Phytochemicals as Nutraceuticals

by Ben Best

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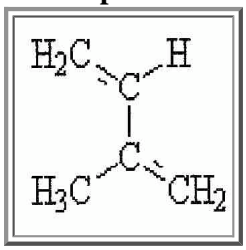
I. Introductory Remarks

In this monograph I write about **phytochemicals**, ie, complex chemicals found in plants, notably in fruits and vegetables -- with the focus on the phytochemicals rather than on their sources. This review is not comprehensive, it is simply a first attempt at classification of phytochemicals that have attracted my attention. Many phytochemicals have not been included.

Isoprene



Phytochemicals with antioxidant properties tend to be brightly colored because they contain **chromophores**, ie, a series of alternating single-bonded and double-bonded carbons. **Isoprene** is often the building block of such units. The darkest green vegetables contain the most chlorophyll, and vegetables with the most chlorophyll require the most antioxidants. Green will mask the other colors, when other-colored antioxidant phytochemicals are present.

Many phytochemicals have an anti-carcinogenic (anti-cancer) action by:

1. slowing cell proliferation (division) by interfering with the cell cycle
2. inducing apoptosis (cell suicide)
3. inhibiting **phase 1 enzymes** (enzymes that convert harmless substances into carcinogens)
4. inducing **phase 2 enzymes** (enzymes that can attach carcinogens to molecules that facilitate speedy excretion).

Phytochemicals are not classified as vitamins with official RDA values, but they can contribute greatly to health and well-being. We are adapted to a world that contains phytochemicals in our diet. The macula of the eye is adapted to concentrate the yellow caroteniods lutein and zeaxanthin to protect against harmful blue light.

Although the emphasis is on the positive effects of phytochemicals, note that very many can be toxic and harmful. Plants containing the most harmful phytochemicals are usually not treated as foods. Oxalic acid is included here because it is primarily harmful and is found in plant foods.

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II. Terpenoids = Isoprenoids

II-A. Carotenoid Terpenoids

Carotenoids make corn yellow, carrots orange and tomatos red. Carotenoids also give color to salmon, goldfish, flamingos and autumn leaves (when the green chlorophyll has gone, the

Food	Beta-Carotene *	Alpha-Carotene *
Sweet potato (baked)	9.5	0

carotenoids and phenols remain). Bell peppers of different colors offer a selection of carotenoids.

- **Orange Carotenoids** -- alpha, beta and gamma carotene
- **Red Carotenoids** -- lycopene and astaxanthin
- **Yellow Carotenoids** -- lutein and zeaxanthin

Carrots, raw	**8.8**	**4.6**
Pumpkin, canned	**6.9**	**4.8**
Kale, cooked	**6.2**	**0**
Spinach, raw	**5.6**	**0**

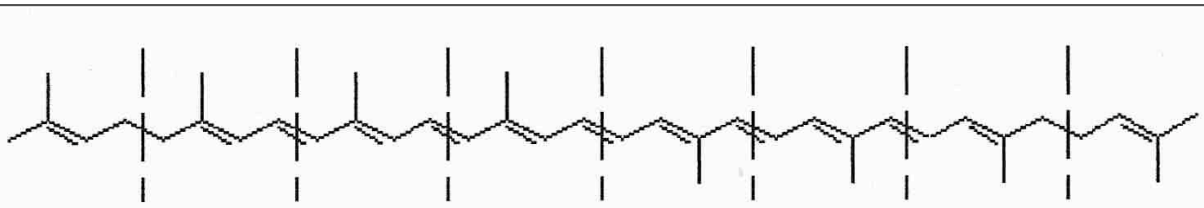
*** milligrams per 100 grams**

More than 600 carotenoids have been found in plants. About half of the roughly 50 carotenoids in the human diet are absorbed into the blood stream. Lycopene and beta-carotene each constitute about 30% of plasma carotenoids. Only alpha, beta and and a few other carotenes (***not*** lycopene or lutein) can be converted to Vitamin A. Hypervitaminosis of Vitamin A cannot be caused by excessive alpha or beta carotene intake because the conversion and absorption rates are too slow. Both alpha-carotene and beta-carotene are protective against liver cancer and lung cancer in cell culture and animal studies.

Heating, chopping and/or crushing of vegetables frees-up carotenoids, especially beta-carotene & lycopene. Carotenoids are nearly insoluble in water and are best absorbed when associated with oils. In the blood stream carotenoids are transported in the most lipid-rich (LDL) cholesterol particles. Tissues with the most LDL receptors receive the most carotenoid.

II-A-1. Lycopene

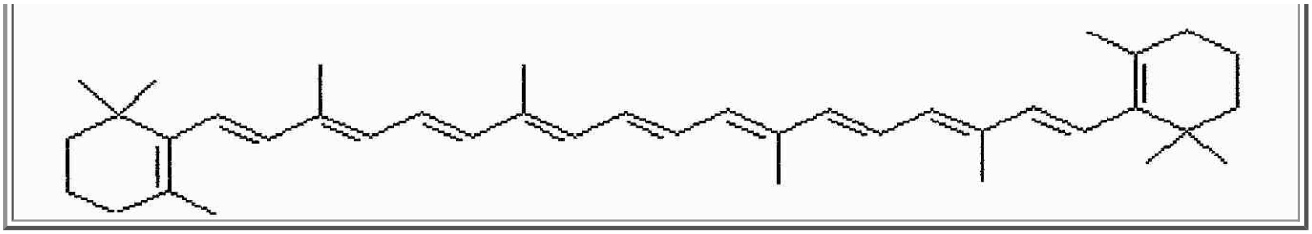
Lycopene



- red color of tomatoes, watermelon, pink grapefruit, guava & papaya
- almost all lycopene in the American diet comes from tomato-containing foods
- the natural *trans* form is poorly absorbed
- light & heat converts the *trans* form to the *cis* form, which is more bioavailable
- binds tightly to fibers, freed by high heat
- not soluble in water, better in oil
- bioavailability from tomato paste is nearly four times greater than from fresh tomatoes
- powerful antioxidant which reduces damage to DNA and proteins
- gives better skin protection against UV light than beta-carotene
- accounts for nearly half the total carotenoids in the blood serum
- concentrates in the skin, testes, adrenal and prostate where it protects against cancer
- can reduce LDL cholesterol levels
- suppresses Insulin-like Growth Factor (IGF-1) stimulation of tumor growth

