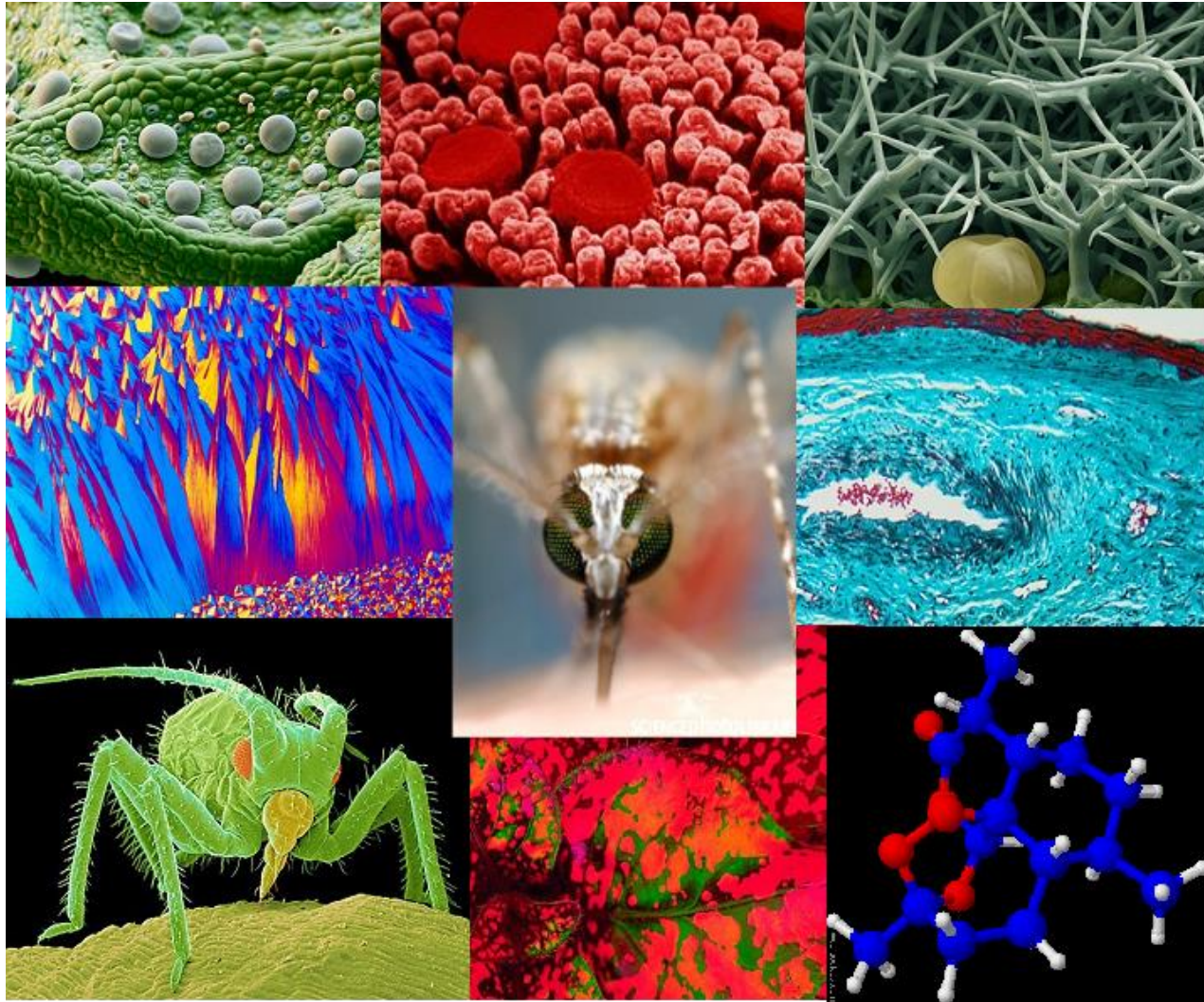




Δευτερογενής μεταβολισμός




Δευτερογενείς μεταβολίτες (φυσικά προϊόντα – εξειδικευμένοι μεταβολίτες)

 >200.000 ενώσεις

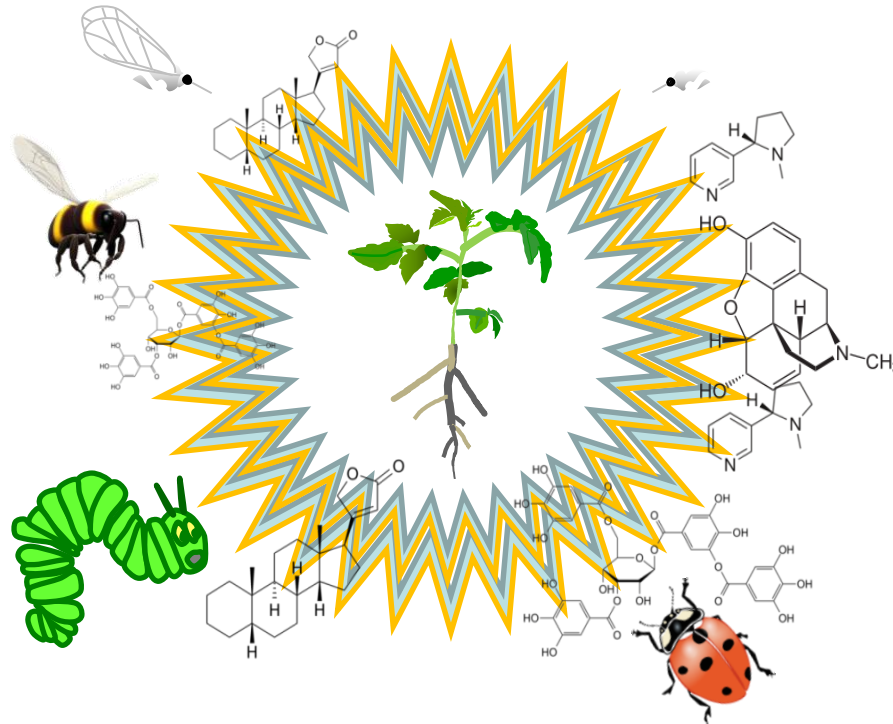
 προέρχονται από ενδιάμεσες ενώσεις του πρωτογενούς μεταβολισμού

 μόνο σε επιμέρους ιστούς / σε συγκεκριμένα αναπτυξιακά στάδια / σε ορισμένα είδη (οικογένειες, ποικιλίες κοκ) φυτών

 δεν απαιτούνται για την ομαλή διεξαγωγή των βασικών φυσιολογικών λειτουργιών ?

Ρόλος

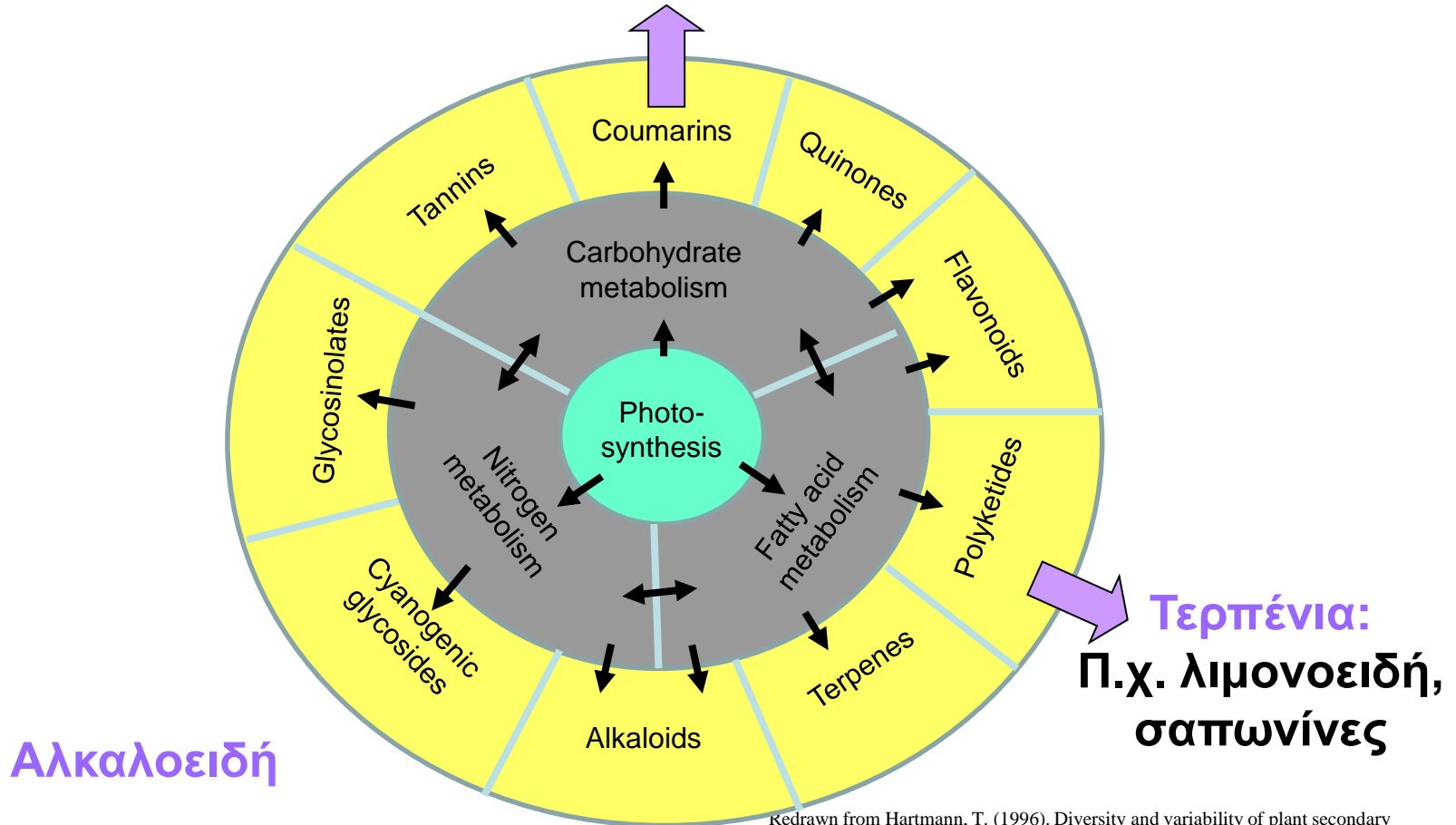
- ✓ σε σημαντικές λειτουργίες της οικολογίας του φυτού (προστασία από βιοτικούς και αβιοτικούς παράγοντες, προσέλκυση επικονιαστών)



- ✓ στην αύξηση και ανάπτυξη του φυτού (π.χ. φυτόλη χλωροφύλλης, καροτενοειδή, αμπζισικό οξύ, *dolichols*- μεταφορείς σακχάρων κατά τη γλυκοσυλίωση πρωτεϊνών, φλαβονοειδή και αναπαραγωγή)

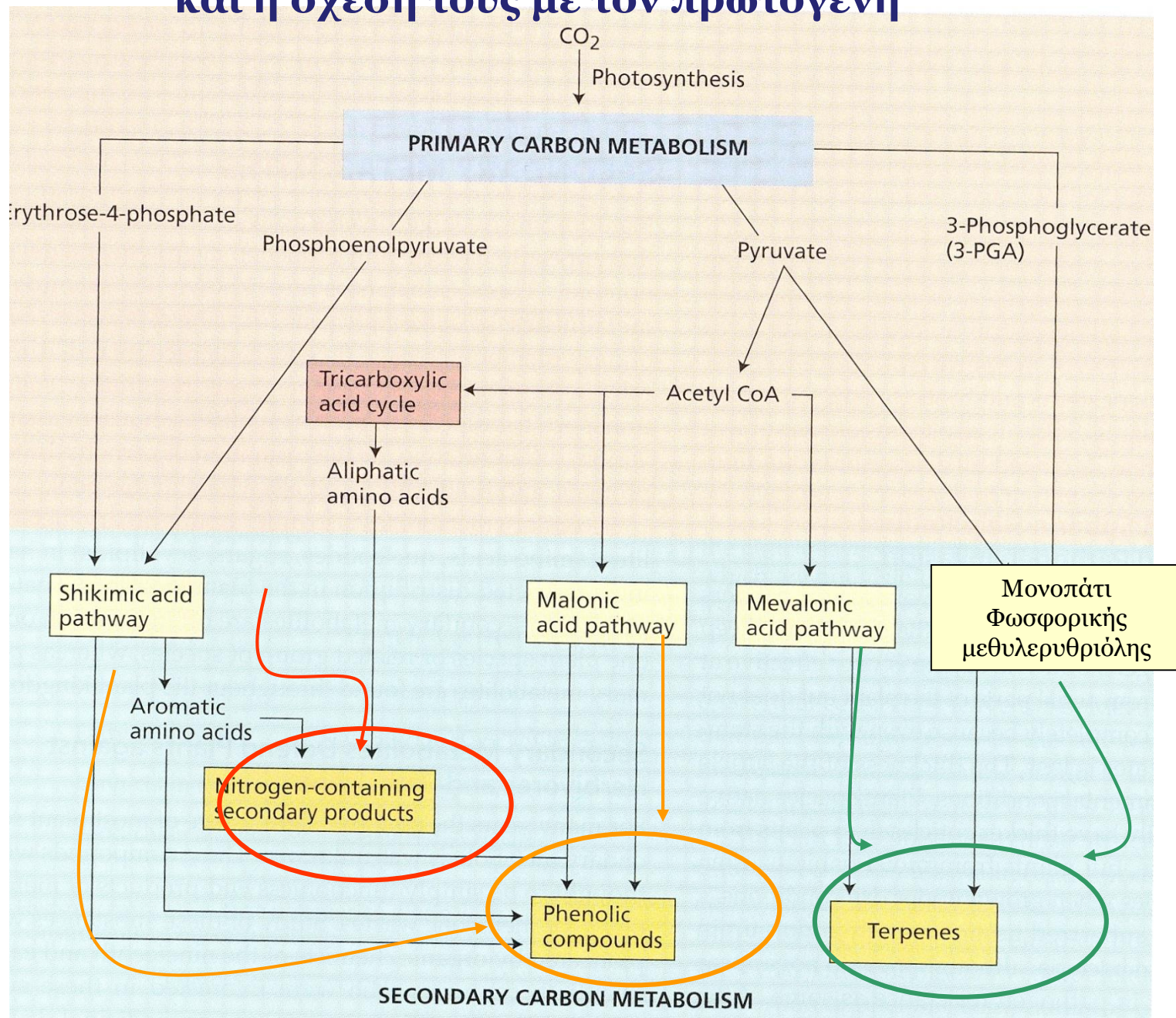
Τρεις βασικές δομικές ομάδες

Φαινολικές ενώσεις: π.χ. φλαβονοειδή, σαλικυλικό οξύ, λιγνίνη, κτλ



Redrawn from Hartmann, T. (1996). Diversity and variability of plant secondary metabolism: a mechanistic view. *Entomologia Experimentalis et Applicata* 80: [177-188](#).

Τα κυριότερα μονοπάτια βιοσύνθεσης δευτερογενών μεταβολιτών και η σχέση τους με τον πρωτογενή



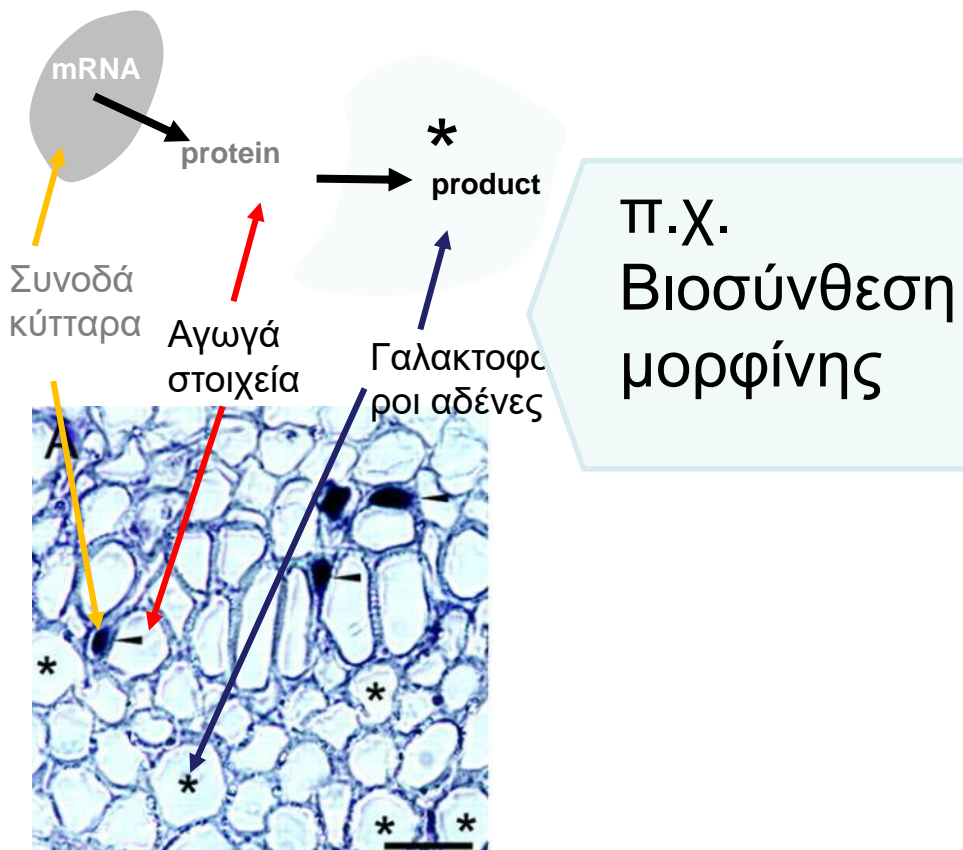
Διοχέτευση μεταβολιτών και σχηματισμός “μεταβολονίου”

Metabolic channeling & metabolon formation

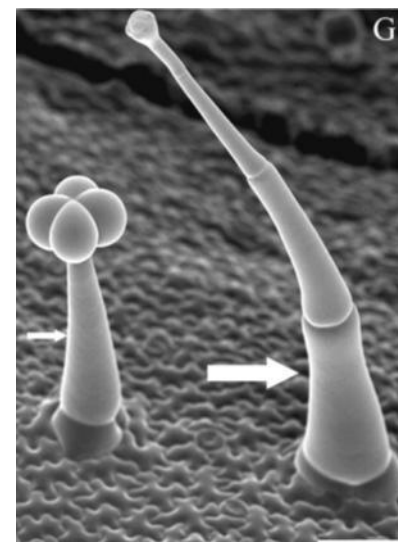
- ❖ πολυγονιδιακές οικογένειες γονιδίων
- ❖ regioselective / regiospecific
- ❖ γλυκοσυλ-, μεθυλ-, ακυλο- τρανσφεράσες / οξειδάσες

- οργανοειδική έκφραση των ενζύμων
- κυτταροειδική
- υπο-κυτταρική
- σχηματισμός “μεταβολονίου”

