Development of role and function of plant pigments for life

By:
Retno Mastuti
Biology Department – Brawijaya University
What is plant pigments?

- Plant compounds that are perceived by humans to have color
- Varied structures and colors → examined their chemical and physical properties, their mode of synthesis, and their physiological and ecological roles.
- Plant pigments also have a long history of use by humans
Secondary metabolites or secondary compounds are compounds that are not required for normal growth and development, and are not made through metabolic pathways common to all plants.

The most common roles for secondary compounds in plants are ecological roles that govern interactions between plants and other organisms.
Secondary compounds are grouped into classes based on similar structures, biosynthetic pathways, or the kinds of plants that make them. The largest such classes are the **alkaloids, terpenoids, and phenolics**.

Many secondary compounds are brightly colored pigments like anthocyanin that color flowers red and blue. These attract pollinators and fruit and seed dispersers.

Secondary compounds often occur in combination with one or more sugars. These combination molecules are known as glycosides. Usually the sugar is a glucose, galactose or rhamnose.
Alkaloids

- Alkaloids generally include alkaline substances that have nitrogen as part of a ring structure.
- More than 6500 alkaloids are known and are the largest class of secondary compounds.
- They are very common in certain plant families, especially:
  - peas – Fabaceae
  - sunflower – Asteraceae
  - poppy – Papaveraceae
  - tomato – Solanaceae
  - dogbanes – Apocynaceae
  - milkweeds - Asclepiadaceae
  - citrus – Rutaceae.
Terpenoids are dimers and polymers of 5 carbon precursors called isoprene units (C$_5$H$_8$).

Terpenoids often evaporate from plants and contribute to the haze we see on hot sunny days.
Phenolics

- Compounds that contain a fully unsaturated six carbon ring linked to an oxygen are called phenolics.
- **Flavonoids are complex phenolics.** They are often sold in health food stores as supplements to vitamin C.
- **Anthocyanins are a type of flavonoid** that give flowers red and blue pigments.
- Some phenolics form polymers: **Tannins** - are astringent to the taste. They can also be used to tan leather. They often give water a tea-colored look.
- **Lignin** is a major structural component of wood.
(a) Structures of four phenolics. (b) Willows (Salix species) accumulate salicylic acid in their bark. (c) Rutin is produced abundantly in buckwheat (Fagopyrum esculentum) and many other plants. (d) Lignin is the strengthening polymer that makes wood valuable commercially. These baseball bats are made of the wood of white ash (Fraxinus americana). To learn how these bats are made, see the boxed reading entitled "The Bats of Summer: Botany and our National Pastime" on page 366 in Chapter 16.
The major classes of plant pigments:

- Chlorophyll,
- Anthocyanins,
- Carotenoids, and
- Betalains
Pigments

Ancient times: Dyeing cloth, printing, painting, coloring foods

Highly suitable natural colorants for preparing health foods

Have neither hepatocarcinogenic nor mutagenic effects in mammal

 Anthocyanins, Carotenoids, betalains

In Plants: Attracting pollinators; Seed dispersal; Protect from harmful effects of UV lights; insect repelling signal; resistance of underground plant parts to soil pathogen; ROS scavenging; Limiting damage caused by wounding and infiltration in plant tissues; High antioxidant capacities

Natural colorants

Have diverse activities: Anti inflammatory, hepatoprotective, cancer chemo preventative activities, reduce oxidative stress, protect LDLs from oxidation, A new class of dietary cationized antioxidant
Pigmen fotosintetik

- **Klorofil a**: jumlahnya paling banyak, mengabsorpsi cahaya biru (430 nm) dan merah (662 nm)

- **Klorofil b**: struktur = klorofil a, tetapi tidak sebanyak klorofil a, mengabsorpsi maksimal cahaya pada $\lambda = 453$nm and 642 nm, meningkatkan kisaran cahaya yg digunakan sbg energi

- **Karotenoid**: pigmen *accessory* pada semua organisme fotosintetik, hidrofobik (larut lemak), berada pada membran lipid, mengabsorpsi cahaya maksimal pada $\lambda$ antara 460 nm dan 550 nm, tampak berwarna merah, oranye dan kuning

- **Fungsi karotenoid**: melindungi tanaman dari radikal bebas yang terbentuk dari radiasi UV atau lainnya. Radikal bebas berbahaya karena mengandung ekstra ‘odd’ elektron yang sebenarnya tidak diharapkan keberanaannya. *This means that they are constantly trying to get rid of this extra electron. They do this by attacking whatever bonds they can.*
Anthocyanins:

- a class of flavonoids derived ultimately from phenylalanine, water-soluble,
- synthesized in the cytosol, and localized in vacuoles.
- provide a wide range of colors ranging from orange/red to violet/blue.
- various structures,
- their specific color depends on co-pigments, metal ions and pH.
- Common types: Anthocyanins, aurones, chalcones, flavonols and proanthocyanidins
- are widely distributed in the plant kingdom. Produce many colors in flowers.
Carotenoids

- The lipid-soluble, yellow-to-red, a subclass of terpenoids,
- Are distributed ubiquitously in plants.
- Are synthesized in chloroplasts and
- Are essential to the integrity of the photosynthetic apparatus.
- Common types: Carotenes and xanthophylls (e.g. astaxanthin)
- In green plants (masked by chlorophyll), vegetables like carrots, mangoes and so on. Some birds, fish and crustaceans absorb them through their diets
Betalains