II-A-2. Beta-Carotene

Beta-Carotene

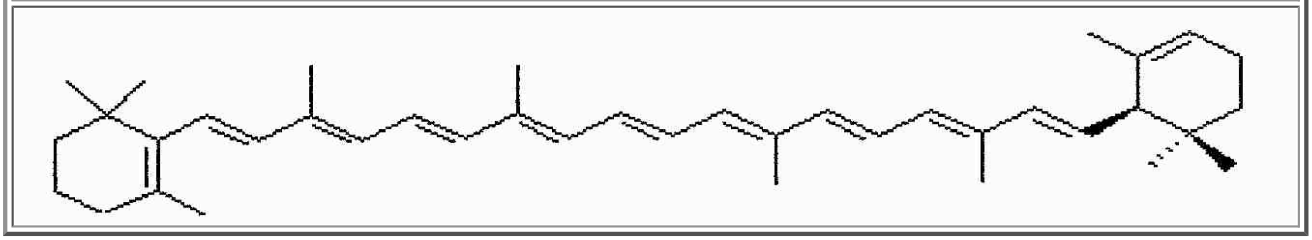


Although epidemiological studies have shown reduced lung cancer incidence among those with high plasma serum levels of beta-carotene, some large intervention studies showed an increased incidence of lung cancer among smokers taking beta-carotene supplements. (For more details, see General AntiOxidant Properties.)

- weak antioxidant, but strong against singlet oxygen
- supplements can enrich LDL cholesterol ß-carotene content without affecting other carotenes
- can boost the activity of NK (Natural Killer) immune cells
- can stimulate DNA repair enzymes
- gives better cornea protection against UV light than lycopene

II-A-3. Alpha-Carotene

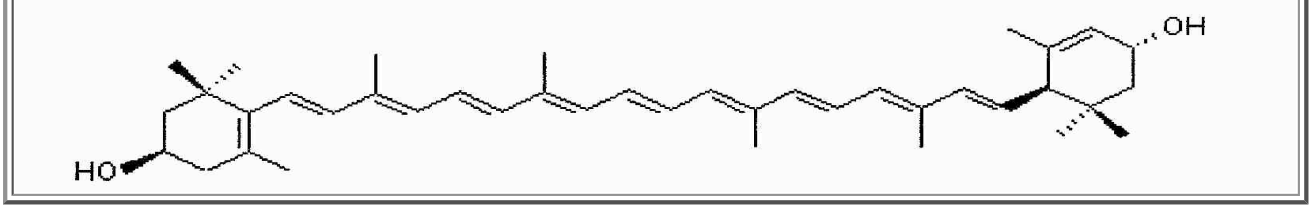
Alpha-Carotene



- ten times more anti-carcinogenic than beta-carotene
- enhances release of immunogenic cytokines IL-1 and TNF-alpha

II-A-4. Lutein

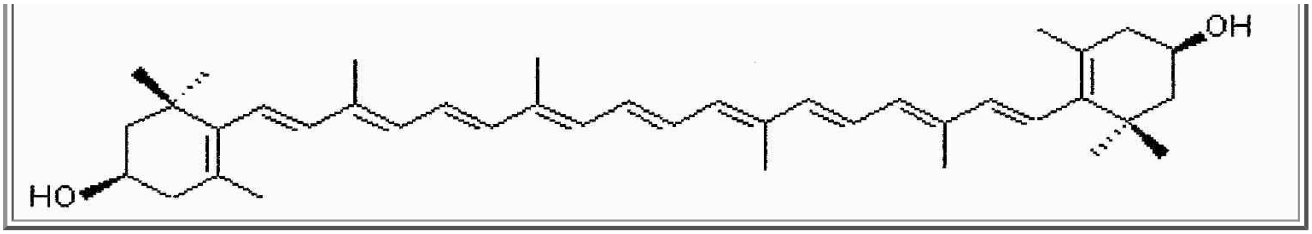
Lutein



- gives corn, avocado and egg yolk a yellow color
- lutein and zeaxanthin constitute about half of all carotenoids in the retina
- lutein and zeaxanthin are the only carotenoids in the macula of the eye
- absorbs damaging blue light
- protects the eye from macular degeneration and cataracts
- may protect against colon cancer
- highest concentrations in kale, spinach, watercress and parsley (in that order)

II-A-5. Zeaxanthin

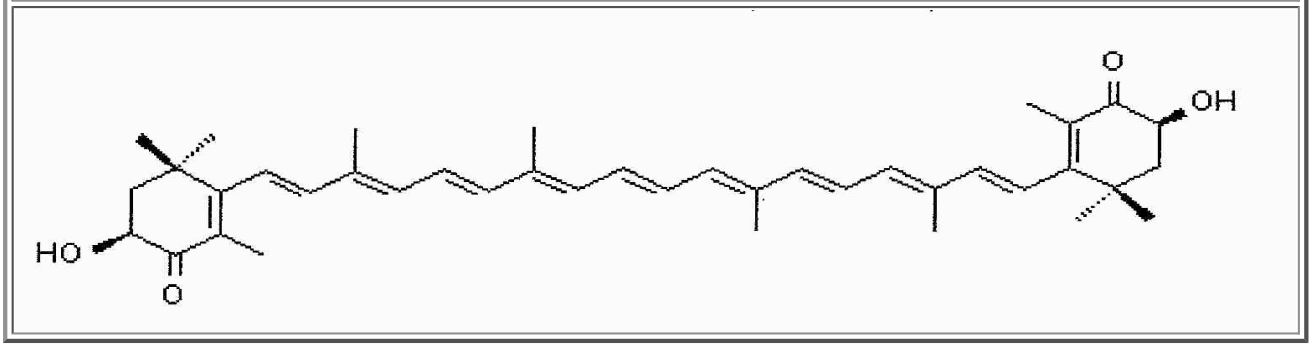
Zeaxanthin



- lutein and zeaxanthin are the only carotenoids in the macula of the eye
- (the macula retina is about 5% of the total retina)
- lutein and zeaxanthin are present in nearly equal amounts in the macula
- absorbs damaging blue light
- protects the eye from macular degeneration and cataracts