Ένζυμα και μεταβολίτες είναι διαμερισματοποιημένα



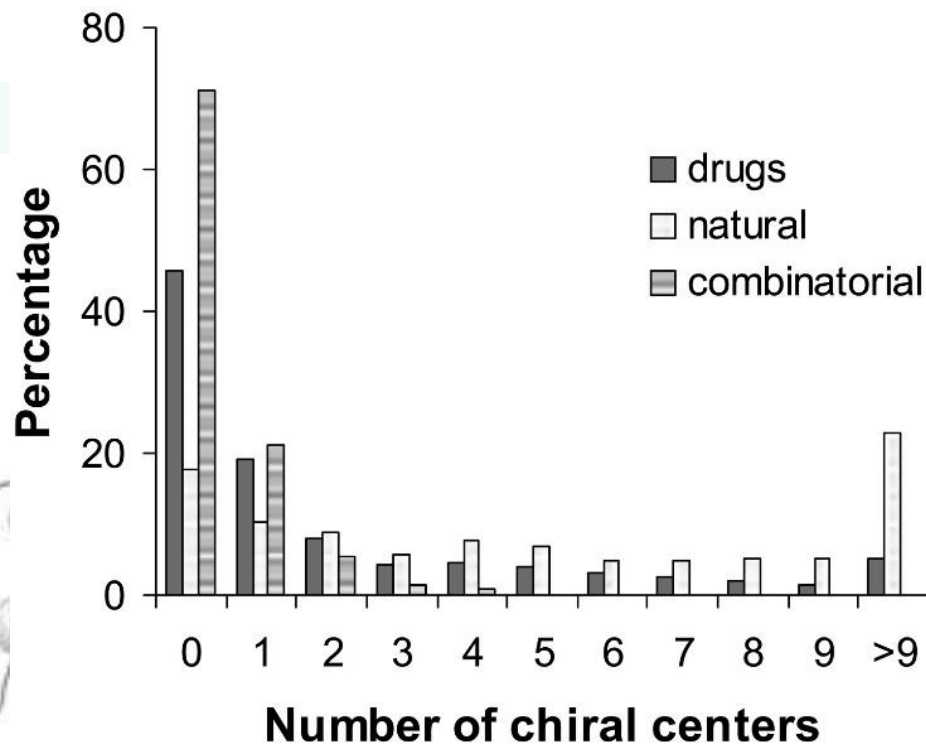
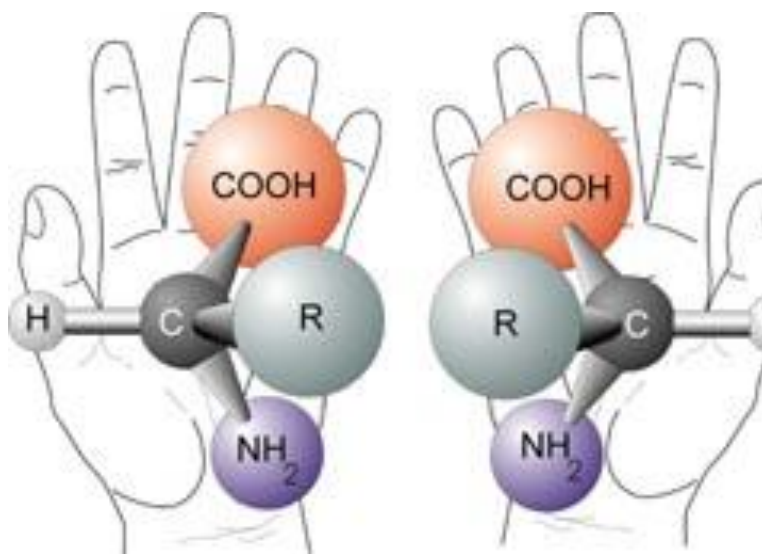
Συσσώρευση σε τριχώματα _ “βιοχημικά εργοστάσια”



Bird, D.A., Franceschi, V.R. and Facchini, P.J. (2003). A tale of three cell types: Alkaloid biosynthesis is localized to sieve elements in opium poppy. *Plant Cell*. 15: [2626-2635](#). See also Ziegler, J. and Facchini, P.J. (2008). Alkaloid biosynthesis: Metabolism and trafficking. *Annu. Rev. Plant Biol.* 59: 735-769. Dai, X., Wang, G., Yang, D.S., Tang, Y., Broun, P., Marks, M.D., Sumner, L.W., Dixon, R.A. and Zhao, P.X. (2010). TrichOME: A comparative Omics database for plant trichomes. *Plant Physiol.* 152: [44-54](#). Schillmiller, A.L., Miner, D.P., Larson, M., McDowell, E., Gang, D.R., Wilkerson, C. and Last, R.L. (2010). Studies of a biochemical factory: Tomato trichome deep expressed sequence tag sequencing and proteomics. *Plant Physiol.* 153: [1212-1223](#).

οι δευτερογενείς μεταβολίτες χαρακτηρίζονται από την ύπαρξη εναντιομερών

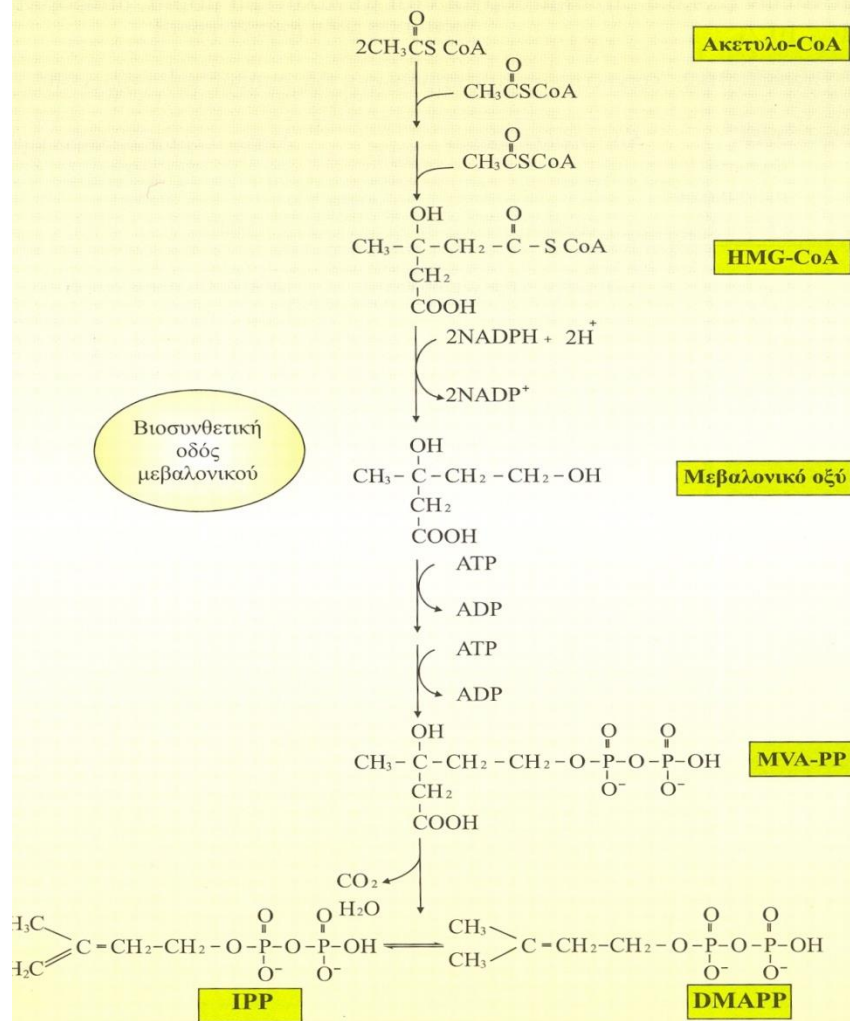
Δύσκολα να παραχθούν συνθετικά



Η μεταβολική μηχανική φυσικών συστημάτων είναι σημαντική μέθοδος για την παραγωγή απαραίτητων ενώσεων φυτικής προέλευσης

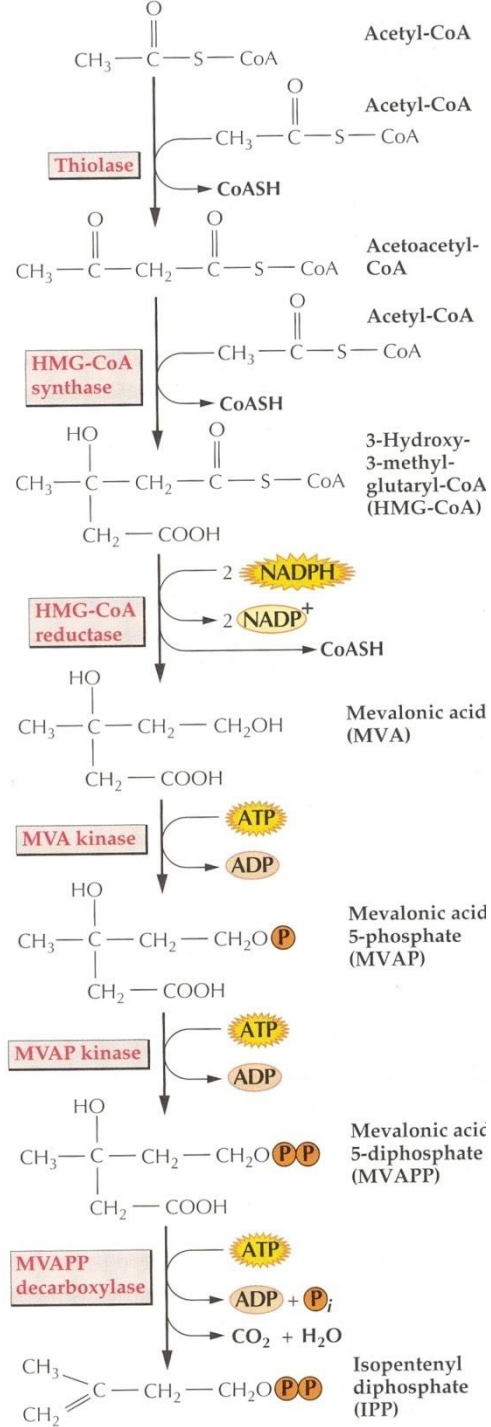
Τερπένια (τερπενοειδή ή ισοπρενοειδή)

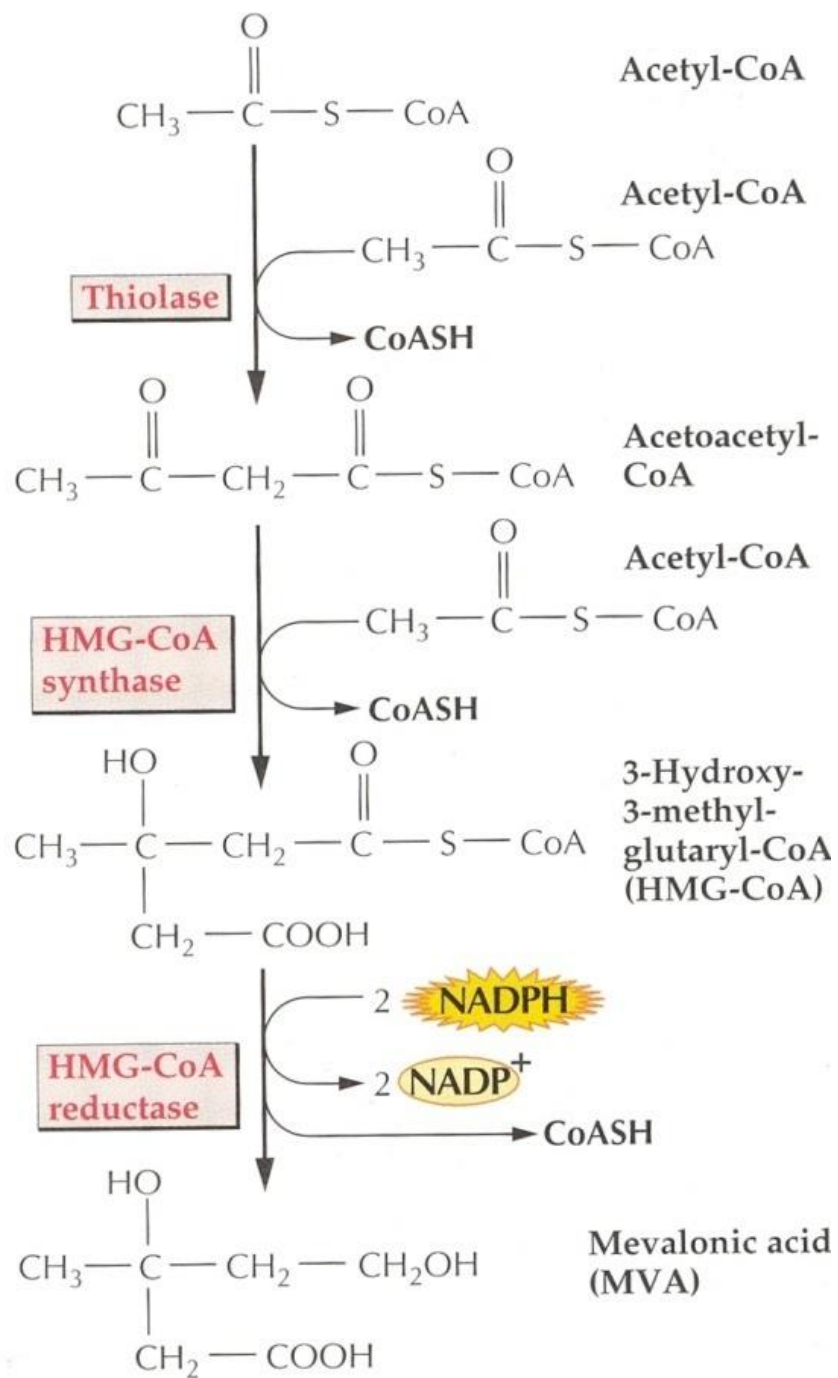
Τερπένια (τερπενοειδή ή ισοπρενοειδή)

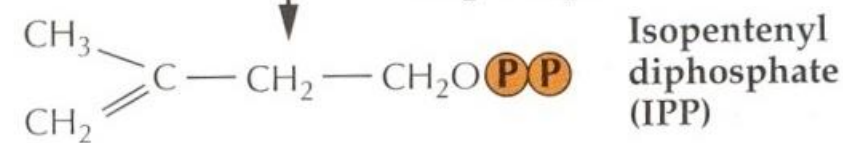
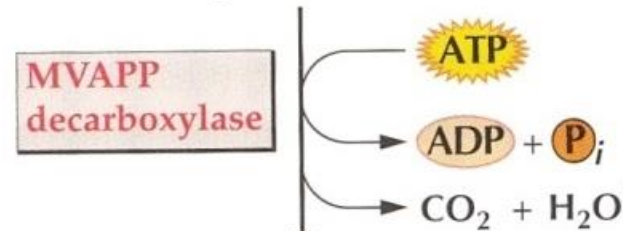
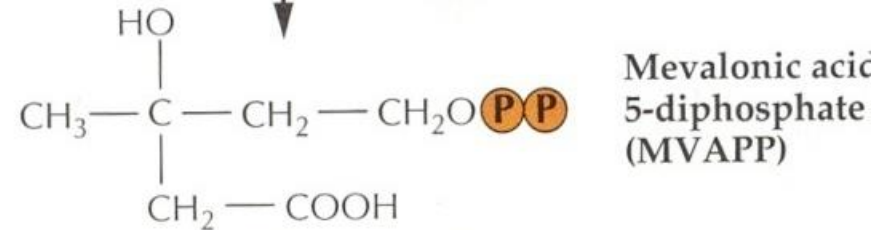
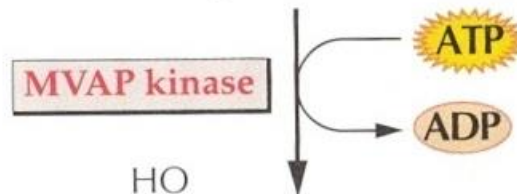
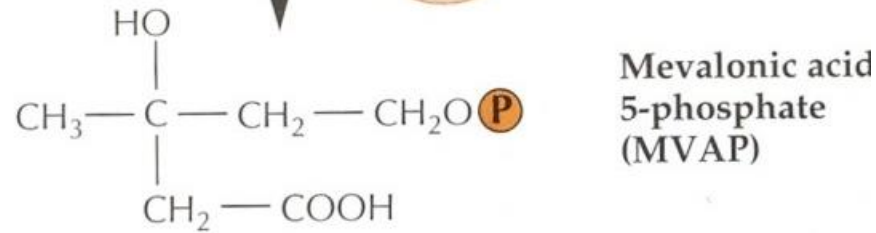
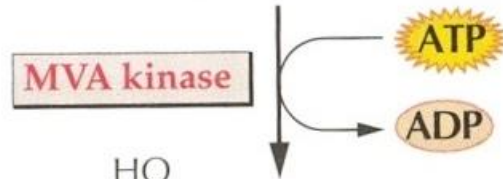
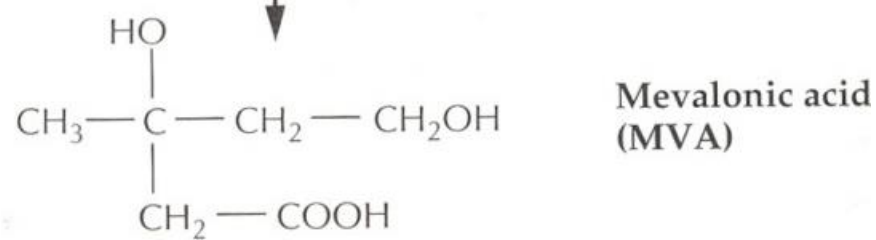


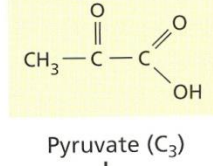
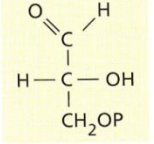
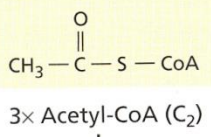
υλοκυτταρικός εντοπισμός

- στο ER
- σε σφαιρικά κυστίδια

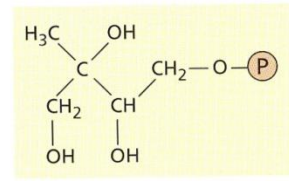
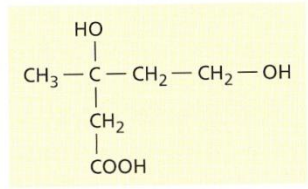








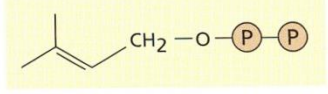
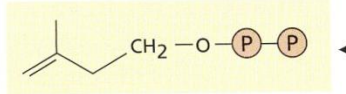
Mevalonate pathway



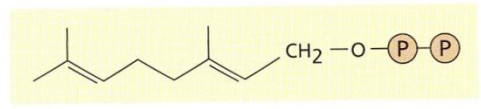
Methylerythritol phosphate pathway

κυτοπλάσμα

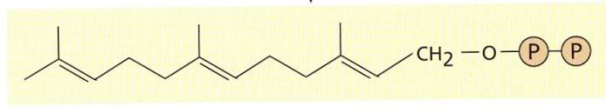
πλαστίδια



→ Isoprene (C₅)

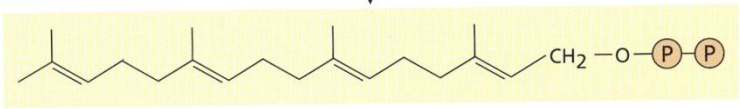


→ Monoterpenes (C₁₀)



→ Sesquiterpenes (C₁₅)

2x → Triterpenes (C₃₀)

