light and so insects distinguish flower colour different from humans. Some butterflies are also successful pollinators as they are able to distinguish flower colour like honeybees.

Certain edible fruits, especially those that are brightly coloured, are devoured by several birds and animals. In many cases their seeds pass through the gut of the animal without any injury. In this way, these seeds are dispersed through their droppings, often many kilometers away from the place of origin.

Then, plants are able to survive the harshest conditions with the help of certain pigments acting like a shield. For instance, exposure to pollution by various metallic ions may cause phytotoxic responses in plants that can be minimized to some extent by â-carotene along with ascorbic acid and phenolic compounds. Some pigments responsible for pink, red and purple leaf colour even help acclimatize germinating plants to a new environment.

Colours of higher plant organs depend largely on the pigments they contain. These pigments are not only responsible for the beautiful colours we observe around us, they are also integral to the survival of the plants and life on earth too.

Pelargonidin gives these Dahlias their ravishing colours
Another plastidial pigment in plants is carotene. Carotene is a large molecule purely made up of hydrocarbons (C40H56). This orange pigment occurs in four naturally occurring forms, of which â-carotene is the most prevalent form found in higher plants. Xanthophyll (C40H56O2), or the oxygenated carotene, is another pigment belonging to the same group. It is a yellow to brown pigment. Among various types of xanthophylls, lutein (3,3-dihydroxy-oc-carotene) is the most common pigment found in green plants. Both carotene and xanthophyll collectively constitute carotenoids. Carotenoids act as accessory absorbers of the blue-violet portion of the visible spectrum. The trapped light energy is then transferred to chlorophyll molecules for further use in photosynthesis.

The other function of carotenoids in plant cells is to protect the photosynthetic machinery. Chlorophyll is quite delicate and is not very stable under bright sunlight as well as in too much ultraviolet radiation. Such radiations cause photooxidative damages as the excited chlorophyll molecule produces free radicals (particularly those including oxygen), which in turn damage the chlorophyll molecule itself, and the thylakoid membrane as well. However, carotenoids act as antioxidants. By taking the excitation energy of
chlorophyll, carotenoids convert it into heat energy instead of releasing free radicals.

Another natural plant pigment is anthocyanin. They are non-plastidial water-soluble pigments and are dissolved in the cell sap. Anthocyanins are glycosides and their sugar-free components are known as anthocyanidins. The parent compound present in anthocyanidins is phenylbenzopyrylium chloride or flavylum chloride.

Anthocyanin pigments are amphoteric—their acid salts are usually red, their metallic salts usually blue and in neutral solution the anthocyanins are violet. As a result, they are responsible for the large variety of colours in flowers, fruits and fall leaves. Anthocyanins are formed by a reaction between sugars and certain proteins in cell sap. Various sugars have been found in anthocyanins. The most common monosaccharides are glucose, galactose and rhamnose; the disaccharides are gentiobiose and rutinose and trisaccharide is gentianose. The most common anthocyanins are violanthropein (C15H11ClO6) and yellow pigment xanthophyll (C25H30O4) and yellow pigment crocetin (C26H30O7), are found in the pods of annatto and in saffron flowers, respectively. Some carotenoid pigments, like capsanthin (C40H56O3) and capsorubin (C32H42O5), confer red colour also like in red peppers.

The exact role of the anthocyanins is not known with certainty. But their bright coloured appearance definitely helps plants in cross-pollination by attracting insects. Like carotenoids, anthocyanins have been credited with protecting the chlorophyll from degradation in strong sunlight. Moreover, they can absorb considerable amount of sunlight and convert it into heat energy.

**Colourful Flowers and Fruits**

Among various plant pigments, carotenoids and anthocyanins are largely responsible for the colour of flowers and mature fruits. Carotenoids impart orange to yellow colours to different plant organs. For instance, â-apo-8-carotenal is accountable for the orange colour of tangerines and oranges. Lutein, the yellow xanthophyll, is found in marigolds and some other flowers. A few naturally occurring apocarotenoids (or carotenoid acids which contain less than 40 carbon atoms and carboxyl groups) such as orange pigment bixin (C40H56O3) and yellow pigment crocetin (C26H30O7), are found in the pods of annatto and in saffron flowers, respectively. Some carotenoid pigments, like capsanthin (C40H56O3) and capsorubin (C32H42O5), confer red colour also like in red peppers.