II-A-6. Astaxanthin

Astaxanthin



- gives color to salmon, shrimp and crab
- ten times more powerful antioxidant than any other carotenoid
- boosts T-cell production and cytokine release
- can cross the blood-brain barrier (brain antioxidant)
- has water-soluble component allowing it to release trapped radicals to Vitamin C

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II-B. Non-Carotenoid Terpenoids

II-B-1. Perillyl Alcohol

- in cherries and mint
- anticancer, slows cell division and increases apoptosis

II-B-2. Saponins

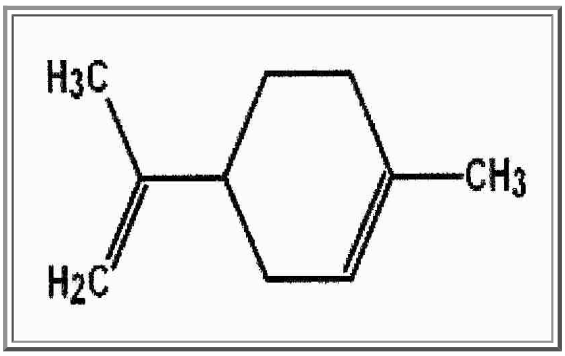
- in legumes (chickpeas and soybeans)
- removes cholesterol
- effective against colon cancer

II-B-3. Terpeneol

- gives carrot flavor to carrots
- causes cell cycle arrest in cancer cells

II-B-4. Terpene Limonoids

Limonene



- in peels & membranes of oranges
- 45 times more anticarcinogenic than hesperetin
- detoxifies carcinogens and promotes cancer cell apoptosis
- l-limonene smells "piney" (like turpentine)
- d-limonene smells like orange
- limonene can be used as a solvent and cleaner
- limonene promotes glutathione-S-transferase (detoxification by glutathione addition)

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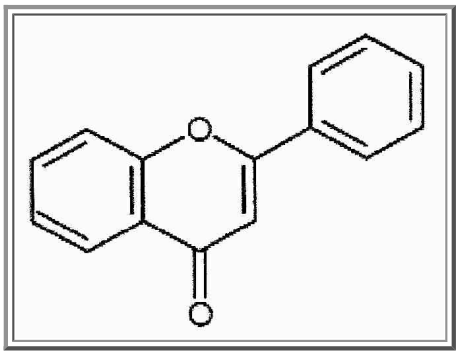
III. Polyphenolics

III-A. Flavonoid Polyphenolics

Flavone



Flavonoids are flavone-like substances that are usually antioxidants and sometimes anti-inflammatory. Flavonoids scavenge free radicals by forming a stable radical that can react with another flavanoid radical to produce two non-radicals. The citrus flavanoids include rutin, hesperidin and naringin. Flavanoids and resveratrol are present in red wine, but are largely absent from white wine because white wine is made by pressing juice away from the solids, whereas red wine is made by fermenting the pulp along with the skin and seeds (although ultrafiltration is sometimes used to reduce astringency and bitterness). For detailed chemistry of the flavonoids, see Flavonoid AntiOxidants.

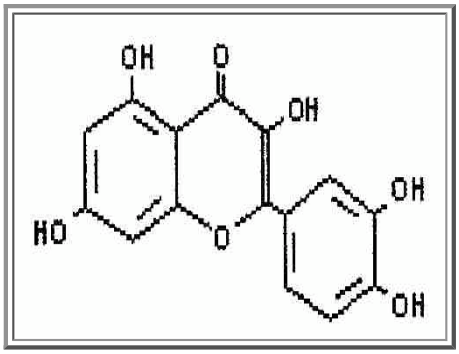
III-A-1. Anthocyanins

Anthocyanins are water-soluble glycosides and acyl-glycosides of anthocyanidins. Anthocyanins make roses red and violets blue. They make cherries & strawberries red and blueberries blue. Blueberries increase anthyocyanin content as they ripen. Anthocyanins have anti-inflammatory effects. Anthocyanins are easily damaged by heat (cooking). Up to 30 different anthocyanins have been found in wild blueberries and Concord grapes. Proanthocyanidins (colorless substances sometimes called "pycnogenols") are short-chained polymers of anthocyanidins that release anthocyanins with heat and/or acidic hydrolysis.

- **in many berries, especially blueberries, blackberries and black raspberries**
- **white grapes lack color because they have no anthocyanins**
- **in green tea**
- **co-occurs with phenolic acids in many berries**
- **protects endothelial cells from oxidative damage**

III-A-2. Catechins

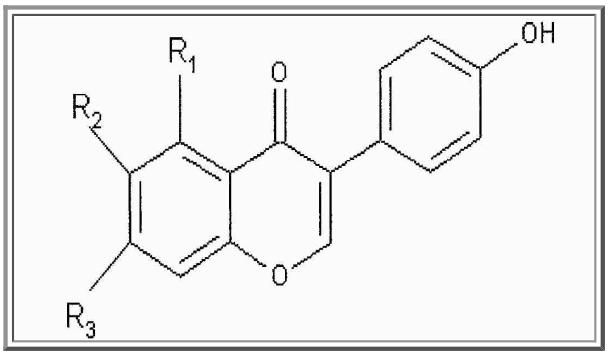
Catechin



- **flavanols**
- **antioxidant found in dark chocolate**
- **lost in drying grapes to raisins**
- **inhibits catechol-O-methyltransferase norepinephrine degredation**
- **increases metabolic rate ("burns fat" while increasing free-radical production)**
- **can halt the initiation and progression of cancer**
- **may strengthen capillaries**
- **can protect against DNA damage, therefore useful for patients undergoing chemotherapy or radiation therapy**

- **the active ingredient in tea**
- **15-20% of green tea solids**
- **5-10% of black tea solids**
- **EpiGalloCatechin Galleate (EGCG) is the most abundant polypheolic in green tea**
- **EGCG not found in black tea, but is found in cranberries**
- **EGCG can increase basal metabolic rate**
- **EGCG inhibits protein nitration**
- **catechins polymerize to tannins in black tea**
- **theaflavins & thearubigins (tannins) are orange-red/black polymers**
- **the longer tea is brewed, the more bitter (more tannins)**
- **tannins are astringent (cross-link proteins, "tan" animal skin to leather)**
- **tea drinking is associated with reduced cancer of ovary, prostate, stomach, colon & oral cavity**
- **inhibits NF-κB transcription of proinflammatory and antiapoptotic (cancer-promoting) genes**