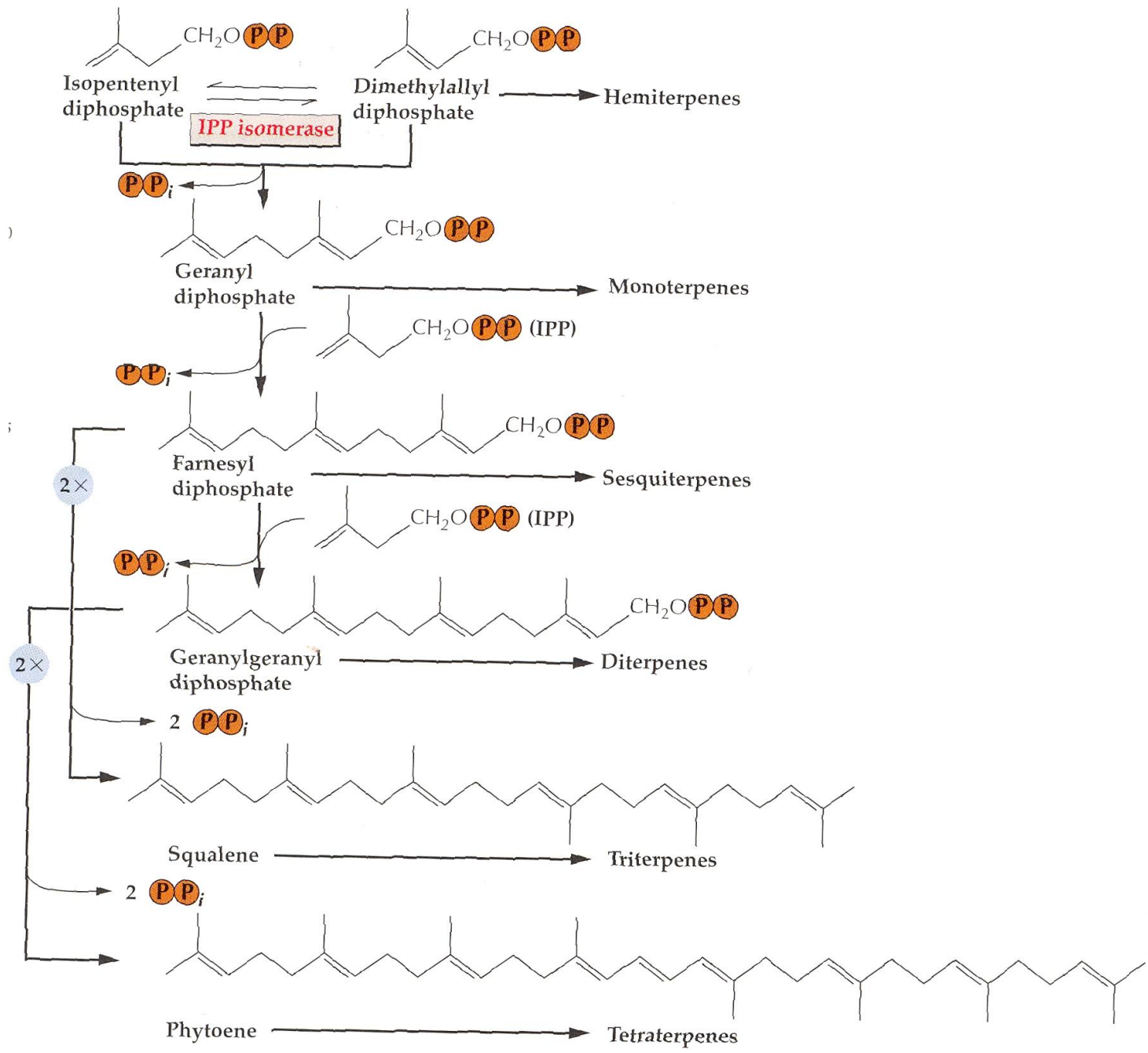


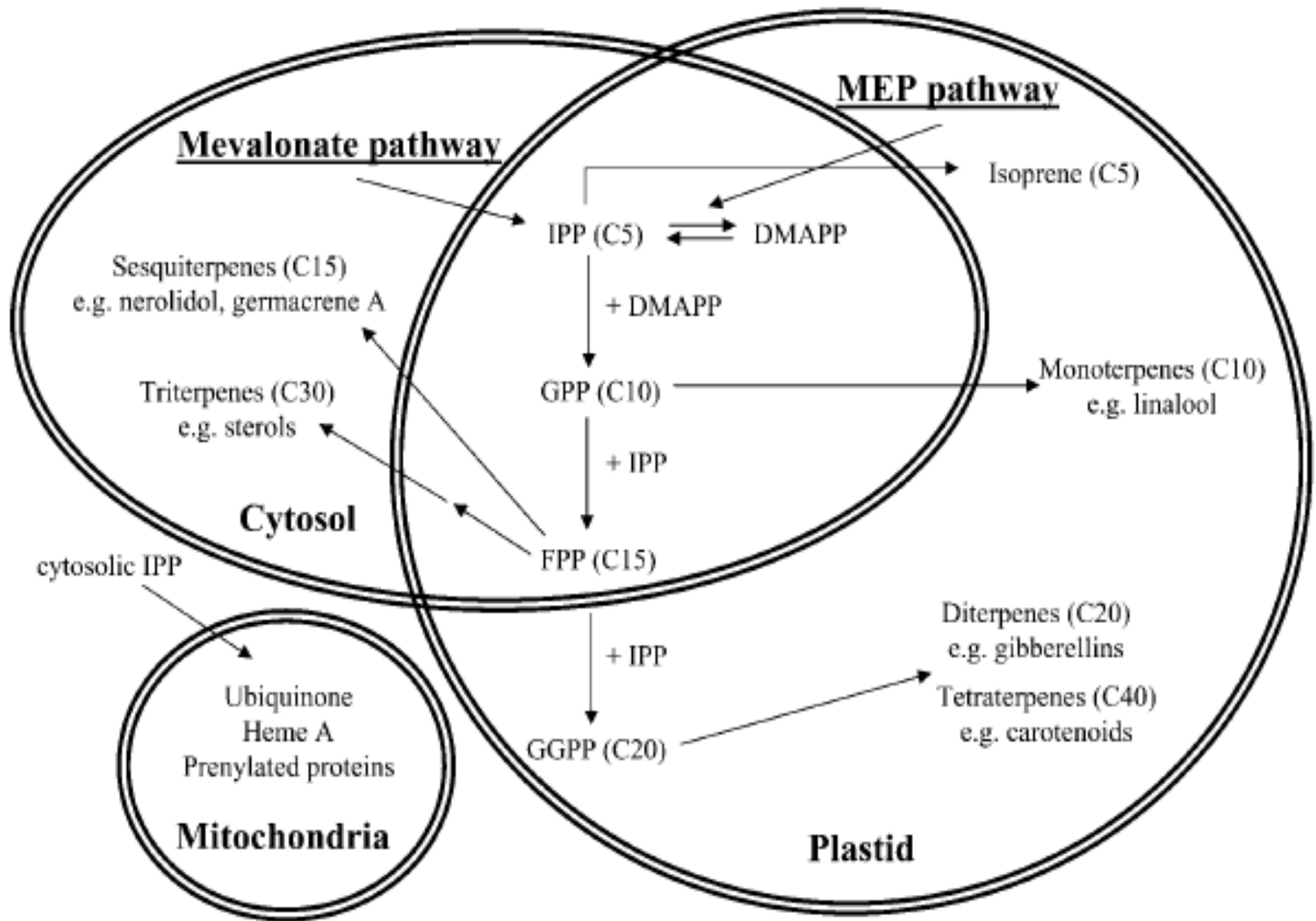
→ Diterpenes (C₂₀)

2x → Tetraterpenes (C₄₀)

Polyterpenoids

prenyltransferases



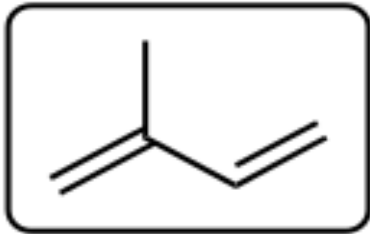


Διαμερισματοποίηση της βιοσύνθεσης ισοπρενοειδών στο φυτικό κύτταρο

Μονοτερπένια (C₁₀) και Σεσκιτερπένια (C₁₅)

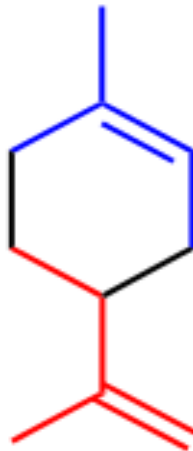
- **Πτητικές ενώσεις** με προστατευτικό ρόλο, κυρίως ενάντια σε έντομα (π.χ. πυρεθροειδή, γερανιόλες, καμφορά, πινένιο-ρητίνη κωνοφόρων)
- **Αθέραια Έλαια** (Μίγματα μονοτερπενίων και σεσκιτερπενίων, συνήθως σε αδενώδεις τρίχες και αδένες)
- **Φυτοαλεξίνες** (C₁₅) : αντιμικροβιακή δράση στο σημείο προσβολής- επαγωγίμες ενώσεις (π.χ. *Rishitin* από πατάτα/ντομάτα, *capsidiol* από πιπεριά/καπνό)

Isoprene

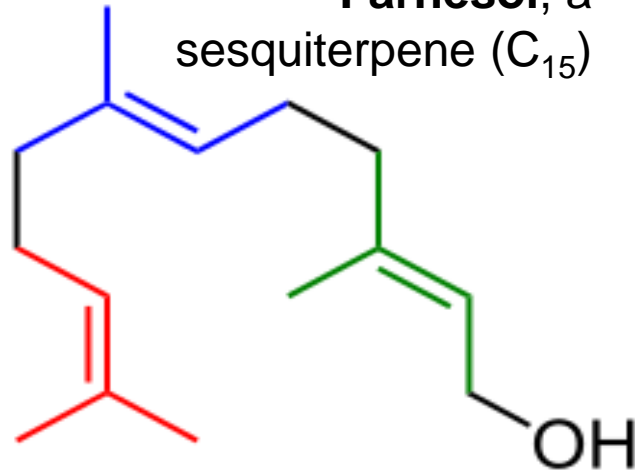


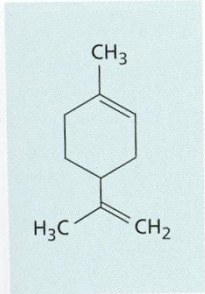
Isoprene (C₅)

Limonene, a monoterpene
(C₁₀)

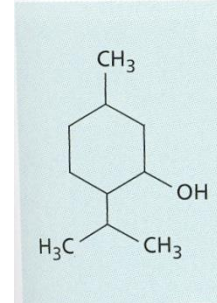


Farnesol, a sesquiterpene
(C₁₅)



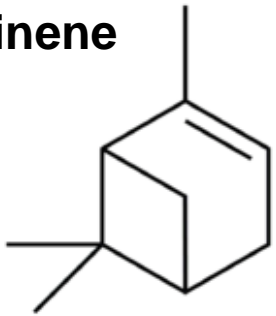


λεμονένιο



μενθόλη

Pinene



Eucalyptol

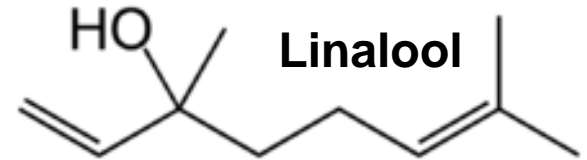
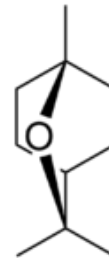


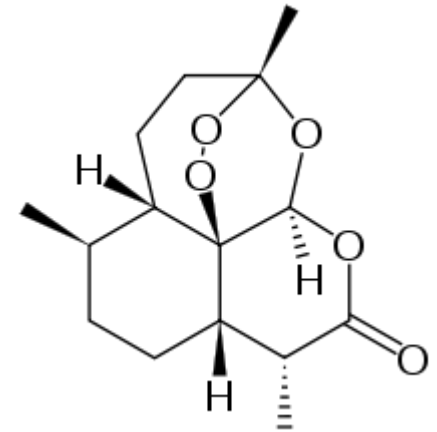
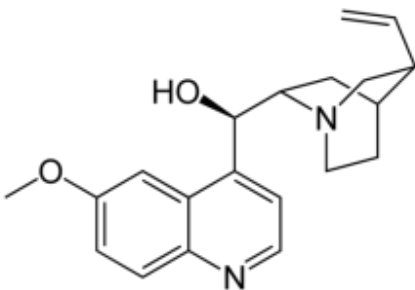
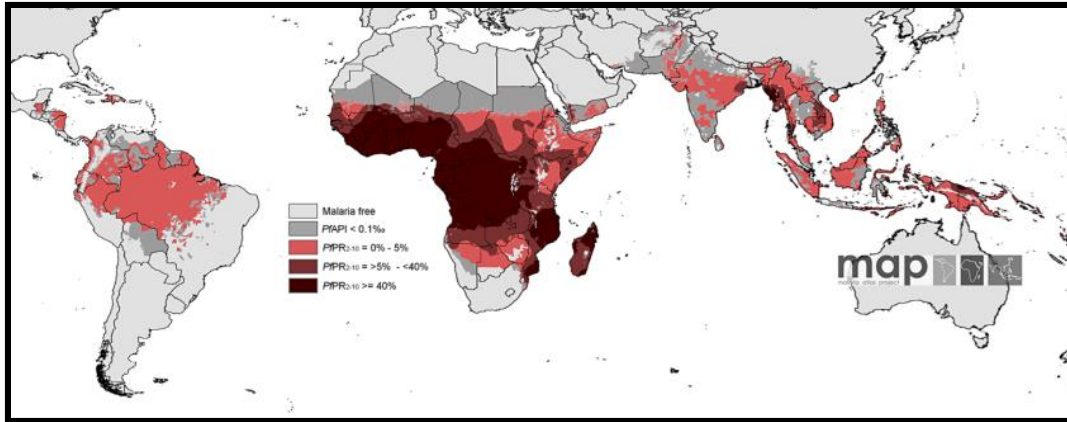


Table 5. Sesquiterpenes Emitted from FC and GG Flowers

Sesquiterpene	Amount ($\mu\text{g}\cdot\text{flower}^{-1}\cdot 24\text{ h}$)	
		
α -Cubebene	1.2 ± 1.1	(n.d. ^a)
β -Elemene	0.1 ± 0.1	(n.d.)
<i>trans</i> -Caryophyllene	(n.d.)	0.3 ± 0.1
Germacrene D	6.2 ± 1.6	(n.d.)
Bicyclosesquiphellandrene	0.2 ± 0.1	(n.d.)
α -Murolene	0.2 ± 0.1	(n.d.)
δ -Cadinene	2.1 ± 1.5	(n.d.)
α -Copaene	0.2 ± 0.1	(n.d.)
β -Cubebene	0.05 ± 0.01	(n.d.)
Bicycloelemene	0.05 ± 0.01	(n.d.)
Bicyclogermacrene	0.1 ± 0.05	(n.d.)
Caryophyllene oxide	(n.d.)	0.05 ± 0.01
α -Farnesene	(n.d.)	0.05 ± 0.01
Total sesquiterpenes	(10.4)	(0.4)

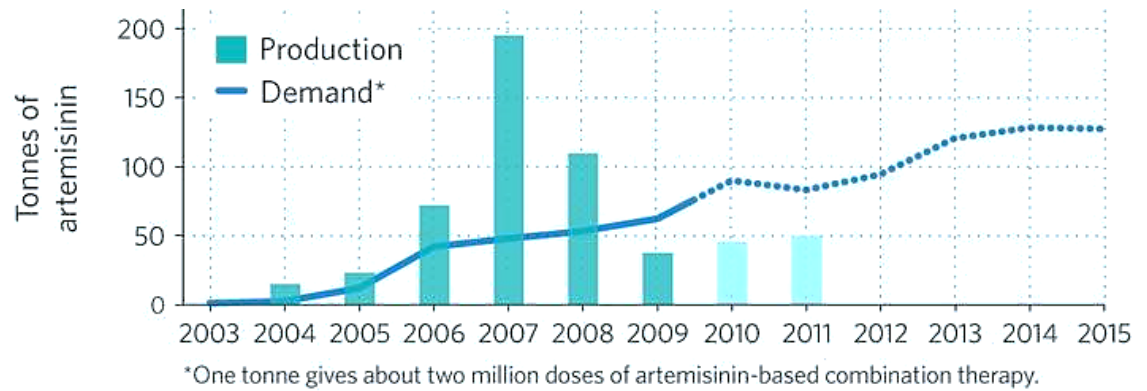
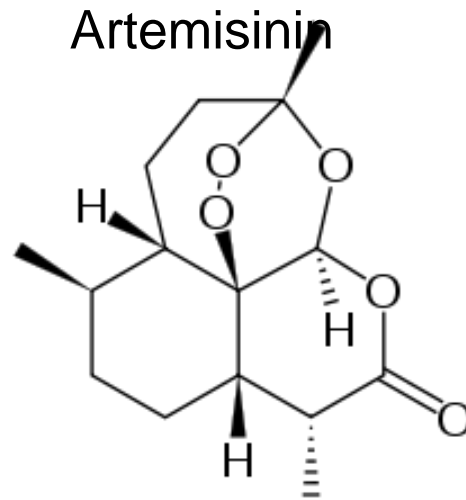
Διτερπένια (C₂₀)

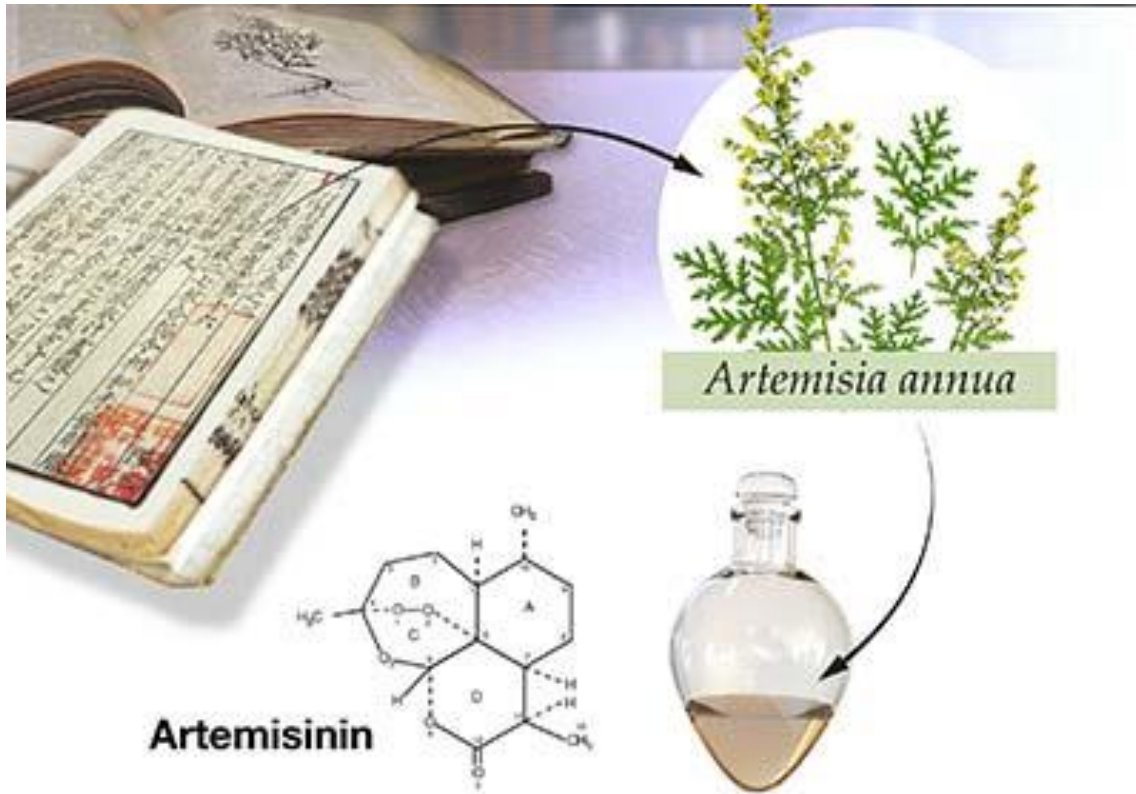
αντιελονοσιακά: κινίνη και αρτεμισίνη



Artemisinin από *Artemisia annua*

Artemisia annua



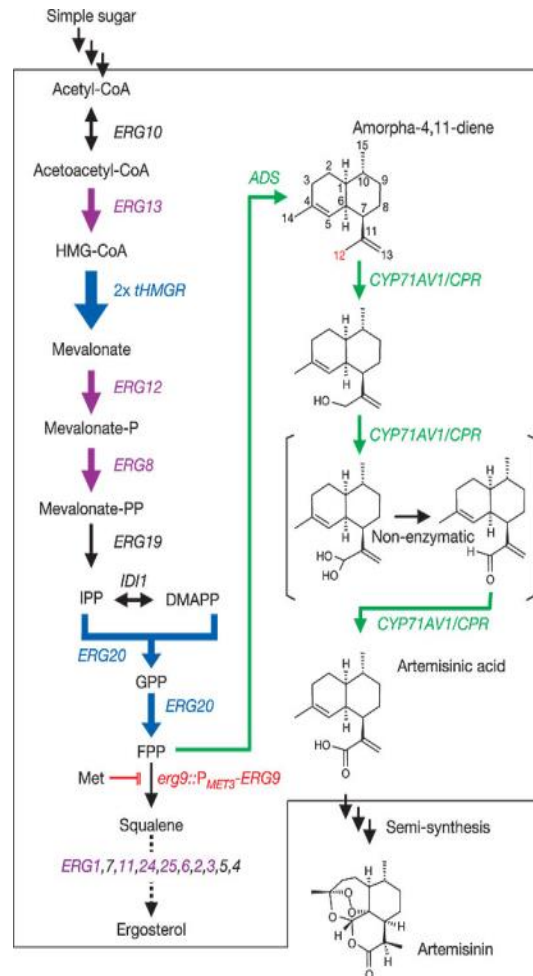
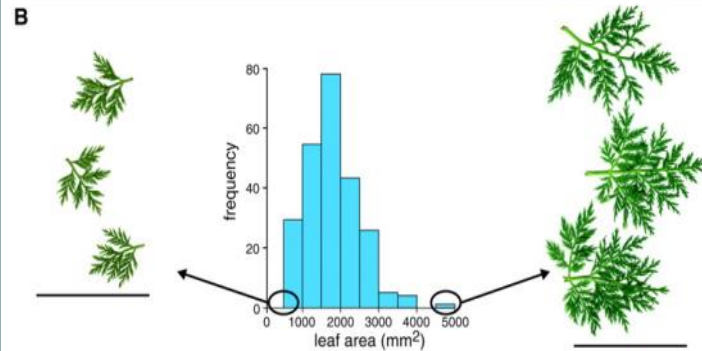
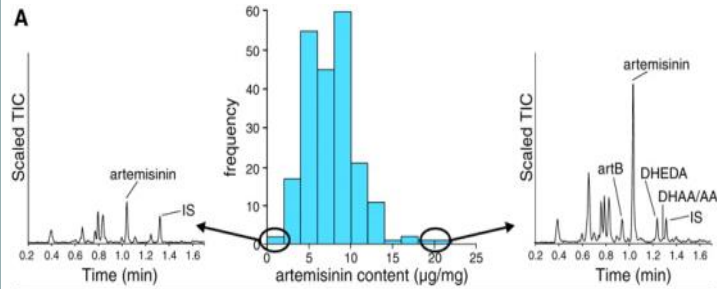