Table 1. Major groups of anthocyanidin pigments

<table>
<thead>
<tr>
<th>Trivial name</th>
<th>Chemical Formula</th>
<th>Chemical name</th>
<th>Where they can be found</th>
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<tbody>
<tr>
<td>Pelargonidin</td>
<td>C15H11ClO6</td>
<td>3,4,5,7-Tetrahydroxyflavylum chloride</td>
<td>Orange-red to scarlet flowers, e.g. scarlet geranium (Pelargonium), orange-red dahlia (Dahlia)</td>
</tr>
<tr>
<td>Cyanidin</td>
<td>C15H11ClO6</td>
<td>3,3,4,5,7-Pentahydroxyflavylum chloride</td>
<td>Crimson to bluish-red flowers, e.g. deep red dahlia (Dahlia), red roses (Rosa), blue corn flower (Zea).</td>
</tr>
<tr>
<td>Delphinidin</td>
<td>C15H11ClO6</td>
<td>3,3,4,5,7-Hexahydroxyflavylum chloride</td>
<td>Violet to blue flowers, e.g. larkspur (Delphinium)</td>
</tr>
<tr>
<td>Peonidin</td>
<td>C16H12ClO6</td>
<td>3,4,5,7-tetrahydroxy-3-methoxyflavylum chloride</td>
<td>Crimson to bluish-red flowers, e.g. red peony (Paeonia)</td>
</tr>
<tr>
<td>Malvidin (Syringidin)</td>
<td>C16H12ClO6</td>
<td>3,4,5,7-tetrahydroxy-3,5-dimethoxyflavylum chloride</td>
<td>Violet to blue flowers, e.g. primula (Primula viscosa)</td>
</tr>
<tr>
<td>Hirsutidin</td>
<td>C16H12ClO6</td>
<td>3,4,5-trihydroxy-3,5,7-trimethoxyflavylum chloride</td>
<td>Blue flowers, e.g. primula (Primula hirsuta)</td>
</tr>
</tbody>
</table>

However, differences in flower and fruit colour are not necessarily due to differences in pigment molecules. Singly the cyaniding group of pigments make a variety of expressions, depending on the number and positions of the hydroxyl and methoxy groups. When these are fixed, the colour depends on pH and solvent of cyaniding pigments. For this reason, roses, china roses, apples, cranberries and strawberries are red; hydrangeas, blueberries and corn flowers are blue whereas some grapes, blackberries and red cabbages are purple.

The acidity factor in the colour expression of anthocyanins has been to some extent over emphasized. If the cell sap is quite acidic, the pigments impart a bright red colour; in less acidic condition, its colour is more purple. Again the blue colour of some flowers, such as Asian pigeonwings, occurs chiefly due to the accumulation of aluminium ions in the cell sap, which in turn form basic organic salts after reacting with the pigment molecule.

It is interesting to note that anthocyanin pigments are absent in certain higher plant genera, mainly grouped under the order Centrospermales. Then what makes bougainvilleas and beets so colourful? Actually the purple colour of the bracts of Bougainvillea is due to betacyanins, a pigment molecule similar to that of plant growth regulator auxin, having the same basic indole ring structure.

Another group of widely distributed water-soluble natural plant pigments are flavones, also known as...
anthoxanthins. Chemically flavones are hydroxylated derivatives of 2-phenyl-4-chromone and are very closely related to the anthocyanins. They occur naturally in the free state, or as glycosides, or may be associated with tannins. Flavones (C_{15}H_{10}O_{2}) and some other related pigment compounds like flavonols (C_{15}H_{10}O_{3}) and flavanones (C_{16}H_{15}O_{5}) are yellow in colour and occur mainly as ‘dust’ on flowers and leaves of a number of plants including primroses. Some commonly occurring flavones and flavonols are apigenin, chrysin, quercetin, etc. whereas some flavanones found in higher plants are liquirilligenin, haringenin, etc.

When Autumn Comes
Autumn puts an end to hot summer days. It is the time of year when tree leaves begin to show their beautiful colours. Most of the broad-leaved trees in the Northern hemisphere shed their leaves in the fall. However, the dead brown leaves of the oaks (Quercus spp.) and a few other species may stay on the tree until growth starts again in the spring.

In the Southern hemisphere, where the winters are mild, some of the broad-leaved trees are evergreen—the leaves stay on trees during winter and keep their green colour intact. Most of the conifers like cedars, firs, pines, spruces, etc. are evergreen in both the hemispheres. Even the needle or scale leaves remain green or greenish the year round, and individual leaves may stay on for two to four or more years. All these evergreen plants and also some deciduous plants never show fall colours as these plants possess some genetically controlled adaptive characteristics. Such characteristics do not allow the physiological properties of plants to be influenced by certain environmental parameters like temperature, light or water, etc. Consequently no biochemical processes of colour change take place in these plant organs.

The change in the hue of leaves is the result of biochemical activities that take part in the plant tissues as the season changes from summer to winter. Plant leaves contain the key pigment chlorophyll that gives them their green colour. However, leaves have some other pigments present most of the time. These are orange to yellow coloured carotenoid pigments. In most of the plants there is about three times as much chlorophyll as carotenoids. Again anthocyanin is responsible for the red, pink and purple colours in leaves that are so attractive.