III-A-3. Isoflavones



Glycitein: R_1=H, R_2=OCH_3, R_3=OH

- **most concentrated in soy beans (genistein, glycitein and daidzein)**
- **soy bean has 2-4 milligrams isoflavone/gram, predominantly genistein**
- **found in legumes and pomegranate seeds**
- **genistein inhibits tyrosine kinases involved in tumorigenesis**
- **also found in other legumes, parsley and grains**
- **elevates HDL cholesterol (good cholesterol)**
- **lowers LDL cholesterol (bad cholesterol)**
- **potent antioxidants against superoxide and hydrogen peroxide**
- **estrogenic-like qualities (phytoestrogen)**
- **lignans and isoflavones are the two main categories of phytoestrogens**
- **may reduce menopausal symptoms**
- **prevention of bone resorption (osteoporosis) in post-menopausal women**
- **genistein may prevent breast cancer, but promote existing breast cancer**
- **soy isoflavones shown to inhibit prostate cancer cells by 30%**
- **genistein inhibits tyrosine kinases involved in tumorigenesis**

III-A-4. Hesperetin

- **a flavanone**
- **main flavonoid in oranges and other citrus fruits**
- **antioxidant that regenerates Vitamin C**
- **slows proliferation of cancer cells**
- **slows replication of viruses, including polio, herpes & flu**

III-A-5. Naringin

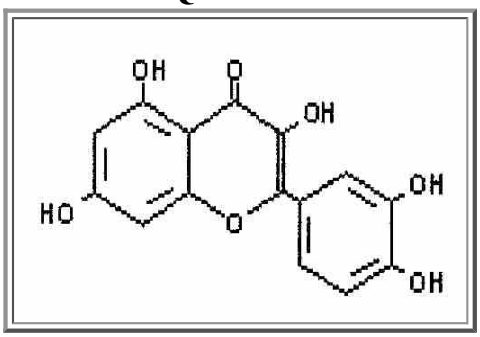
- **a flavanone**
- **gives grapefruit its characteristic bitter taste**
- **may enhance ability to taste by taste-bud stimulation**
- **reduces LDL cholesterol, but not HDL cholesterol**
- **may interfere with intestinal enzymes, thereby increasing oral drug absorption**
- **enhances alcohol & lipid metabolism in the liver, while increasing liver antioxidant activity**
- **protects against alcohol-induced stomach ulcers**
- **protects against radiation-induced DNA damage**
- **antiapoptotic properties**

III-A-6. Rutin

- **in asparagus, buckwheat and citrus fruits**
- **not lost in drying grapes to raisins**
- **strengthens capillary walls**

III-A-7. Quercetin

Quercetin



- **a flavonol**
- **high in red onions, buckwheat, red grapes and green tea**
- **highest in apple skins**
- **not lost in drying grapes to raisins**
- **structural backbone of citrus flavonoids hesperetin & rutin**
- **inclined toward oligomerization into colorless "pycnogenols"**
- **strong antioxidant, reduces LDL oxidation**
- **vasodilator and blood thinner**
- **can kill viruses, such as herpes**
- **antihistaminic activity can relieve allergy symptoms**
- **inhibits COMT (Catechol-O-MethylTransferase) enzyme thereby reducing epinephrine breakdown**
- **(increased epinephrine increases fat oxidation and energy expenditure -- "thermogenesis")**
- **inhibition of heat shock protein can promote apoptosis in cancer cells and other cells**
- **sirtuin-like deacetylase action**

III-A-8. Silymarin

- **found in artichokes and milk thistle**
- **protective against skin cancer**
- **strong antioxidant, anti-carcinogenic and anti-inflammatory**
- **anti-atherosclerotic (inhibits expression of adhesion molecules)**
- **helps digestion of fat**

III-A-9. Tangeretin

- **from tangerines**
- **36 times stronger than hesperetin at stopping cancer cell proliferation**

III-A-10. Tannins

Tannin is a functional term rather than a distinct chemical group. Tannins have been used to tan and protect leather since the 18th century. Tannins are polyphenolics that make cranberries and pomegranates bitter. Tannins, along with Vitamin C, help build and strengthen collagen. Tannins prevent urinary tract infection by preventing bacteria from adhering to the walls. Combination of tannin plus anthocyanins (as in pomegranate juice) can break-down oxidized cholesterol in the bloodstream and in atherosclerotic plaques. Most of the active compounds in black tea are tannins which are 90% catechins. Epicatechin is the major component of natural tannin in grapes. The hydrolyzable tannins in aged wines come from the oak barrels, and are mainly composed of gallic acid and ellagic acid esters.

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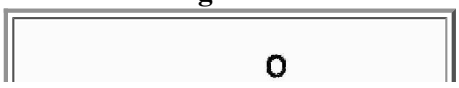
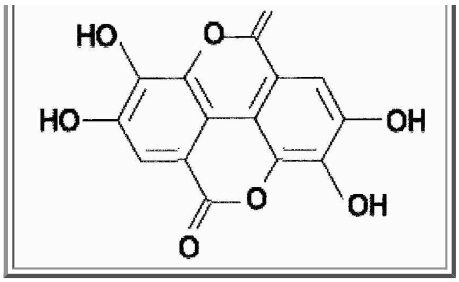
III-B. Phenolic Acids

Ellagic Acid



Cranberry juice is rich in phenolic acids, which reduce adherence of bacteria to teeth and the cells lining the bladder -- thereby reducing urinary tract infections and dental caries. Sweetening reduces the anti-adhesion properties of phenolic

acids. Phenolic acids reduce oxidation of LDL cholesterol. Phenolic acids reduce the formation of cancer-promoting nitrosamines from dietary nitrates and nitrites. The most important phenolic compounds in grapes (red wine, grape juice, raisons) are proanthocyanidins, resveratrol and ellagic acid.