Dr Tu Youyou

Nobel Prize in Physiology or Medicine 2015

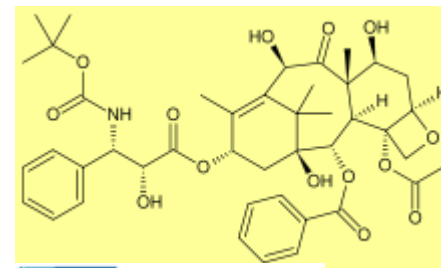
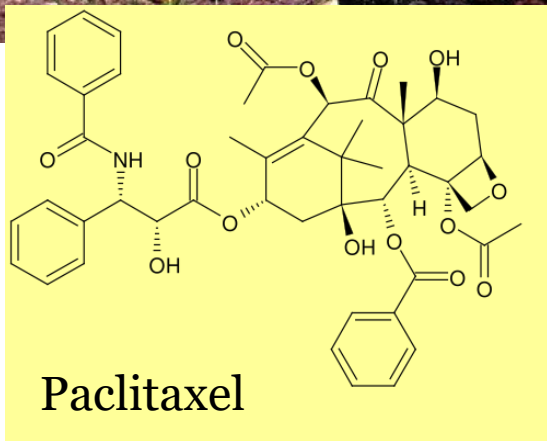
Μεθοδολογίες αύξησης της παραγωγής αρτεμισίνης

Γενετική προσέγγιση:
αναγνώριση γονιδίων
βιοσύνθεσης για γενετική
βελτίωση



Ημισυνθετική μέθοδος: εισαγωγή γονιδίων σε ζύμη για μεταβολική μηχανική

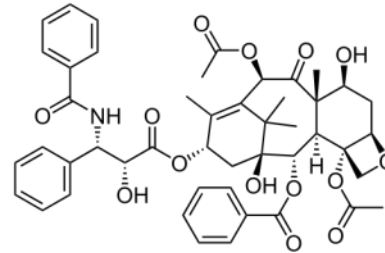
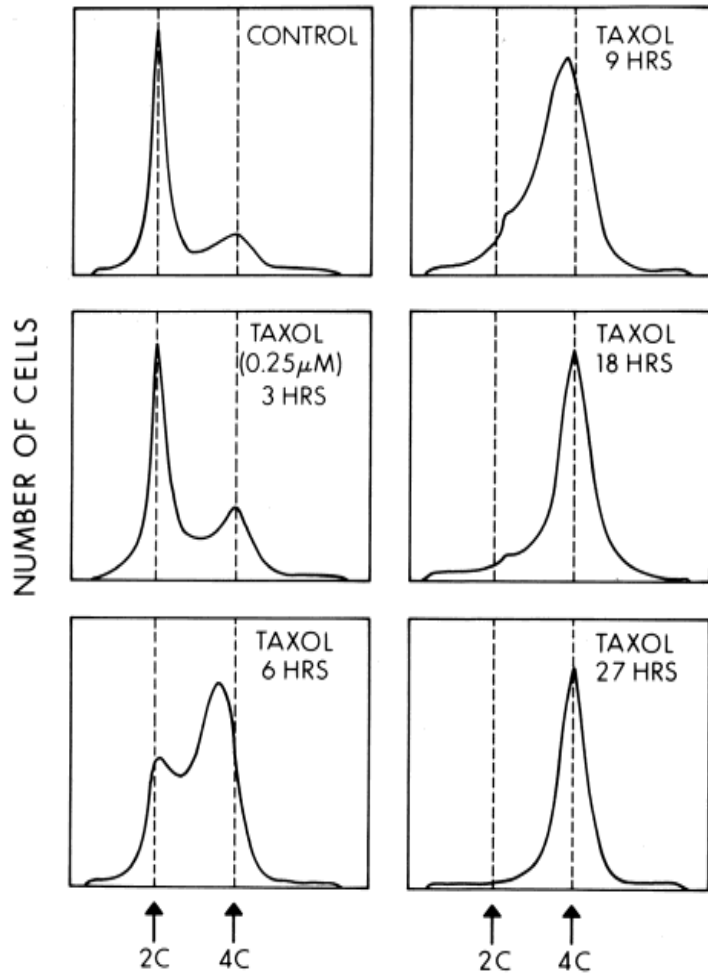
Reprinted from Graham, I.A., et al. and Bowles, D. (2010). The genetic map of *Artemisia annua* L. identifies loci affecting yield of the antimalarial drug artemisinin. *Science*. 327: [328-331](#) with permission from AAAS; Reprinted by permission from Macmillan Publishers Ltd from Ro, D.-Ket al and Keasling, J.D. (2006). Production of the antimalarial drug precursor artemisinic acid in engineered yeast. *Nature*. 440: [940-943](#); see also Westfall, P.J. et al. and Paddon, C.J. (2012). Production of amorphadiene in yeast, and its conversion to dihydroartemisinic acid, precursor to the antimalarial agent artemisinin. *Proc. Natl. Acad. Sci.* 109: [E111-E118](#). Covello, P.S. (2008). Making artemisinin. *Phytochemistry*. 69: [2881-2885](#). Lévesque, F. and Seeberger, P.H. (2012). Continuous-Flow Synthesis of the Anti-Malaria Drug Artemisinin. *Angewandte Chemie International Edition*. 51: [1706-1709](#).



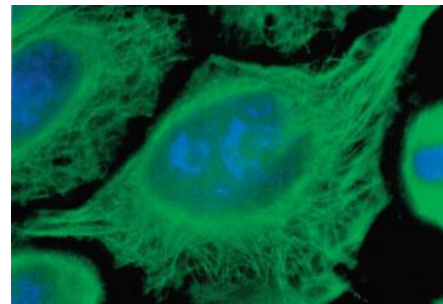
AXOTERE®
(docetaxel)
Injection Concentrate



Taxol



Το Taxol αναστέλλει τις
ΚΥΤΤΑΡΙΚΕΣ ΔΙΑΙΡΕΣΕΙΣ



UGA1208033

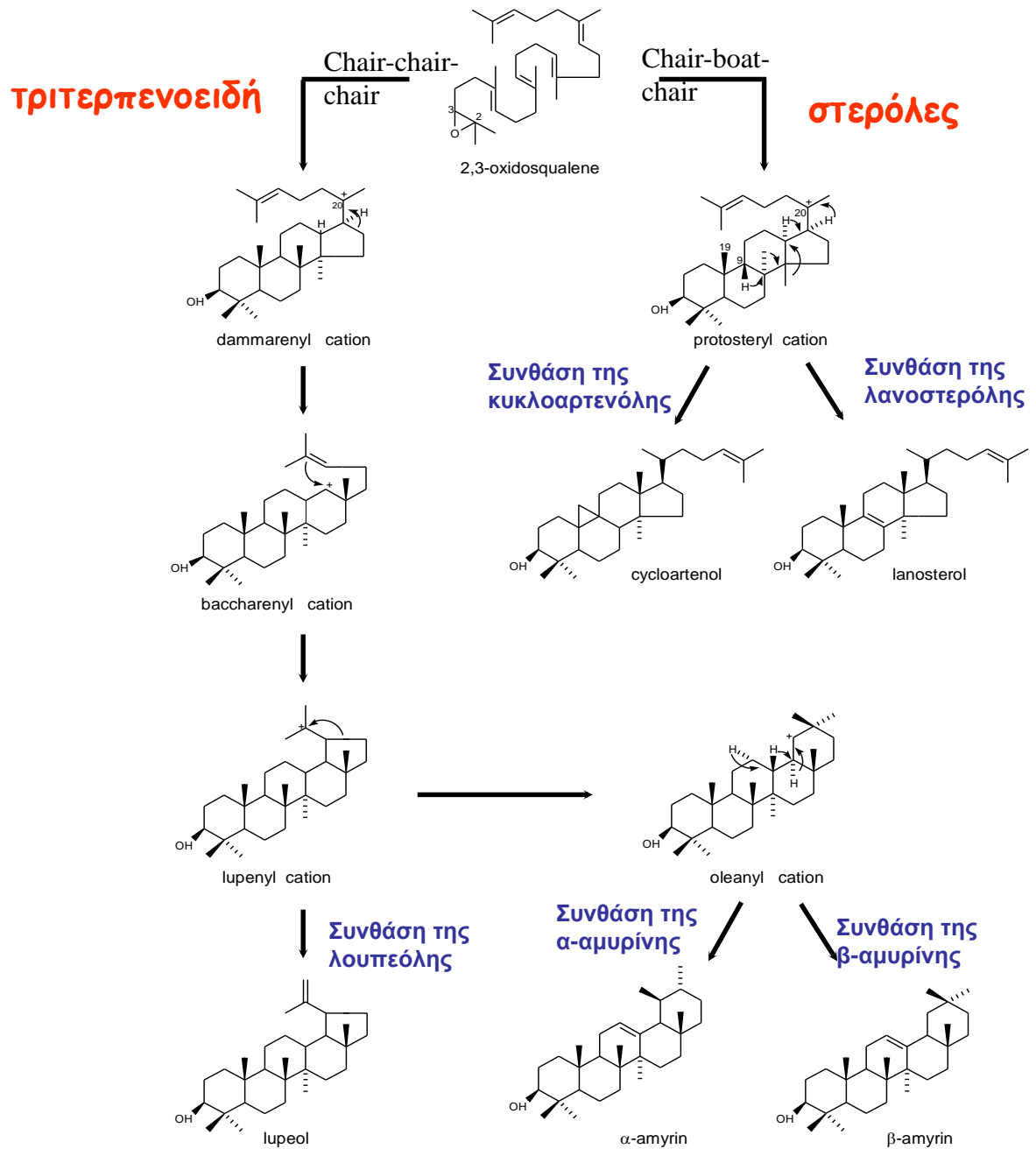
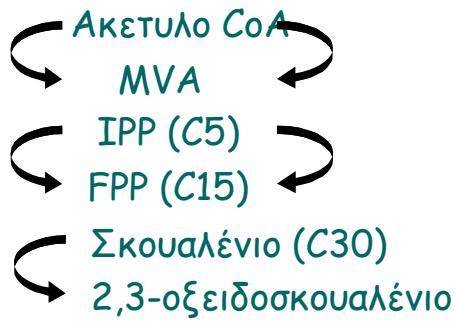


Taxus brevifolia,
Pacific yew

Τριτερπένια (C₃₀)

- ❖ πρόδρομα μόρια πολλών “φυσικών προϊόντων” φυτών
- ❖ συστατικά μεμβρανικών συστημάτων
- ❖ σε κηρους επιδερμίδας φύλλων και κάλλους
- ❖ ρόλος σε διαδικασίες απόπτωσης καρκινικών κυττάρων
- ❖ χημειοταξονομικοί δείκτες

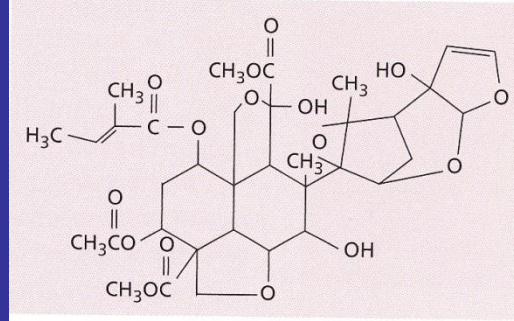
Μονοπάτι τριτερπενοειδών



Τριτερπένια (C₃₀)

❖ λεμονοειδή
(απωθητική δράση σε έντομα)

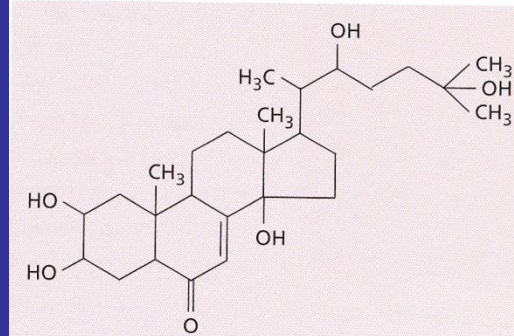
(A) Azadirachtin, a limonoid



❖ στεροειδή (φυτοεκδυσόνες)



(B) α -Ecdysone, an insect molting hormone



❖ καρδενολίδια ή καρδιακά
γλυκοζίδια (τοξικότητα σε
σπονδυλωτά)

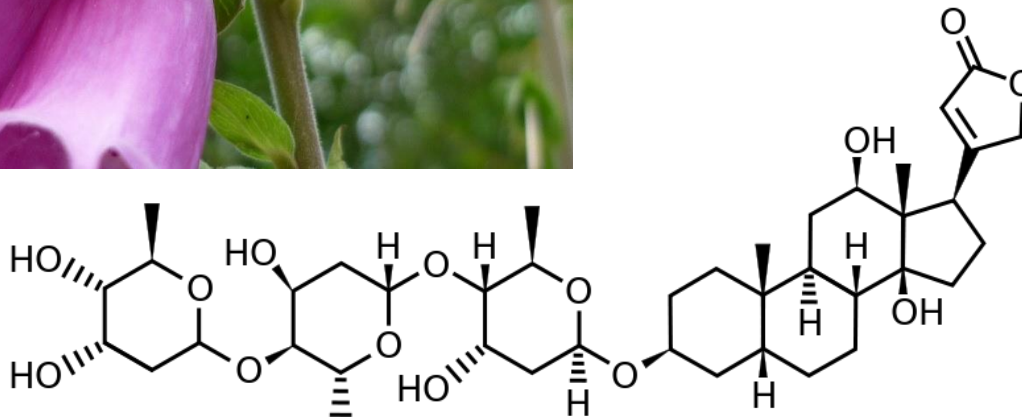
❖ σαπωνίνες

1785 “An Account of the Foxglove, and Some of its Medical Uses” William Withering (1741 – 1799)



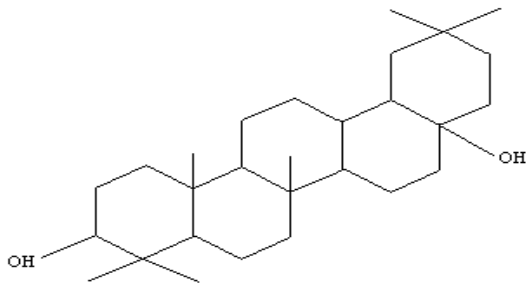
Digoxin, καρδιακό
γλυκοζίδιο από

Digitalis purpurea

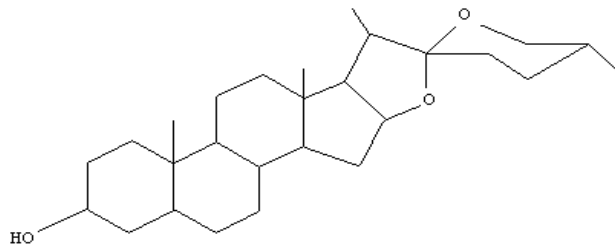


σαπωνίνες

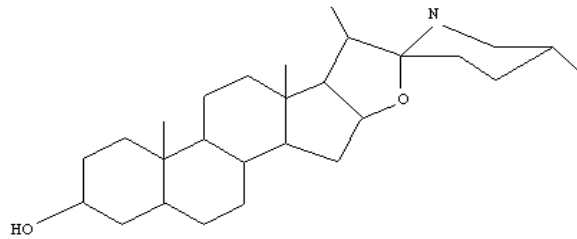
ολιγοσακχαρίδιο + αγλυκόνη:



Τριτερπενοειδή (C-30)



Στεροειδή (C-27)



Αλκαλοστεροειδή (C-27)

Ginseng (*Panax* spp.)