Chlorophyll is not a very stable compound; bright sunlight causes it to degenerate. This is known as solarisation. To maintain the amount of chlorophyll in their leaves, plants constantly synthesize it. The synthesis of chlorophyll in plants requires both sunlight and warm temperatures. Therefore, during summer chlorophyll is continuously broken down and regenerated in the leaves of trees. But declining autumn temperatures result in reduced chlorophyll formation and the disintegration of chlorophyll already present therein. Thus the green colour begins to fade. As the levels of chlorophyll decline, carotenes and xanthophylls along with anthocyanins are unmasked and their colours become visible.

At the advent of autumn, a change in the normal light intensity and temperature (dry sunny days followed by cool dry nights) occurs which may trigger cork formation between the branch and leaf base. This corky layer interferes with the flow of mineral nutrients into the leaf, which results in a decline in the biosynthesis of chlorophyll. Hence, a chlorosis or development of light green colours occurs in the leaf and the leaf ultimately turns yellow. The layer also inhibits the flow of carbohydrates (already synthesized) from the leaf. As the concentration of carbohydrate increases, it reacts to form anthocyanin pigment, which is stored in the sap of
leaf cells. The most important environmental factors favouring the production of anthocyanin are cool temperature (above freezing), drought and bright sunny days that are very common in autumn months.

Various species of birch (Betula), elm (Ulmus), and hickory (Carya) leaves display bright yellow autumn colours when the chlorophyll present in leaves begins to decline in the fall. Their bright yellow colours are due to the presence of excess carotenoids over chlorophyll in stressed condition.

The autumn foliage of some trees, like many oaks, show brown fall colours. Such colour probably generates due to the mixing of varying amounts of the chlorophyll residue and other pigments in the leaf during autumn season. The bright red and orange fall colours for which sugar maple (Acer nigrum) and red oak (Quercus rubra) trees are famous, are due to the production of anthocyanin in the leaves. Also sassafras (Sassafras albidum), sweetgum (Liquidambar styraciflua), and sumac (Rhus spp) produce large amounts of anthocyanin, which accounts for their deep red colours. In these plants, leaves in the upper crown usually develop the brightest red colours, as they are exposed to the most sunlight.

However, several days of rainy or cloudy weather often decrease the intensity of fall colours. Further, trees of the same species growing close together often show much colour variation. This is due to the individual response of plants to environmental factors and different ratios of pigments present in the leaves.

However, tender leaves of certain plants change colour from reddish to various shades of green just after their emergence. Irrespective of autumn months, it happens throughout the year due to the slow rate of chlorophyll synthesis in the young leaf tissues. Other pigments, basically anthocyanins, take this advantage by expressing themselves before the full greening of the leaf.

Variegated Leaf Colour
Complete absence of plastidial pigments causes a segment of a leaf or stem to have white patches. Here white indicates the lack of colour. This partly green and partly colourless condition of plant organs is termed as variegation. Variegation occurs when there is a cell mutation, and all cells produced from that mutant mother cell lack the pigments, either because plastids are not present or the plastid cannot complete the manufacture of pigment molecules. Occasionally bud mutations occur resulting in short-lived colourless, albino plants or variegated branches.

A few years after the rediscovery of Mendel’s laws, C. Correns (1909) and E. Baur (1909-10) described crossings for which the Mendelian laws did not apply. As evidence of their findings, Correns and Baur cited the example of variegated leaves in four o’ clock (Mirabilis jalapa) and snapdragon (Antirrhinum majus) plants. Later Baur found another case of variegation in a pelargonium (Pelargonium zonale) plant.

Species with variegated parts occur rarely in nature although they are sometimes found in the understory of tropical rainforests. However, variegated individuals are extremely common among indoor and outdoor ornamentals, where they are grown as horticultural oddities. In nature, variegated plants can persist via cloning, i.e., vegetative propagation by forming new plants from buds, as in bromeliads, orchids, aloes, and agaves, rather than via seeds (because of their maternal origin), which would necessarily be a rare event. Besides, variegated plants show a lower rate of photosynthesis as the foliar zones where chloroplasts are not present and where no photosynthesis will occur. Consequently, a variegated plant also tends to grow more slowly.

Variegated ornamentals show a varied array of colourful designs of their leaf lamina. Some plants have only a fringe of white around the leaf, e.g., pittosporum; irregular dots and spots, e.g., dumbcane; broad panels of white as in shell ginger, and even an occasional leaf that is totally achlorophyllous as found in English ivy (Hedera helix). Among monocotyledons, strips of stem internode may also be achlorophyllous as found in variegated sugarcane. Some very colourful variegated horticultural forms occur when the leaf cells can produce cell sap pigments, such as anthocyanins, which then produce patches of pink where chlorophyll is absent, e.g., pink caladium.

No sooner is mutant albino or a colourless plant born that it dies. In other words, the survival of plants largely depends on the pigments they contain. Plant pigments are also responsible for supplying energy to all types of existing ecosystems on the earth. It would not be out of place to say that plant pigments work as the basis of biospheric vivacity.