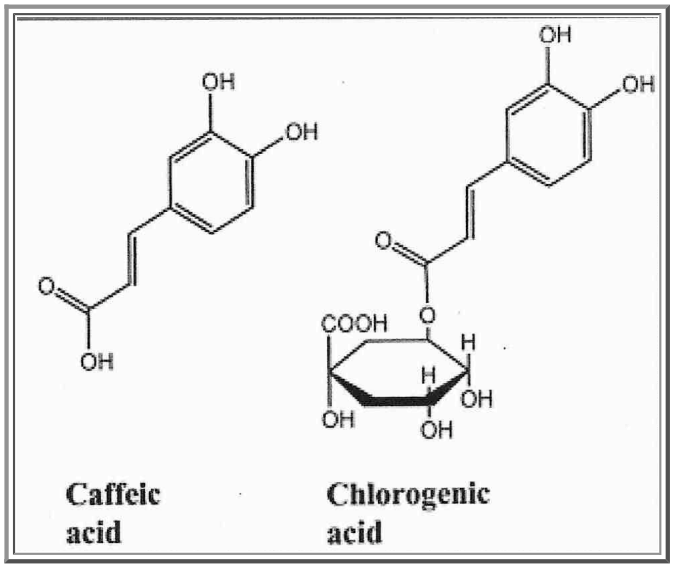
III-B-1. Ellagic Acid

- rich in strawberries. but 50% more in raspberries (mainly ellagitannins)
- reduces esophagal and colon cancers
- inhibits the formation of DNA adducts
- inhibits phase 1 enzymes and potentiates phase 2 enzymes

III-B-2. Chlorogenic Acid

- very high in blueberries, tomatoes and bell peppers
- found in the flesh of grapes, along with ellagic acid
- most frequently an ester of caffeic acid
- caffeic acid is a hydroxycinnamic acid
- caffeic acid reduces mutagenicity of polycyclic aromatic hydrocarbons
- major contributor to the antioxidant activity of coffee
- caffeic acid can regenerate oxidized Vitamin E
- may be pro-oxidant in the propagation phase of LDL oxidation
- roasting coffee increases antioxidant activity

Caffeic Acid Ester



III-B-3. P-Coumaric Acid (Para-Coumeric Acid)

- high in red & green bell peppers
- antioxidant for the colon mucosa
- flavonoid precursor
- binds with nitric acid and its derivatives before they combine with protein amines to form nitrosamine

III-B-4. Phytic Acid

- in legumes and whole grains
- rich in wheat bran and flaxseed
- principle means plants store phosphate
- binds minerals, especially calcium and iron
- mineral chelation may reduce free radicals
- can reduce calcium absorption from the gut
- reduces starch digestion (lowers blood glucose)
- iron-binding effect slows cancer growth and reduces cardiovascular disease
- (cancer cells need iron for growth)

III-B-5. Ferulic Acid

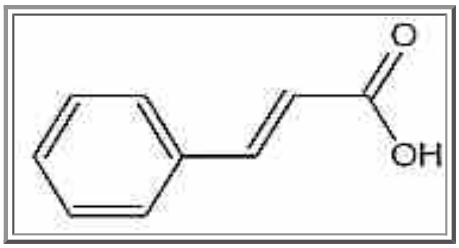
- abundant in cell walls
- seeds of brown rice, whole wheat and oats
- in apple, artichoke, orange, peanut and pinapple
- precursor to vanillin
- antioxidant and anticancer
- antitumor activity in breast & liver cancer

III-B-6. Vanillin

- primary extract from the vanilla bean
- flavoring agent
- commercially synthesized from fermented lignin (paper manufacturing byproduct)
- antimutagenic and antioxidant
- inhibits carcinogenesis
- anti-inflammatory (inhibits peroxynitrite)
- inhibits double-strand DNA breaks (NHEJ)

III-B-7. Cinnamic Acid

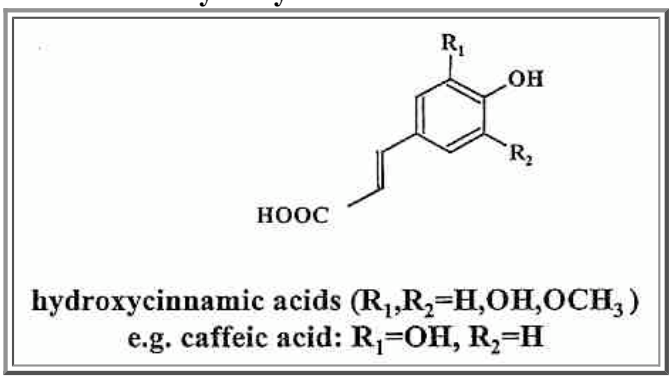
Cinnamic Acid



- phenylacrylic acid
- gives oil of cinnamon's characteristic odor and flavor
- antibacterial, antifungal, antiparasitic properties
- building block for lignans
- rich in balsam tree resins, wood and inner bark
- combine with flaconoids & benzoic acid derivatives to form tannins & pigments
  that give vintage wines bouquet & color

III-B-8. Hydroxycinnamic Acids

Hydroxycinnamic Acids



- a superset which includes p-coumaric, caffeic and ferulic acid
- major phenolic acids in blueberries & blackberries
- in the flesh of grapes
- the only polyphenol in white grape juice

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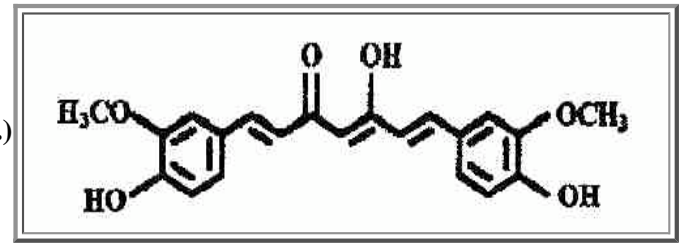
III-C. Other Non-Flavonoid Polyphenolics

III-C-1. Curcumin

Curcumin



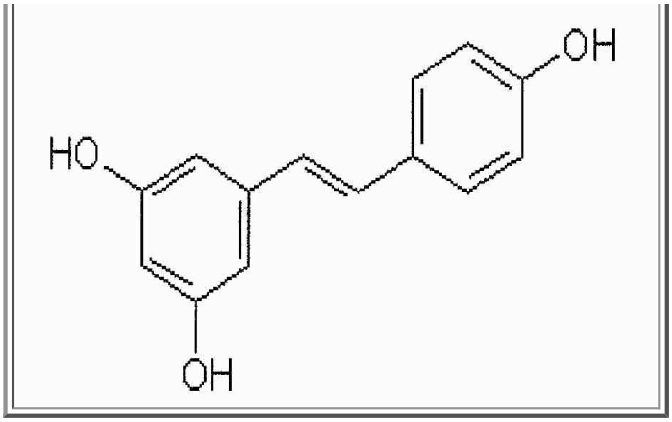
Curcumin is a phytochemical in the spice tumeric which is used to make curry. (The spice "cumin" contains *no* curcumin, despite the similar name). Curcumin inhibits the gene that makes inflammatory COX-2 enzymes, preventing their production. (Celebrex simply inhibits COX-2 enzymes.) Curcumin is both strongly anti-inflammatory and strongly anti-oxidant. Curcumin inhibits release of the pro-inflammatory cytokine TNF-alpha. Curcumin is a more effective anti-clotting agent than aspirin, without the ulcer-inducing stomach irritation caused by aspirin.