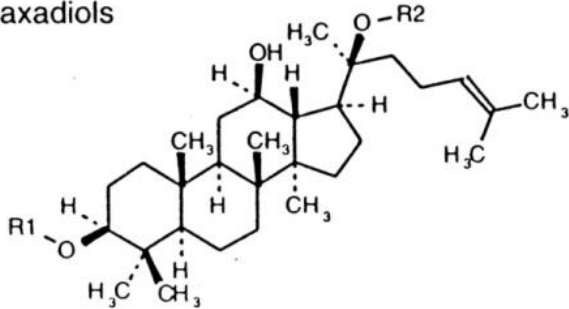
100 year old
wild ginseng
root sold for
\$250,000

300 year old
ginseng root
sold for
\$400,000

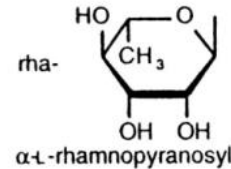
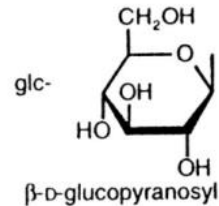
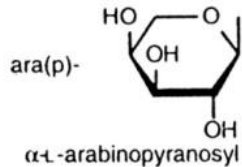
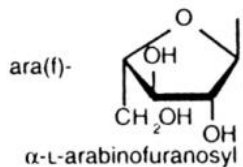


Η σύνθεση των ginsenosides ποικίλει

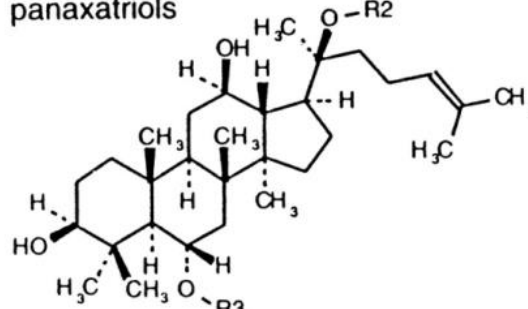
panaxadiols



	R1	R2
ginsenoside Rb ₁	O-glc-(1→2)-glc-	O-glc-(1→6)-glc-
ginsenoside Rb ₂	O-glc-(1→2)-glc-	O-ara(p)-(1→6)-glc-
ginsenoside Rc	O-glc-(1→2)-glc-	O-ara(f)-(1→6)-glc-
ginsenoside Rd	O-glc-(1→2)-glc-	glc-



panaxatriols



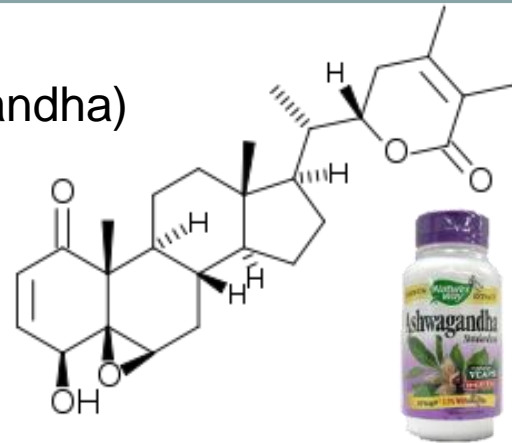
	R2	R3
ginsenoside Re	glc-	O-rha-(1→2)-glc-
ginsenoside Rf	H-	O-glc-(1→2)-glc-
ginsenoside Rg ₁	glc-	glc-
ginsenoside Rg ₂	H-	O-rha-(1→2)-glc-



Οι βιοχημικές ιδιότητες επηρεάζονται από την ηλικία των φυτών και τις συνθήκες ανάπτυξης

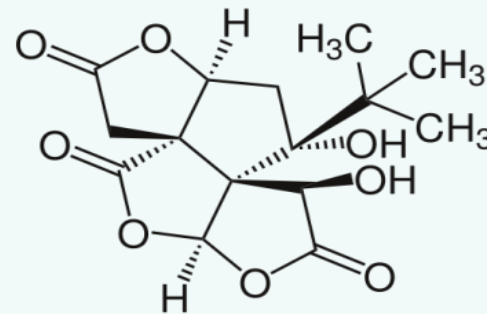


Withfarin A,,
Withania somnifera (ashwagandha)



Yinxingye

Ginkgo biloba

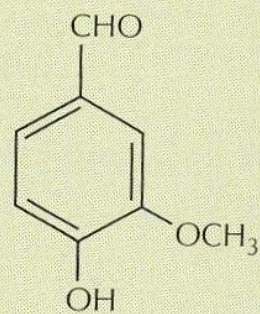


Bilobalide

ginkgolides και bilobalides

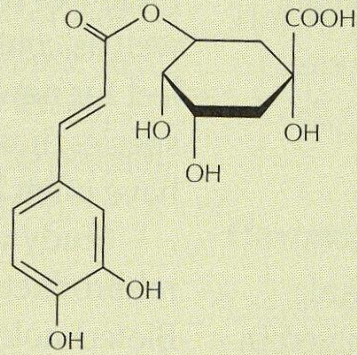
Φαινολικές ενώσεις

Vanilla



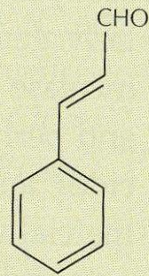
Vanillin

Coffee beans



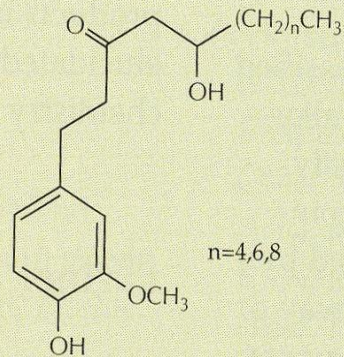
Chlorogenic acid

Cinnamon bark



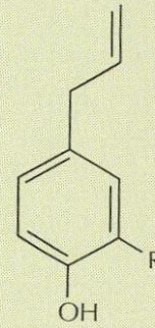
Cinnamaldehyde

Ginger rhizome



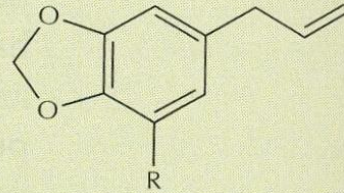
Gingerols

Cloves



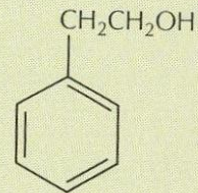
R = H Chavicol
R = OCH₃ Eugenol

Nutmeg



R = H Safrole
R = OCH₃ Myristicin

Orchid

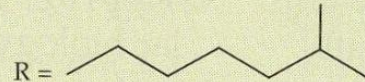
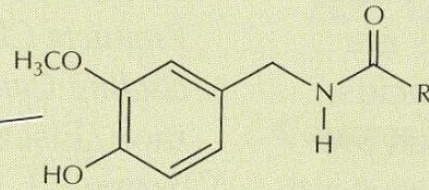
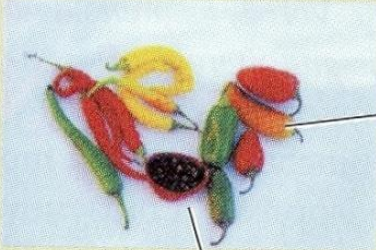


Phenylethyl alcohol

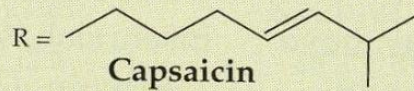


Syzygium aromaticum

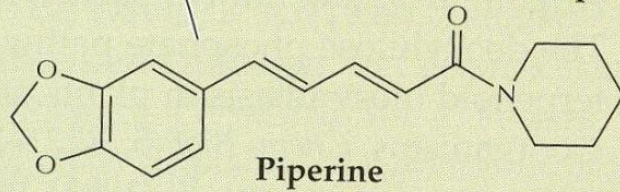
Red and black peppers



Nordihydrocapsaicin

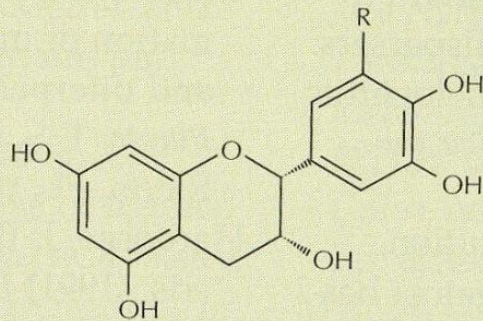


Capsaicin



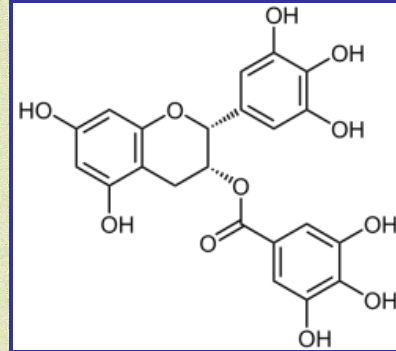
Piperine

Green tea



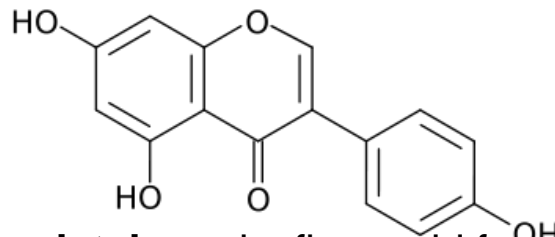
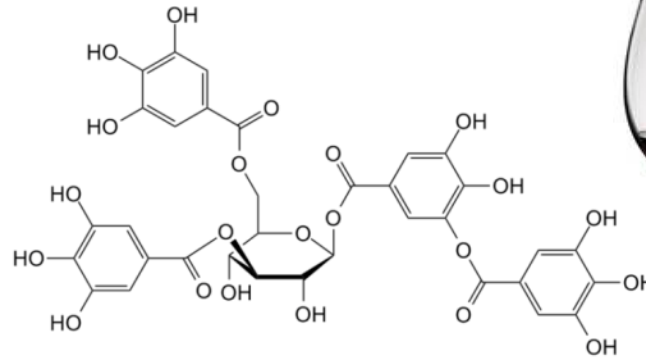
R = H (-)-Epicatechin

R = OH (-)-Epigallocatechin

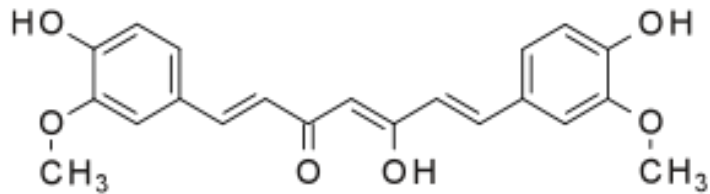


Epigallocatechin gallate

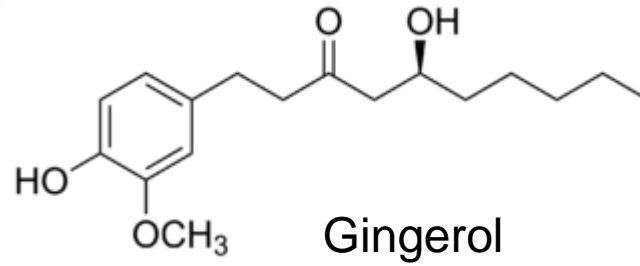
Tannins Found in tea, wine, nuts and many plants



Genistein an isoflavonoid from soy beans



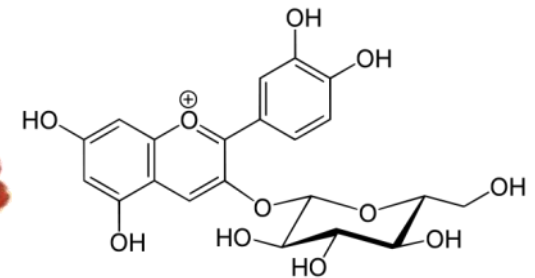
Curcumin from the spice turmeric



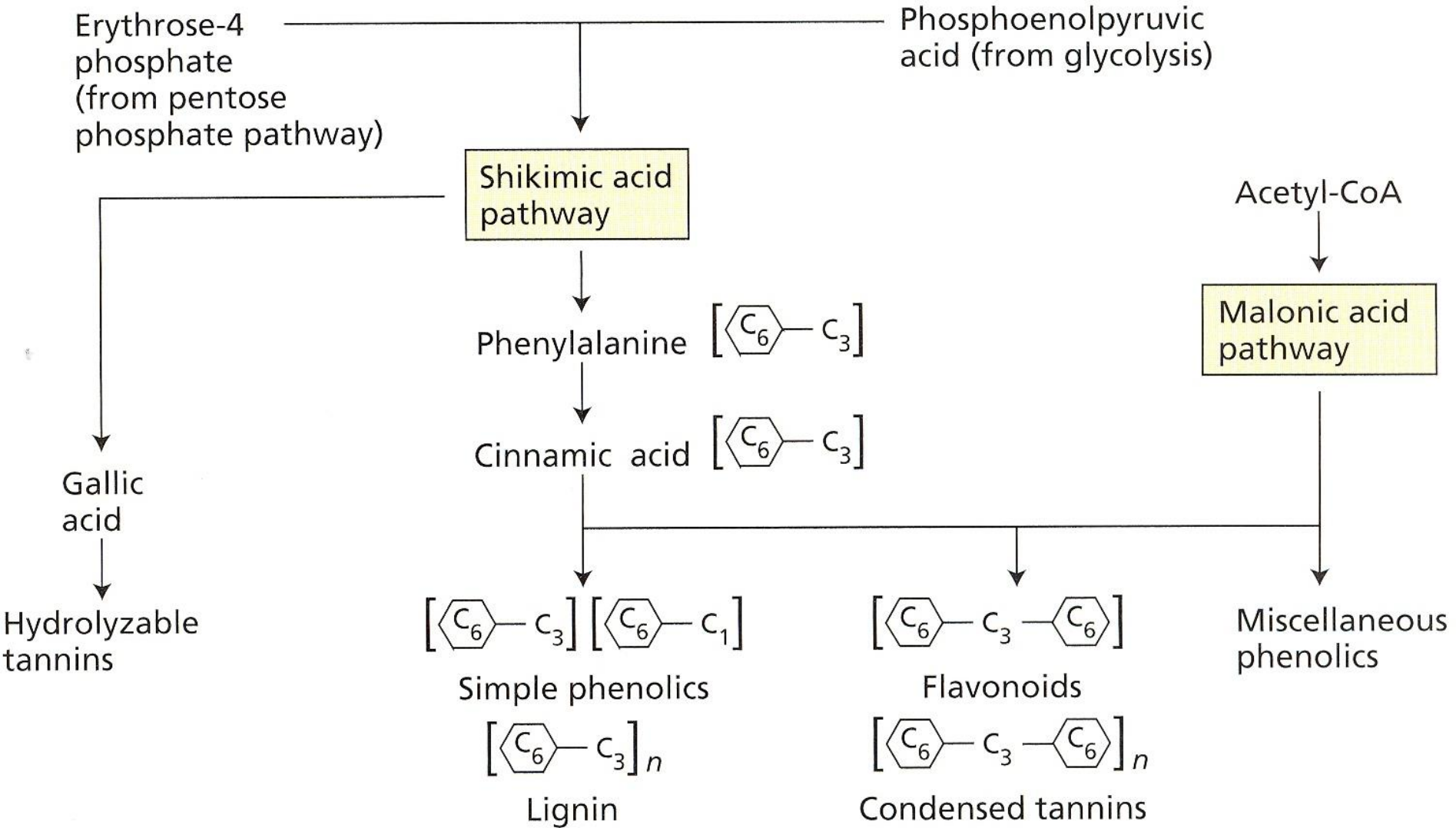
Zingiber officinale

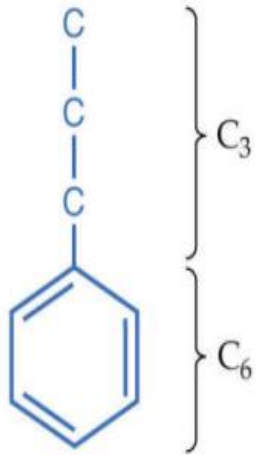
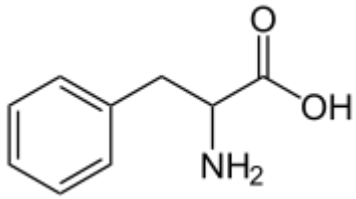


*Vitis
vinifera*



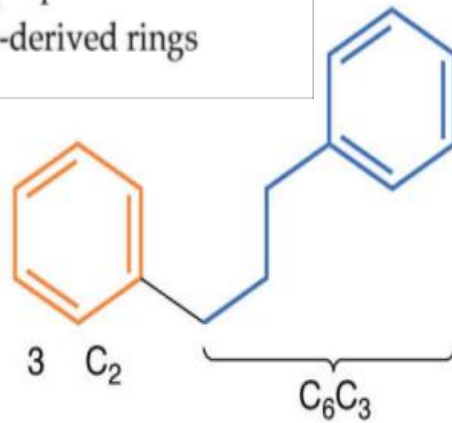
Φαινολικές ενώσεις



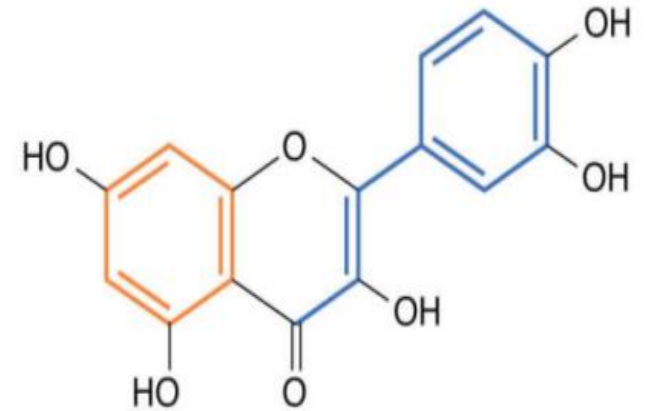


Phenylpropanoid skeleton (C_6C_3)

— Phenylpropanoid skeleton
 — Acetate-derived rings

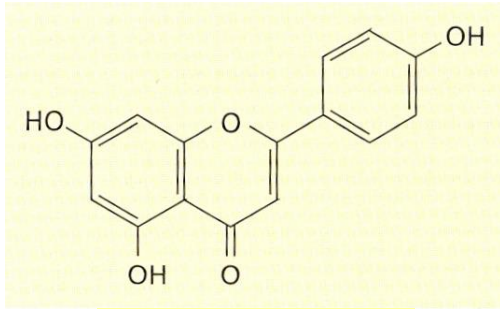


Phenylpropanoid-acetate skeleton ($C_6C_3-C_6$), with phenylpropanoid-derived (C_6C_3) and acetate-derived (3 C_2) rings

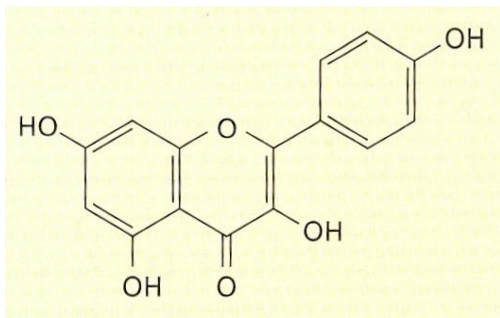


Quercetin, a flavonoid ($C_6C_3-C_6$)

❖ Στα άνθη ➔ οδηγοί νέκταρος



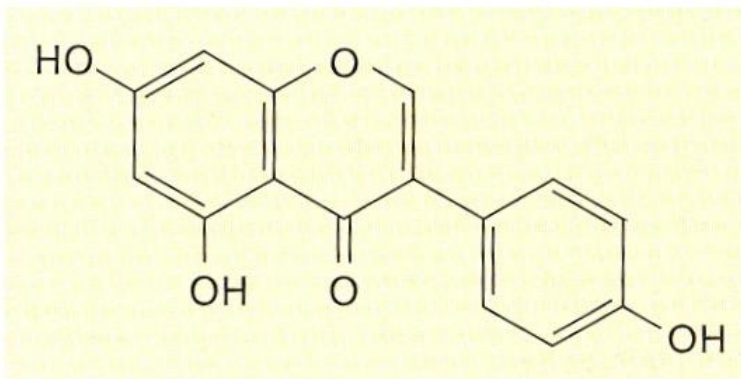
φλαβόνες



φλαβονόλες



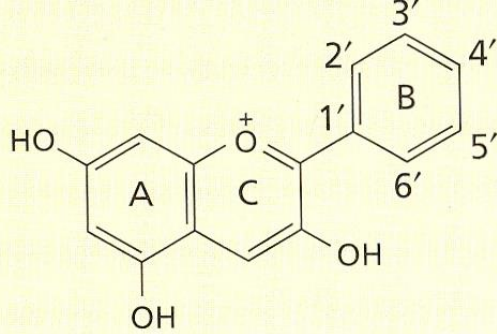
- ❖ στα επιδερμικά κύτταρα φύλλων και βλαστών
- ➔ προστασία από UV-B
- ❖ αλληλεπιδράσεις με άλλους οργανισμούς π.χ. ριζόβια
- ❖ ρυθμιστικός ρόλος στην ανάπτυξη του φυτού ως διαμορφωτές της μεταφοράς αυξίνης



**Ισοφλαβόνες
(ισοφλαβονοειδή)**

- ❖ Δράση εναντίων εντόμων
- ❖ Αντι-οιστρογονική δράση (στεριότητα σε φυτοφάγα)
- ❖ Αντι-καρκινική δράση
- ❖ Αντιμικροβιακή δράση (φυτοαλεξίνες)