- are nitrogen-containing water-soluble compounds
- Consist of yellow betaxanthin and red-purple betacyanins,
- derived from tyrosine
- are found only in a limited number of plant (only 13 families of Ordo Caryophyllales).
- In contrast to anthocyanins and carotenoids, the biosynthetic pathway of betalains is only partially understood.
The biosynthetic pathway of betalains involves the conversion of tyrosine through a series of enzymatic reactions. The primary difference between betanin and betanidin lies in the addition of glucose (R1) in the case of betanin and hydrogen (H) in the case of betanidin. The lateral chain of amino acids or amines (R2) is also a variable in the biosynthesis. 

Key steps in the biosynthetic pathway include:
- **DOPA (3,4-dihydroxyphenylalanine)**: This amino acid is converted to DOPA dihydroxyphenylalanine, which is then oxidized to DOPA dioxygenase.
- **Betalamic acid**: This is a precursor to betaxanthins (yellow color) and betacyanins (magenta color).

The final products are betaxanthins and betacyanins, which give the characteristic colors to betalain-rich foods.
the different localization of the red betacyanins and yellow betaxanthins
Commercial product: betalain from red beet

Amaranthus: promising alternative betalain source
All three classes of pigments act as visible signals to attract insects, birds and animals for pollination and seed dispersal. They also protect plants from damage caused by UV and visible light.

Biosynthesis of plant (flower) pigments: anthocyanins, betalains and carotenoids.
<table>
<thead>
<tr>
<th>Pigment</th>
<th>Common types</th>
<th>Where they are found</th>
<th>Examples of typical colors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophylls</td>
<td>Chlorophyll</td>
<td>Green plants</td>
<td>Green</td>
</tr>
<tr>
<td>Carotenoïds</td>
<td>Carotenes and xanthophylls</td>
<td>Bacteria. Green plants (masked by chlorophyll), vegetables like carrots, mangoes and so on.</td>
<td>Oranges, reds, yellows, pinks</td>
</tr>
<tr>
<td></td>
<td>(e.g. astaxanthin)</td>
<td>Some birds, fish and crustaceans absorb them through their diets</td>
<td></td>
</tr>
<tr>
<td>Flavonoids</td>
<td>Anthocyanins, aurones, chalcones, flavonols and proanthocyanidins</td>
<td>Produce many colors in flowers. Common in plants such as berries, eggplant, and citrus fruits. Present in certain teas, wine, and chocolate.</td>
<td>Yellow, red, blue, purple</td>
</tr>
<tr>
<td>Betalains</td>
<td>Betacyanins and betaxanthins</td>
<td>Flowers and fungi</td>
<td>Red to violet, also yellow to orange</td>
</tr>
</tbody>
</table>
Induction and selection of callus

**Source of Plant**

**Seed germination**
- MS0 medium

**Callus induction**
- MS+2BAP+2NAA

**Callus selection**
Growth curve – log phase determination

Betacyanin accumulation closely associated with cell growth (*Beta vulgaris*, *Phytolaca americanum*, *Chenopodium rubrum*)
The five basic inherited stable phenotypes of red beet cell cultures. Left to right: green [G], yellow [Y], orange [O], red [R] and violet [V].

Micrographs of red beet cells: orange [O], violet [V], red [K] and yellow [Y] cells showing the morphology corresponding to each coloured phenotype. Due to the high friability of the calli, cells scattered spontaneously when dropped in a 7% mannitol solution.
Conclusion

Amaranthus pigments is an alternative candidate of healthy betalain natural colorants

Future prospect

Amaranthus plant improvement through tissue culture method

organogenesis
plantlet
protoplasts


Karuppusamy, S. 209. A review on trends in production of secondary metabolites from higher plants by in vitro, tissue, organ and cell cultures. J. Medicinal Plants Res. 3(23):1222-1239.


Moreno…..2008.


Judul penelitian tugas akhir skripsi/tesis

- Induksi Akumulasi Betasianin pada Kalus *Celosia cristata* Linn. dengan Elisitor Abiotik (Mn$^{2+}$ dan Co$^{2+}$)
- Induksi Akumulasi Betasianin pada Kalus *Celosia cristata* Linn. dengan Elisitor Biotik (Kitosan dan Pektin)
- Potensi Ekstrak Pigmen Betalain Bungan Jengger Ayam (*Celosia cristata*) terhadap Penghambatan Pertumbuhan *Plasmodium berghei*
- Induksi Akumulasi Betasianin Kalus Celosia sp melalui Modifikasi Sukrosa serta kombinasi Glukosa dan Fruktosa pada Medium Kultur MS
- Klasifikasi Genus Anggota Famili Amaranthaceaea Berdasarkan Analisis Morfologi dan Molekuler
- Kasifikasi Enam Genus Anggota Famili Amaranthaceae berdasarkan Morfologi Tumbuhan dan Anatomi Daun dan Batang
- Klasifikasi Enam Genus Anggota Familia Amaranthaceae berdasarkan Morfologi Tumbuhan dan Profil Senyawa Betasianin