- **bright yellow (makes curry yellow)**
- **can scavenge peroxynitrite free-radical**
- **can prevent colon cancer**
- **blocks amyloid-beta aggregation, which may prevent Alzheimer's Disease**
- **inhibits NF-ϰB transcription of proinflammatory and antiapoptotic (cancer-promoting) genes**

III-C-2. Resveratrol

Resveratrol

Resveratrol shows the strongest sirtuin-like deacetylase action of any known phytochemical. Sirtuins have been shown to extend the lifespan of yeast and fruit flies. Contrary to media representations, there are other sources of resveratrol besides alcoholic beverages (red wine) -- such as purple grape juice.



- **a stilbene**
- **especially high in grape skin**
- **the principle stilbene in grapes**
- **in teas (green and black), berries and peanuts**
- **created by plants as defense against fungi**
- **anti-inflammatory, inhibits COX-1 enzyme**
- **blocks adhesion of blood cells to vessel walls**
- **shown to reduce skin and breast cancer in mice**
- **induces phase 2 enzymes**
- **inhibits NF-κB transcription of proinflammatory and antiapoptotic (cancer-promoting) genes**

III-C-3. Lignans

- cinnamic acid dimers (2-unit composites)
- strengthens plant cell walls (wood)
- water soluble, not oil soluble
- flaxseed (not flax oil) the richest dietary source by far
- podophyllotoxin lignan a cytotoxic agent which treats venereal warts
- phytoestrogens
- may reduce cancer risk in women

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IV. Glucosinolates

Glucosinolates convert to **isothionates** (contain sulfur) and **indoles** (contain no sulfur) when vegetables containing them are cut. They are high in cruciferous vegetables, particularly cauliflower & cabbage -- and to a lesser extent in broccoli & brussel sprouts. They act against cancer by phase 2 enzyme induction. Broccoli and cabbage show the greatest protection against bladder cancer.

IV-A. Isothiocyanates

Isothiocyanates are responsible for the hotness of horseradish, radish and mustard. Isothiocyanates are (-N=C=S) compounds. Allyl isothiocyanate is also called mustard oil.

IV-A-1. Phenethyl Isothiocyanate

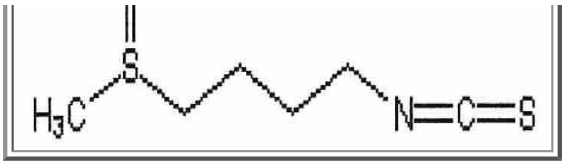
- gives bitter taste to watercress
- inhibits tumorigenisis by polycyclic aromatic hydrocarbons
- induces apoptosis by caspase-8 (not p53) activation
- particularly good against nitroamines in tobacco smoke
- (nitric oxide + nicotine => nitrosonicotine, main carcinogen of tobacco smoke)

IV-A-2. Sulforaphane

Sulforaphane

- especially rich in broccoli

- potent phase 2 enzyme inducer
- causes cell cycle arrest and apoptosis of cancer cells
- produces D-glucarolactone, a significant inhibitor of breast cancer



IV-B. Indoles

IV-B-1. Indole-3-Carbinol (I3C)

- most important indole in broccoli
- inhibits the human papilloma virus (HPV), which can cause uterine cancer
- blocks estrogen receptors in breast cancer cells
- downregulates CDK6 an upregulates p21 & p27 in prostate cancer cells
- induces G_1 cell cycle arrest and apoptosis of breast & prostate cancer cells
- increases p53 expression in cells treated with benzo(a)pyrene
- depresses Akt, NF-kappaB, MAPK and Bcl-2 signalling pathways

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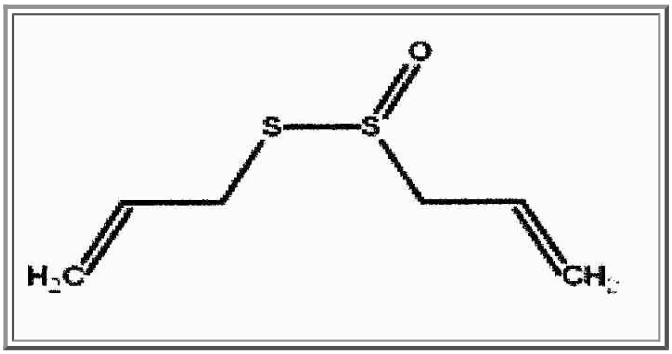
Allicin



V. Thiosulfonates

- organosulfur phytochemicals in garlic and onions (garlic has more sulfur than onions)
- includes mercaptocysteines and allylic sulfides (an **allyl** is a hydrocarbon-sulfur bond)
- allylic sulfides contribute to the strong odor of garlic
- allicin protects garlic from pests
- allicin is toxic to insects and microorganisms
- allicin protects against ulcers by inhibiting *Helicobacter pylori*
- allicin is not stable when removed from garlic
- allicin inhibits mammary, endometrial and colon cell proliferation
- garlic can lower blood cholesterol nearly 10% in high-cholesterol plants
- garlic can lower blood pressure
- garlic can induce nitric oxide synthetase activity
- garlic inhibits platelet aggregation by arachidonic acid, epinephrine and other platelet agonists
- propanethial-S-oxide released from cut onions converted to sulfuric acid in eyes (causes "burning")
- cooking garlic & onions destroys the enzyme allinase, preventing formation of beneficial sulfur compounds

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VI. Phytosterols

VI-A. Beta-Sitosterol

- similar to cholesterol in structure
- plant equivalent of animal cholesterol
- reduces cholesterol manufacture by the liver
- blocks cholesterol absorption
- slows cancer cell growth (cholesterol needed for cell membranes)
- inhibition of epithelial cell division may reduce atherosclerosis