ανθοκυανίνες



Anthocyanidin

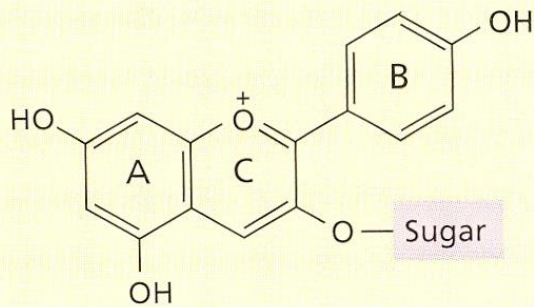
Pelargonidin 4'-OH πορτοκαλί –κόκκινο

Cyanidin 3'-OH, 4'-OH μωβ-κόκκινο

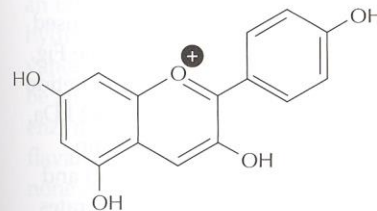
Delphinidin 3', 4', 5'- OH μπλε-μωβ

Peonidin 3'-OCH₃, 4'-OH ροζ-κόκκινο

Petunidin 3'-OCH₃, 4'-OH, 5'-OCH₃ μωβ



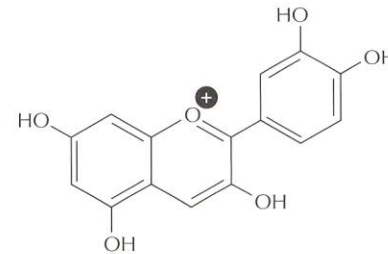
Anthocyanin



Pelargonidin



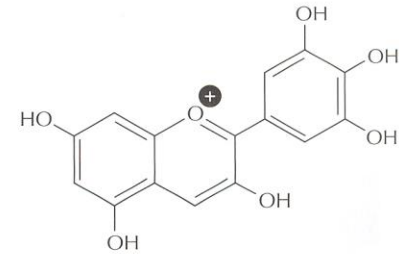
Pelargonium
(Geranium)



Cyanidin



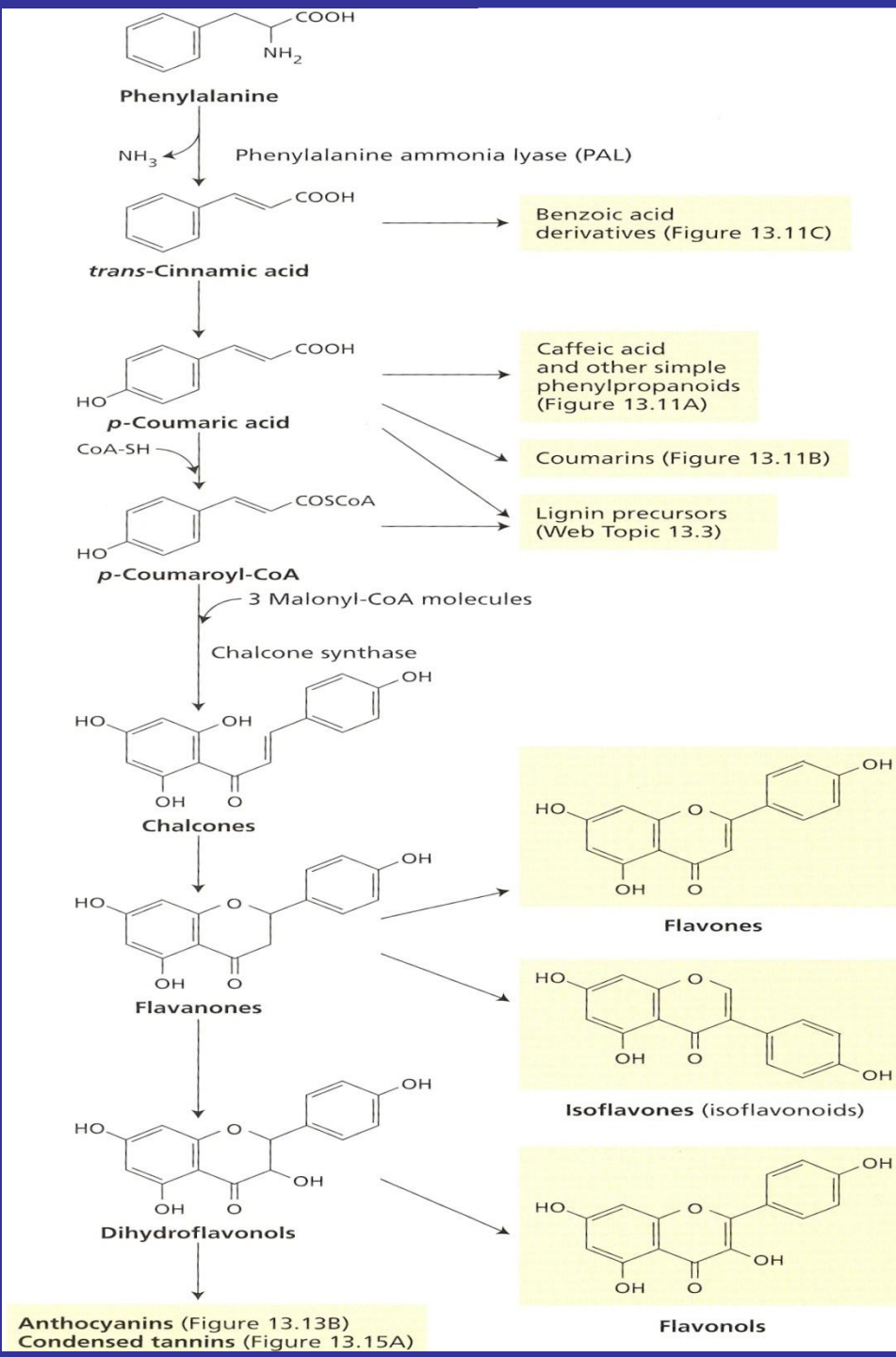
Rosa
(Rose)

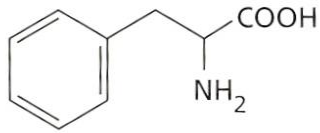


Delphinidin



Delphinium
(Larkspur)

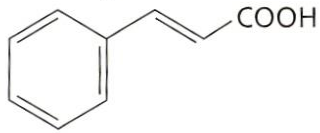




Phenylalanine

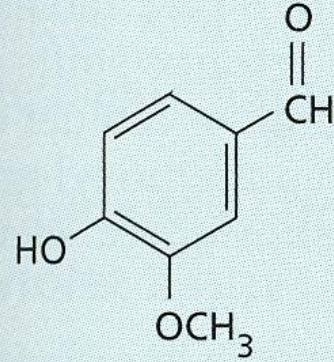


Phenylalanine ammonia lyase (PAL)

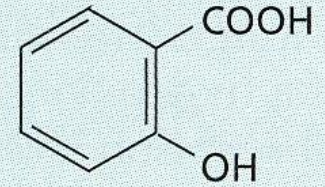


trans-Cinnamic acid

Benzoic acid derivatives



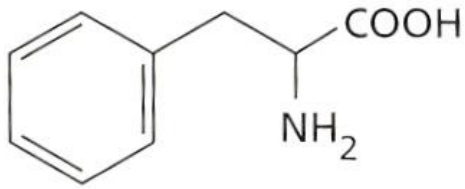
Vanillin



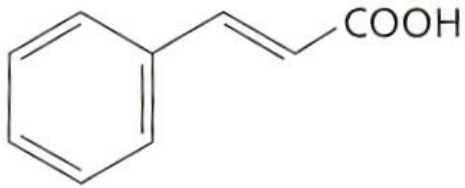
Salicylic acid

Benzoic acid derivatives [C₆-C₁]

⊕ Αλληλοπάθεια/ Διασυστηματική άμυνα φυτού



Phenylalanine



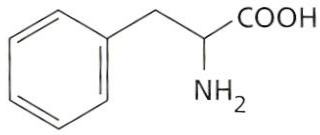
trans-Cinnamic acid

Αμμωνιο-λύαση της
φαινυλαλανίνης
(PAL)

Ρύθμιση

- Φως (μέσω φυτοχρώματος)
- Θρεπτική κατάσταση του φυτού
- Προσβολή από παθογόνα

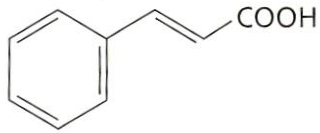
- Πολλαπλά ισόμορφα



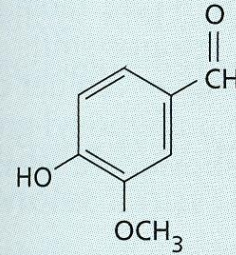
Phenylalanine



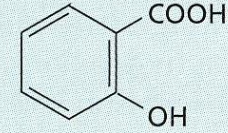
Phenylalanine ammonia lyase (PAL)



trans-Cinnamic acid



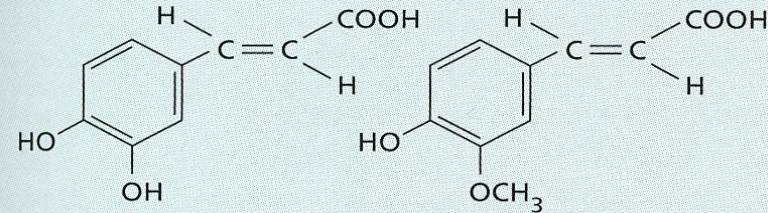
Vanillin



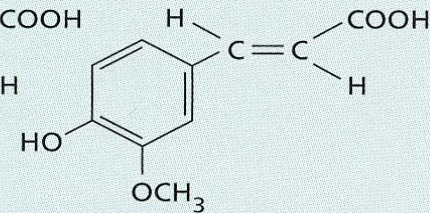
Salicylic acid

Benzoic acid derivatives [C_6-C_1]

Benzoic acid derivatives



Caffeic acid



Ferulic acid

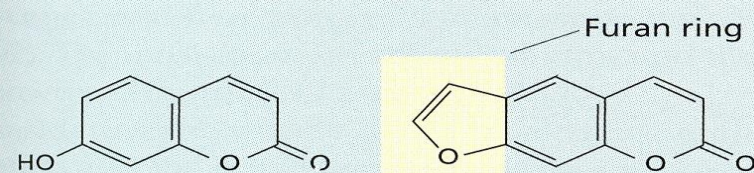
Simple phenylpropanoids [C_6-C_3]

⊕ Αλληλοπάθεια

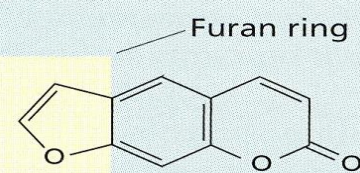
Caffeic acid and other simple phenylpropanoids

Coumarins

Lignin precursors

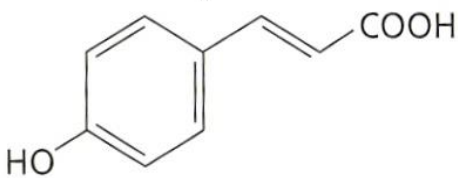


Umbelliferone, a simple coumarin

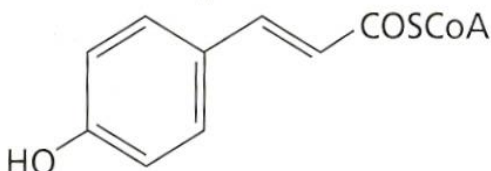


Psoralen, a furanocoumarin

Coumarins [C_6-C_3]



p-Coumaric acid

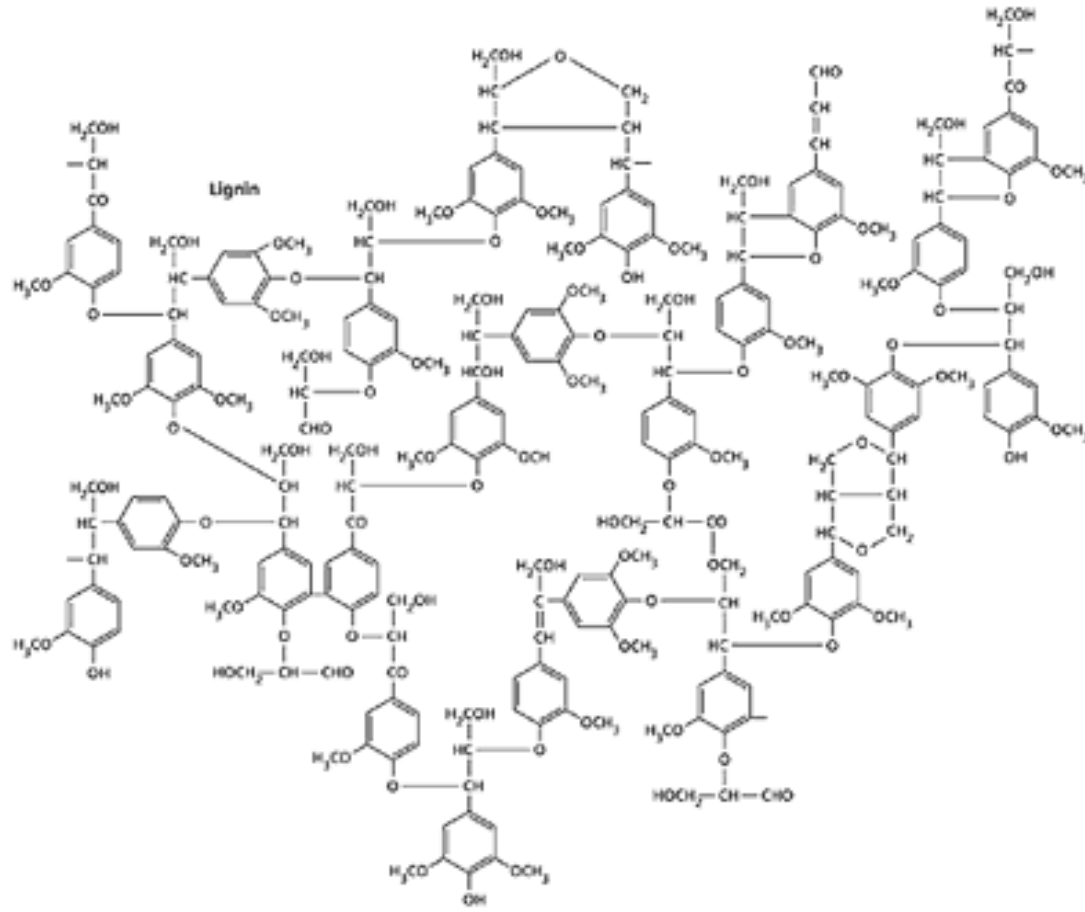


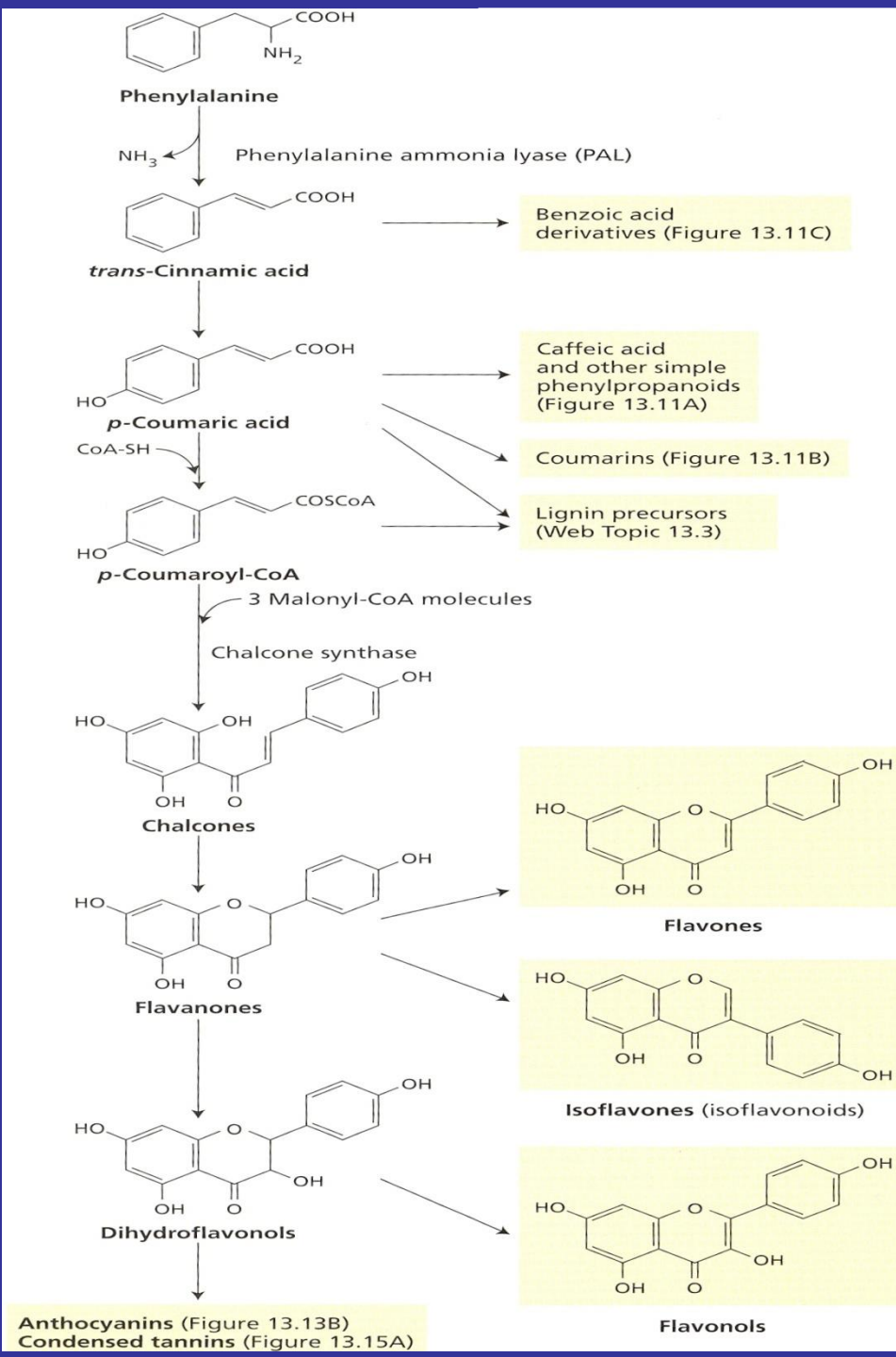
p-Coumaroyl-CoA

⊕ Άμυνα κατά εντόμων, φυτοφάγων, μυκήτων

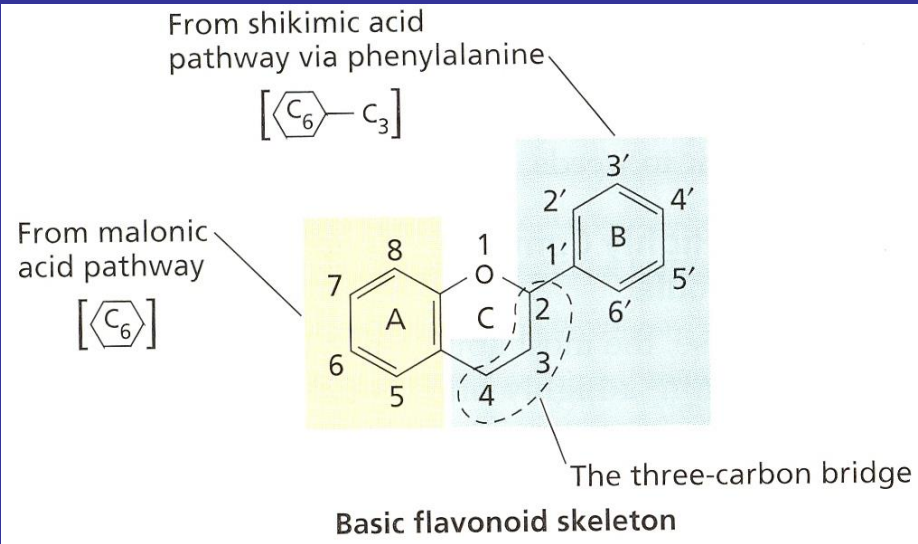
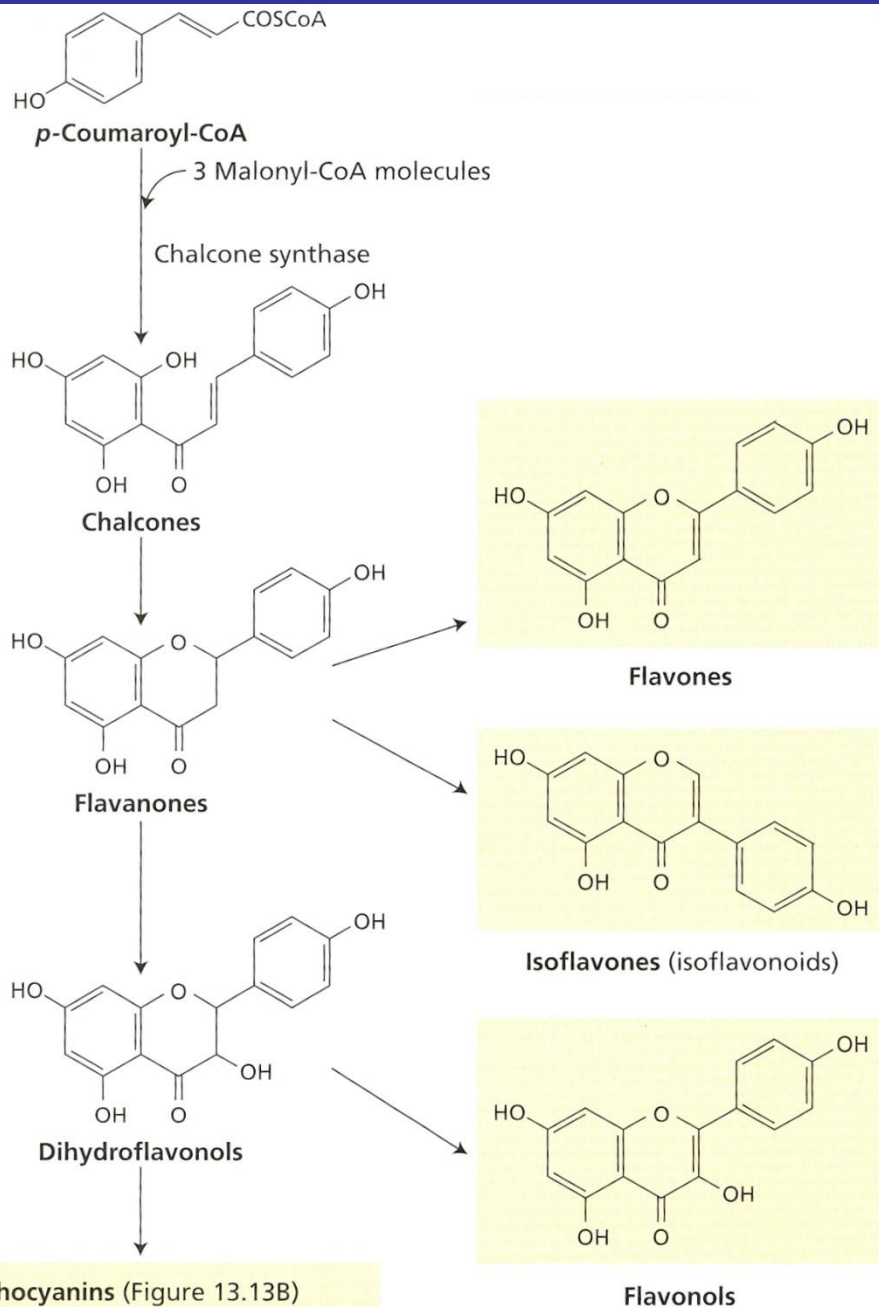
Λίγνινη

- ❖ διακλαδιζόμενο σε τρεις διαστάσεις πολυμερές φαινυλ-προπανοϊκών ομάδων
 - ❖ αφθονότερο προϊόν του δευτερογενούς μεταβολισμού
 - ❖ δεσμευμένο με ομοιοπολικούς δεσμούς με κυτταρίνη και πολυσακχαρίτες του, δευτερογενούς συνήθως, κυτταρικού τοιχώματος (κυρίως τραχειίδες και αγγεία ξυλώματος)
- ➔ μηχανική υποστήριξη και μείωση απώλειας νερού
- ➔ προστασία από παθογόνα και φυτοφάγα

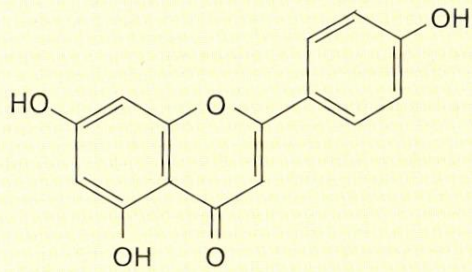




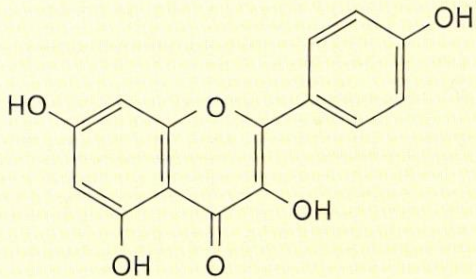
φλαβονοειδή



❖ Στα άνθη ➔ οδηγοί νέκταρος

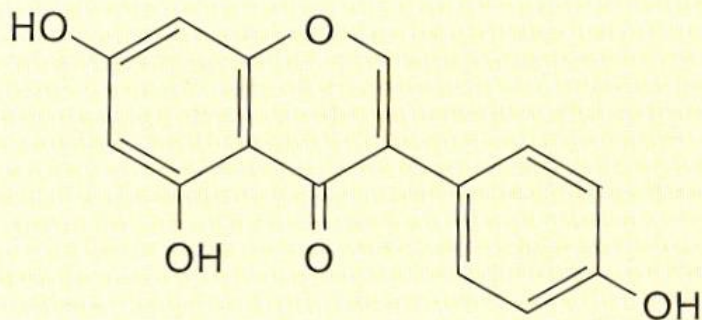


φλαβόνες



φλαβονόλες

- ❖ στα επιδερμικά κύτταρα φύλλων και βλαστών
- ➔ προστασία από UV-B
- ❖ αλληλεπιδράσεις με άλλους οργανισμούς π.χ. ριζόβια
- ❖ ρυθμιστικός ρόλος στην ανάπτυξη του φυτού ως διαμορφωτές της μεταφοράς αυξίνης



**Ισοφλαβόνες
(ισοφλαβονοειδή)**

- ❖ Δράση εναντίων εντόμων
- ❖ Αντι-οιστρογονική δράση (στεριότητα σε φυτοφάγα)
- ❖ Αντι-καρκινική δράση
- ❖ Αντιμικροβιακή δράση (φυτοαλεξίνες)

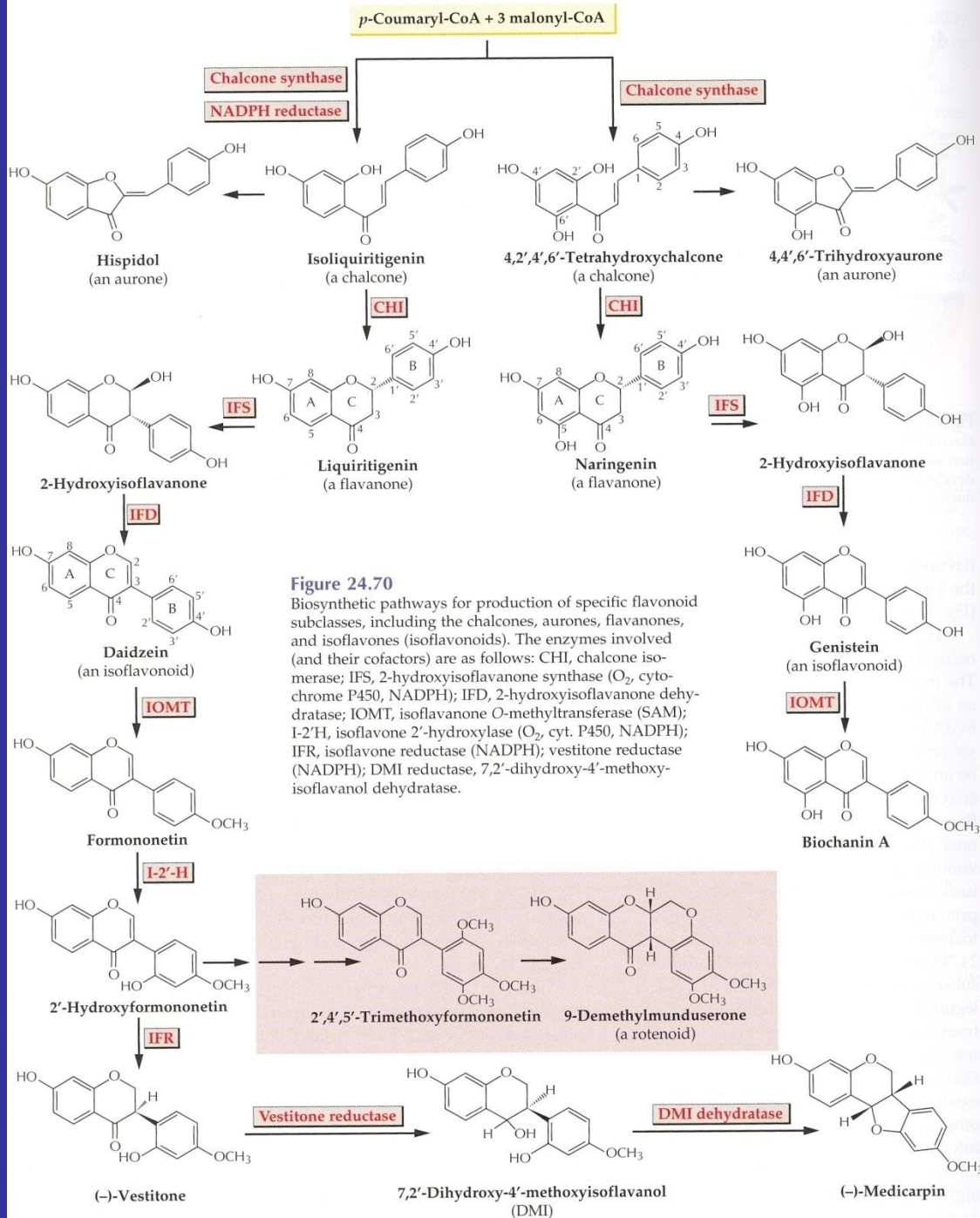
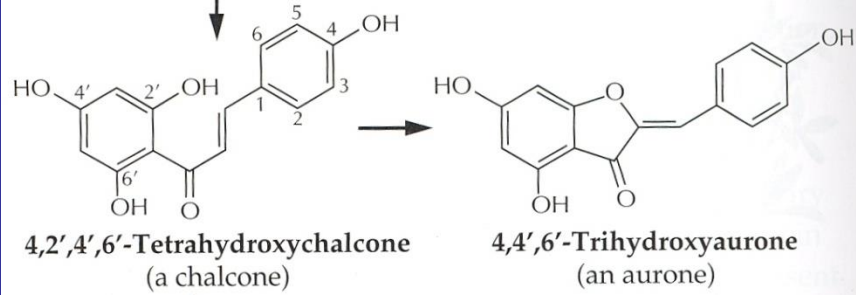


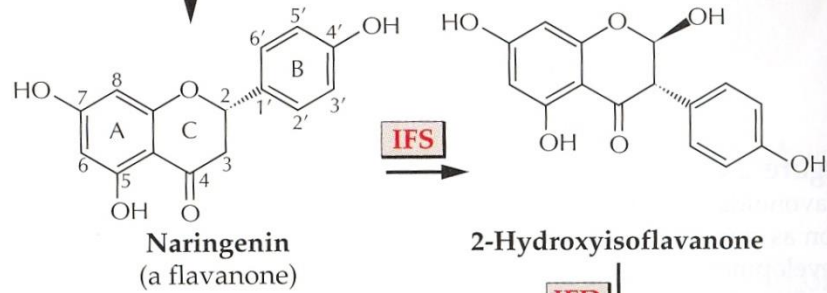
Figure 24.70

Biosynthetic pathways for production of specific flavonoid subclasses, including the chalcones, aurones, flavanones, and isoflavonoids. The enzymes involved (and their cofactors) are as follows: CHI, chalcone isomerase; IFS, 2-hydroxyisoflavanone synthase (O₂, cytochrome P450, NADPH); IFD, 2-hydroxyisoflavanone dehydratase; IOMT, isoflavanone O-methyltransferase (SAM); I-2'H, isoflavone 2'-hydroxylase (O₂, cyt. P450, NADPH); IFR, isoflavone reductase (NADPH); vestitone reductase (NADPH); DMI reductase, 7,2'-dihydroxy-4'-methoxyisoflavanol dehydratase.

Chalcone synthase



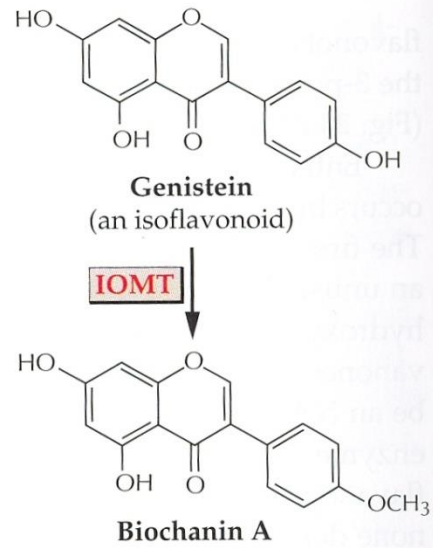
CHI



IFS

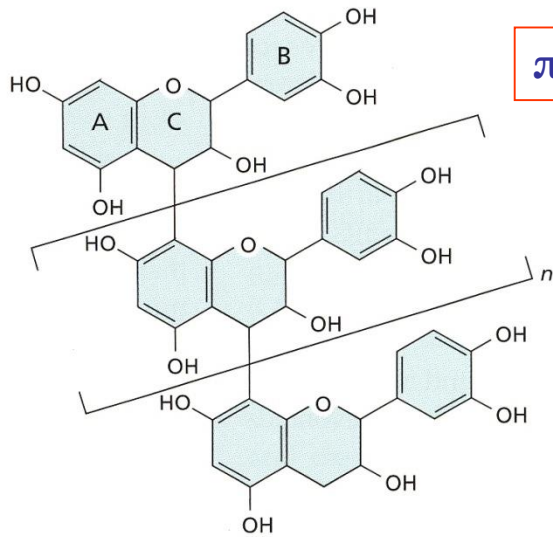
IFD

IOMT

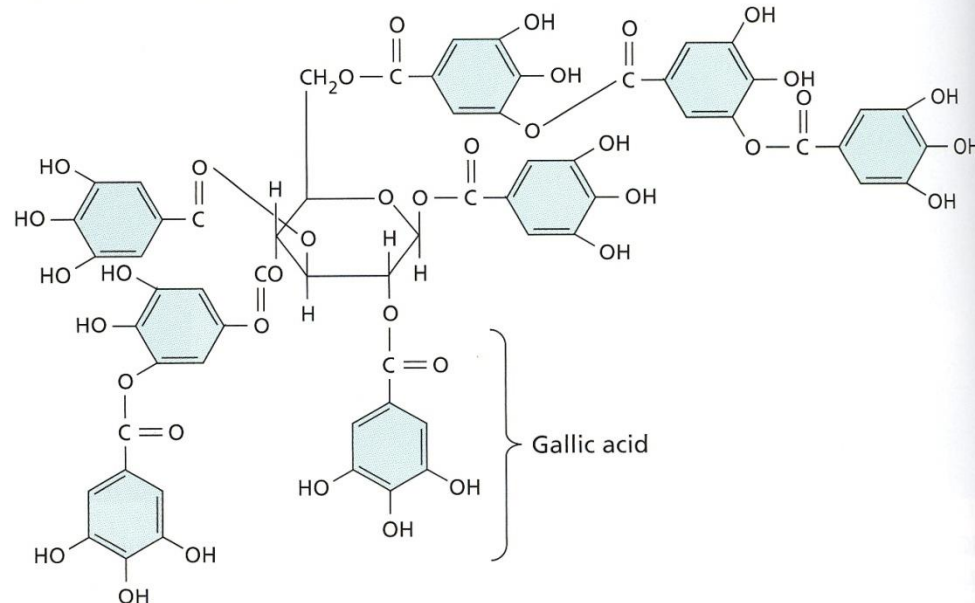


Τανίνες

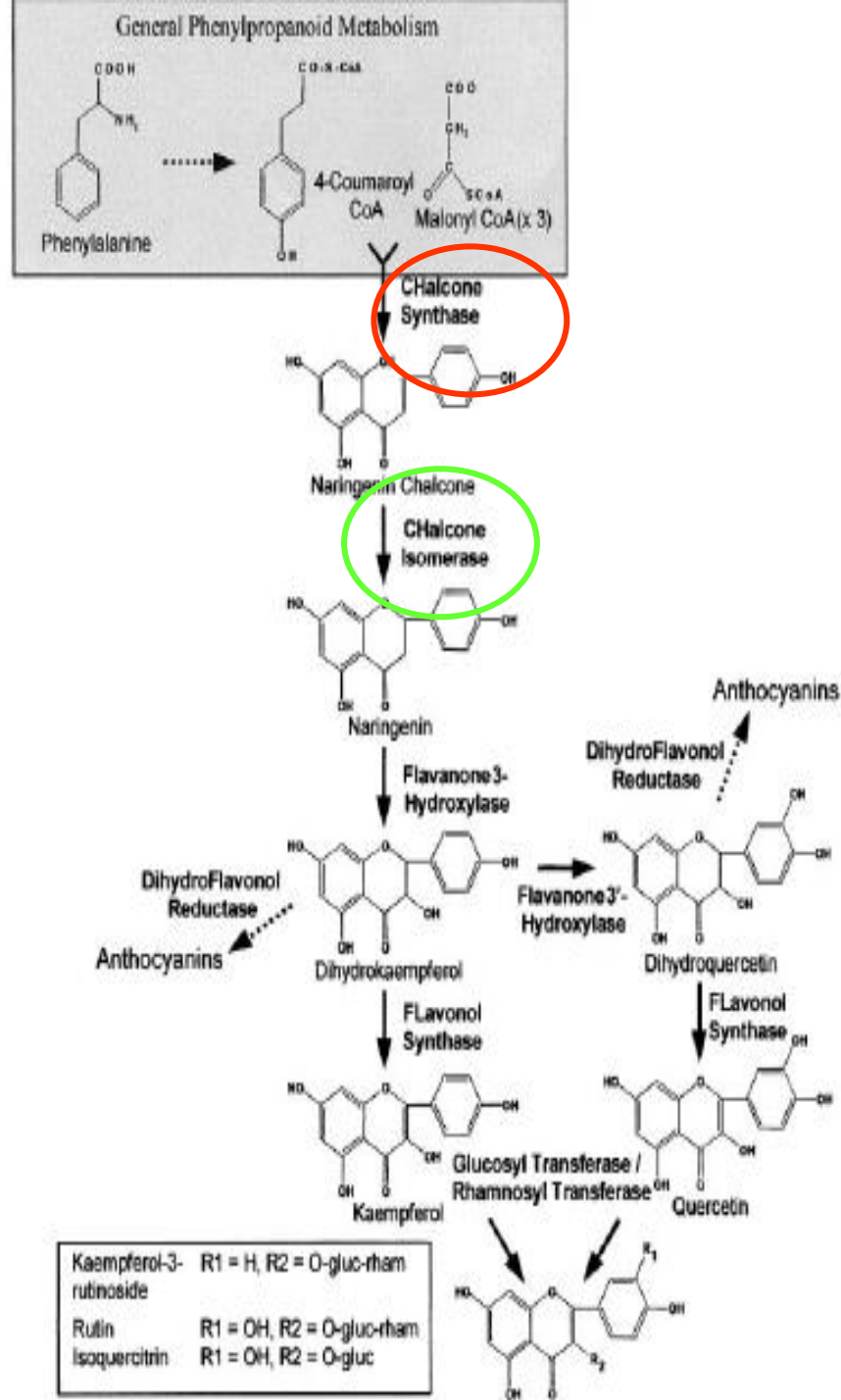
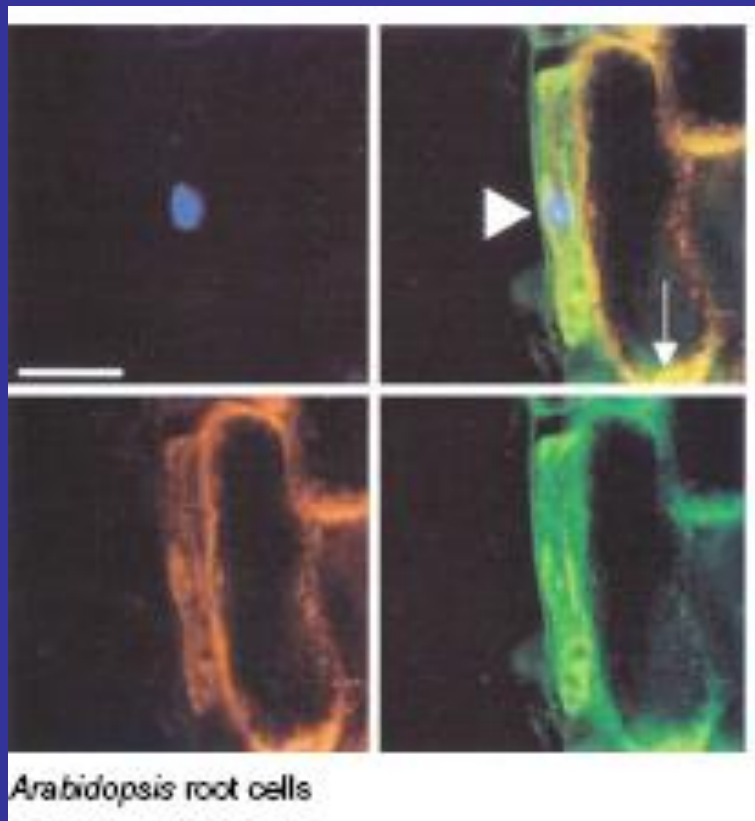
(A) Condensed tannin