Food	Beta-Sitosterol *
Peanut butter	135
Cashews	130
Almonds	122
Peas	106
Kidney beans	91
Avocados	76

*** milligrams per 100 grams**

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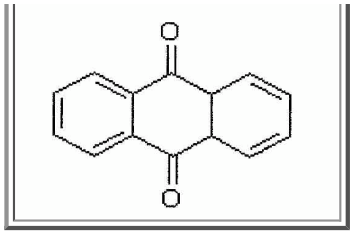
VII. Anthraquinones

Anthraquinone



VII-A. Senna

- sennosides are dianthrones
- from dried leaves of leguminous herbs or shrubs of the pulse family
- purgative for the lower bowel
- increases peristaltic movements in the colon
- nauseating taste
- contraindicated for **hemorrhoids** or inflammation

VII-B. Barbaloin

- = aloin
- from Aloe vera plant (lily & onion family)
- laxative (lower bowel)
- uterine stimulant (abortifacient)
- used by Galen
- heal skin burns & ulcers
- antihelminthic
- can cause gastritis, diarrhea & nephritis

VII-C. Hypericin

- red pigment
- from *Hypericum perforatum* ("St John's Wort")
- analgesic, treat neuralgic pain
- folk remedy for depression, anxiety and insomnia
- no purgative properties
- can sometimes treat ulcers and gut inflammation
- sometimes causes rashes after exposure to UV light

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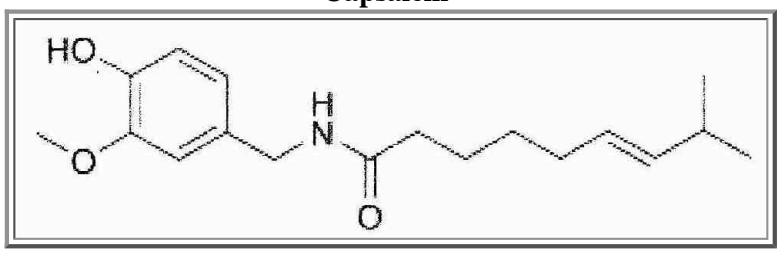
VIII. Capsaicin

Capsaicin



- makes chilli peppers "hot"
- in "pepper spray" for riot control
- burning sensation for mammals, not birds
- stimulates neurons for burning and abrasion sensation
- soluble in fat & alcohol, not water
- can cool mouth with cold milk, alcohol or ice cream
- potency not reduced by cooking or freezing
- promotes apoptosis in pancreatic cancer cells
- no effect on normal pancreatic cells
- may relieve chemotherapy-induced neuropathy
- inhibits NF-ϰB transcription of proinflammatory and antiapoptotic (cancer-promoting) genes

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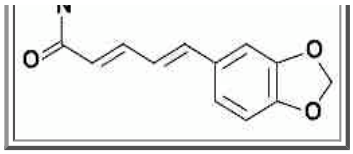
IX. Piperine

Piperine

- found in black pepper (peppercorns, hot jalapeno peppers)

- generates heat, sneezing (spicy taste)
- increases intestinal absorption of foods
- insecticide
- used historically as a spice to mask the taste of spoiling meat



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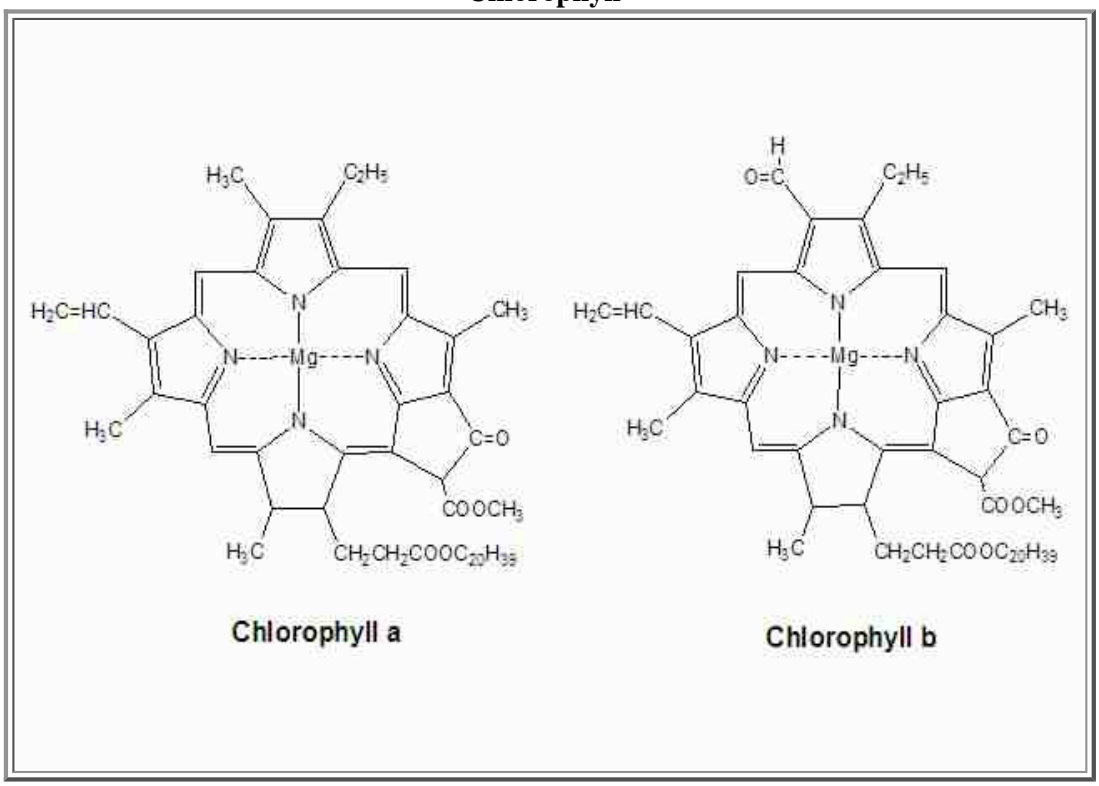
X. Chlorophyll

Chlorophyll



- the most abundant pigment in plants
- the principal light-absorbing pigment in photosynthesis
- from Greek ***chloros*** "yellowish green"
- porphyrine ring similar to heme (of hemoglobin), but magnesium (not iron) central atom
- not water soluble (grass stain)
- breath freshener
- forms tight molecular complexes with some carcinogens: aflatoxin-B1, polyaromatic hydrocarbons (tobacco smoke) & heterocyclic amines (cooked meat)
- chlorophylll absorbs red & violet light strongly
- chlorophyll reflects green light (making leaves green)
- chlorophyll in leaves decays in autumn, leaving carotenoid colors
- **chlorophyll a** has a $-CH_3$ side-chain
- **chlorophyll b** has a –CHO side-chain
- plants contain both chlorophyll a and chlorophyll b
- chlorophyll b is missing from cyanobacteria
- (**cyanobacteria** are the toxin-producing pond scum bacteria known as "blue-green algae")
- chlorophyll a absorbs red light more strongly
- chlorophyll b absorbs violet light more strongly

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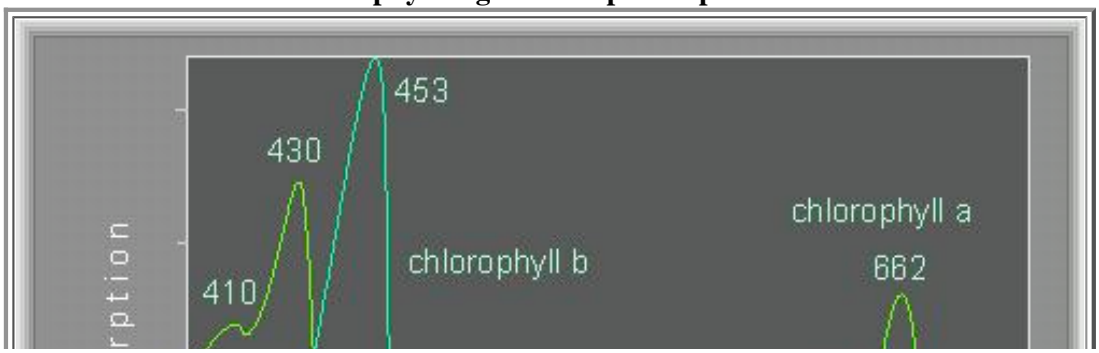
Chlorophyll Light-Absorption Spectrum



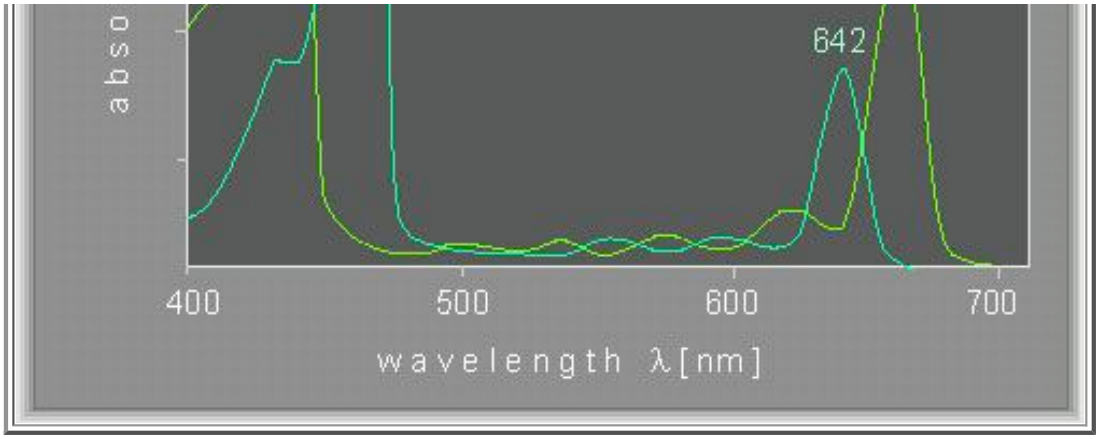
XI. Betaine

- betaine = trimethylglycine
- found in beets
- capable of removing pro-atherosclerotic protein homocysteine

from the body

XII. Pectin

- soluble fiber in apples (gives feeling of fullnes when eaten)
- binds to sugars, releasing them slowly and keeping blood sugar levels steady
- lowers cholesterol



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XIII. Oxalic Acid

See Calcium and Adequate Nutrition for more about kidney stones.

- especially high in rubarb
- also found in raw spinach, beets, cocoa, nuts, parsley and tea
- binds to calcium, reducing availability
- excreted in urine (with calcium) or forms kidney stones

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XIV. Table of Dominant Phytochemical Pigments

The following table gives the phytochemical or phytochemical class which provides the predominant source of coloring for the specified fruits or vegetables

DOMINANT PHYTOCHEMICAL PIGMENTS

COLOR	PIGMENT	FRUIT OR VEGETABLE
RED	Anthocyanins	Strawberries, Raspberries, Cherries, Cranberries, Pomegranates, Apples, Red Grapes
	Lycopene	Tomatoes, Pink Grapefruit, Watermelon
	Betacyanins	Beets
ORANGE	Beta-carotene	Carrots, Mangoes, Apricots, Cantelope, Pumpkin, Sweet Potatoes
	Beta-cryptoxanthin	Oranges, Tangerines
BLUE/PURPLE	Anthocyanins	Blueberries, Plums, Eggplant, Concord grapes
YELLOW	Lutein, Zeaxantin	Corn, Avocado
	Curcumin	Tumeric (Curry)
GREEN	Chlorophyll	Broccoli, Kale, Spinach, Cabbage, Asparagus, Green Tea

BLACK	**Thearubigens**	**Black tea**
	Anthocyanins	**Blackberries**

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XV. Other Sources of Information

For a good non-technical introduction to phytochemicals -- with emphasis on plants of origin rather than chemistry -- see THE COLOR CODE by James A. Joseph, et.al. (2002), and EAT YOUR COLORS by Marcia Zimmerman (2001).

My essay General Anti-Oxidant Actions contains much material which is relevant to understanding phytochemical action and effect.

For a review of the chemistry of phenolics found in grapes and wine, see ANNALS NEW YORK ACADEMY OF SCIENCES; Waterhouse,AL; 957:21-26 (2002).

A good review of the chemistry of polyphenols can be found in AMERICAN JOURNAL OF CLINICAL NUTRITION; Véronique Cheynier; 81(Suppl):223S-229S (2005)

List of phytochemicals

Linus Pauling Micronutrient Center

The World's Healthiest Foods

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