(B) Hydrolyzable tannin

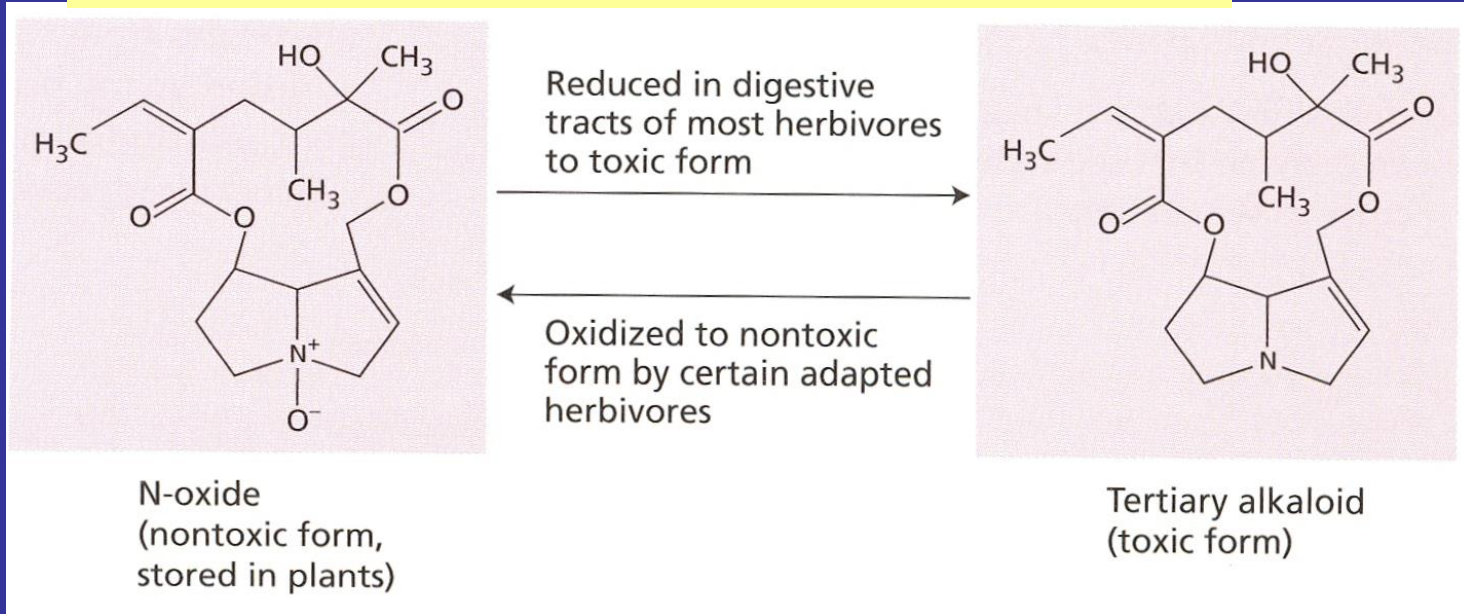


- ❖ μη εκλεκτική δέσμευση πρωτεϊνών
- ➔ τοξικές για φυτοφάγα
- ❖ απωθητικά εχθρών
- ❖ αντιμικροβιακή δράση
- ❖ αγγειοσυσταλτική δράση (δέσμευση endothelin-1)



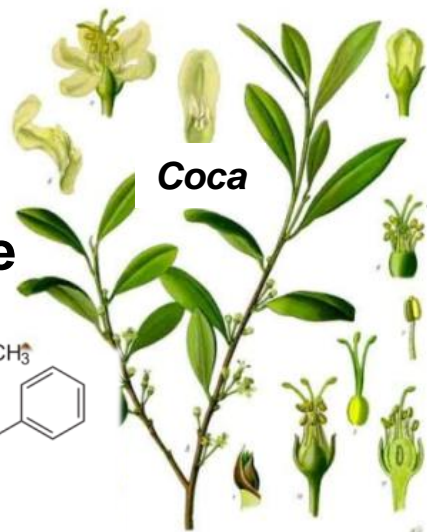
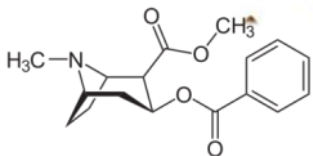
Αζωτούχες ενώσεις- αλκαλοειδή

❖ άμυνα, κυρίως ενάντια θηλαστικών

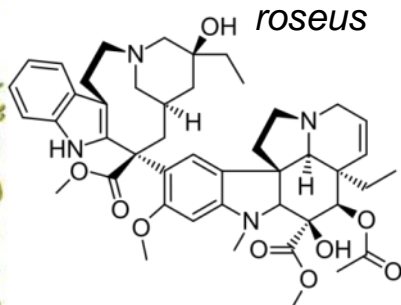


- ❖ παρέμβαση με στοιχεία του νευρικού συστήματος (χημικοί διαβιβαστές)
- ❖ επίδραση στη διαμεμβρανική μεταφορά
- ❖ επίδραση στη πρωτεϊνοσύνθεση

Cocaine



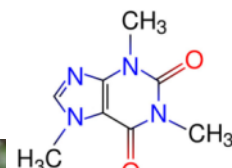
Catharanthus roseus



Vincristine

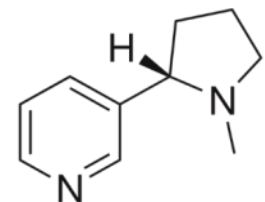


Coffee

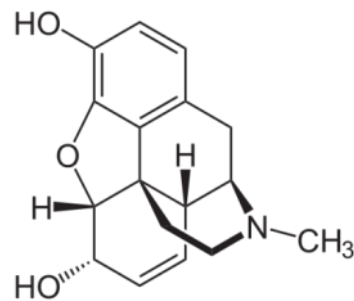


Caffeine

Nicotine



Nicotiana tabacum



Morphine


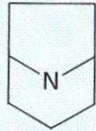
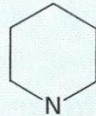
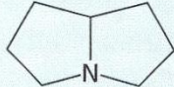
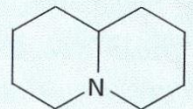
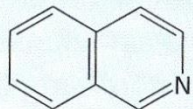
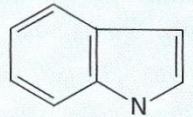
Papaver somniferum



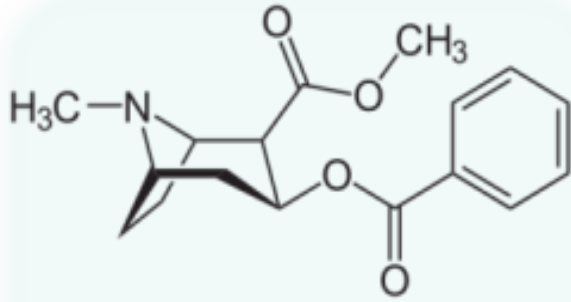
Αλκαλοειδή

TABLE 13.2

Major types of alkaloids, their amino acid precursors, and well-known examples of each type

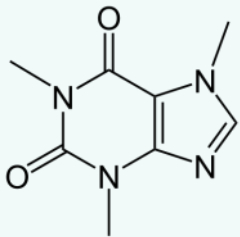
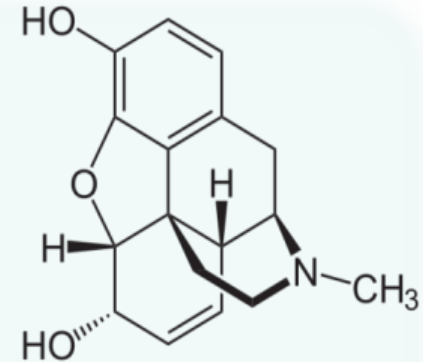
Alkaloid class	Structure	Biosynthetic precursor	Examples	Human uses
Pyrrolidine		Ornithine (aspartate)	Nicotine	Stimulant, depressant, tranquilizer
Tropane		Ornithine	Atropine	Prevention of intestinal spasms, antidote to other poisons, dilation of pupils for examination
			Cocaine	Stimulant of the central nervous system, local anesthetic
Piperidine		Lysine (or acetate)	Coniine	Poison (paralyzes motor neurons)
Pyrrolizidine		Ornithine	Retrorsine	None
Quinolizidine		Lysine	Lupinine	Restoration of heart rhythm
Isoquinoline		Tyrosine	Codeine	Analgesic (pain relief), treatment of coughs
			Morphine	Analgesic
Indole		Tryptophan	Psilocybin	Halucinogen
			Reserpine	Treatment of hypertension, treatment of psychoses
			Strychnine	Rat poison, treatment of eye disorders

Βιοσύνθεση από διάφορα αμινοξέα

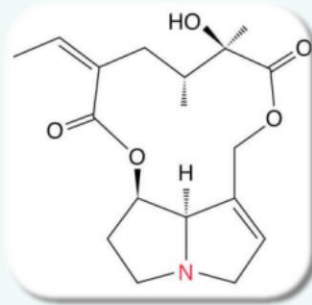


Tropane alkaloids
include cocaine

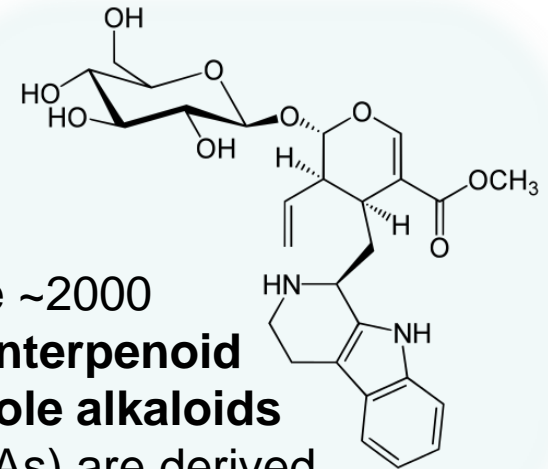
There are approximately 2500 **benzyloisoquinoline alkaloids (BIAs)**, including morphine



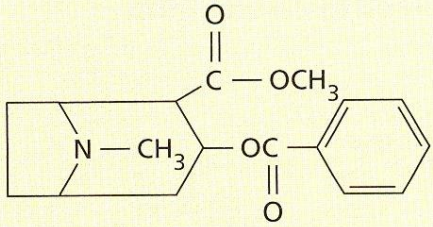
Caffeine is a **purine alkaloid**



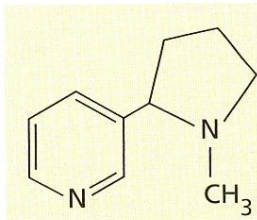
Senecionine is a **pyrrolizidine alkaloid**



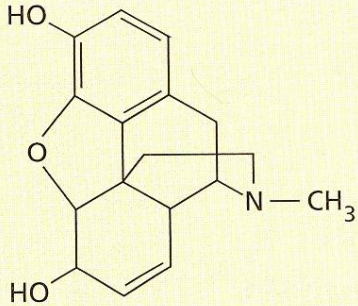
The ~2000 **monoterpenoid indole alkaloids (MIAs)** are derived from strictosidine



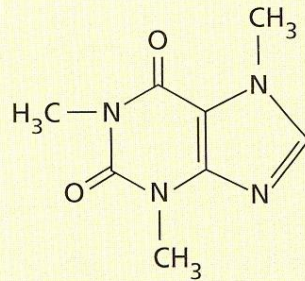
Cocaine



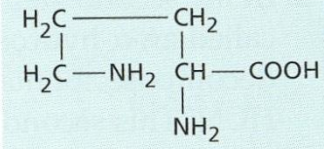
Nicotine



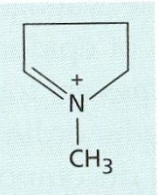
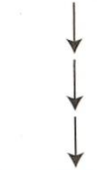
Morphine



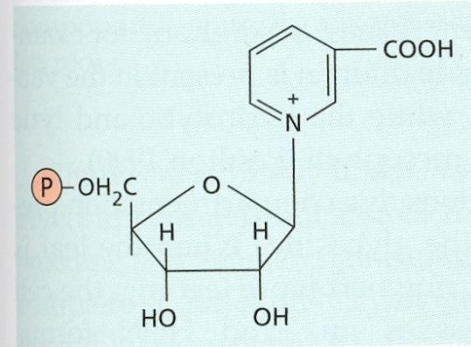
Caffeine



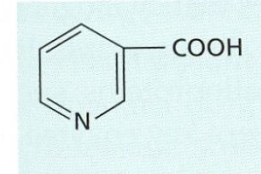
Ornithine



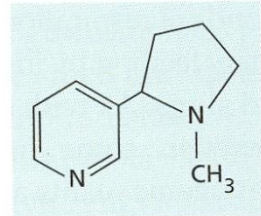
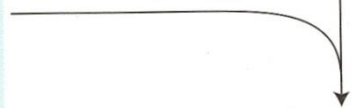
N-Methyl pyrrolinium



Nicotinic acid mononucleotide (NADP⁺)

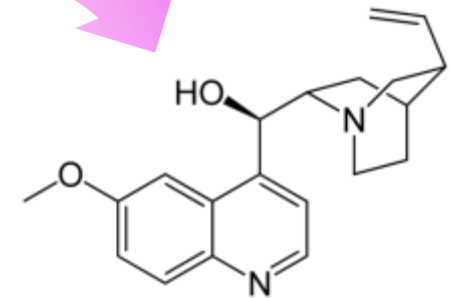


Nicotinic acid



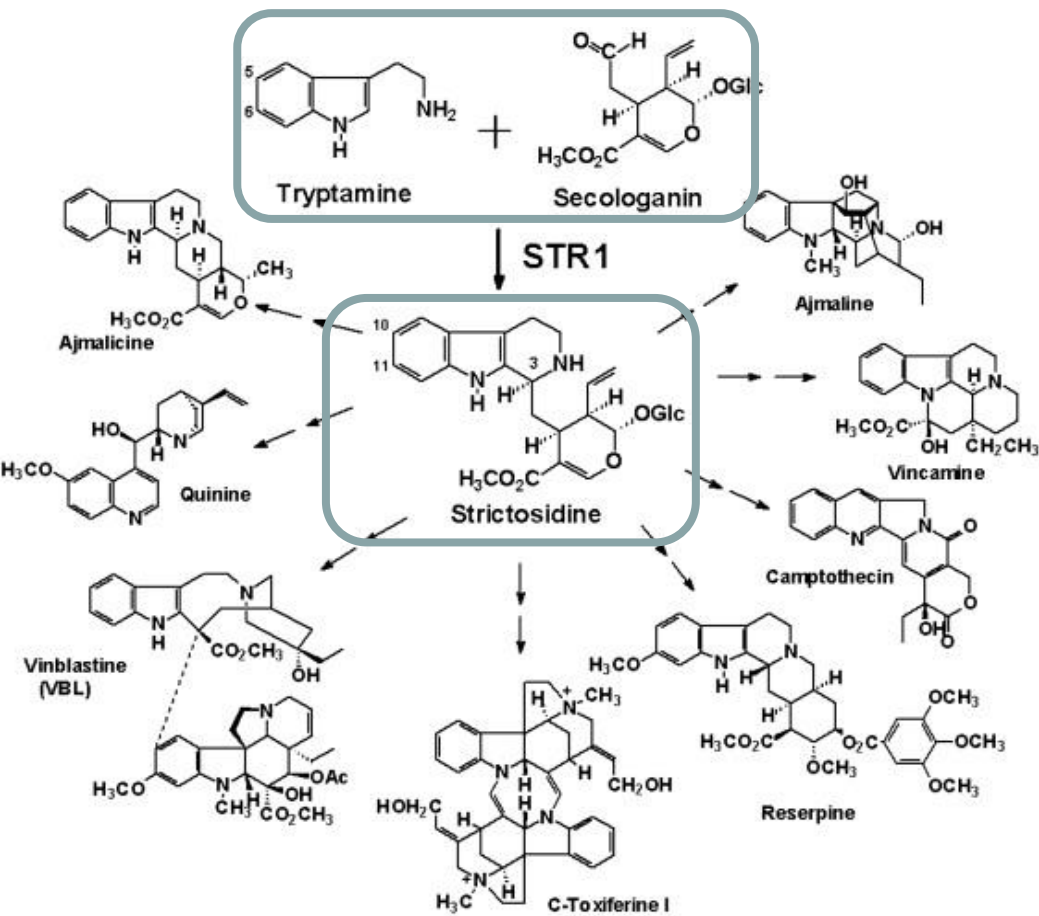
Nicotine

Κινίνη από τον κορμό Cinchona



Cinchona bark was brought to Europe from Peru in the 17th century. Quinine was purified from it in 1820. Synthesis is very difficult and too expensive, so cinchona trees remain the source of the drug

Μονοτερπενοειδή αλκαλοειδή ινδολίου (MIAs) προέρχονται από strictosidine



Rauwolfia serpentina

“Indian snakeroot”

και Madagascar periwinkle

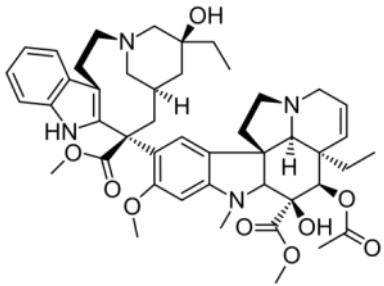


Catharanthus roseus

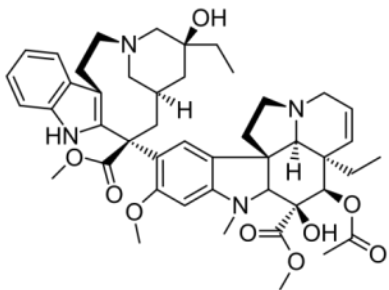


Madagascar periwinkle,
Catharanthus roseus

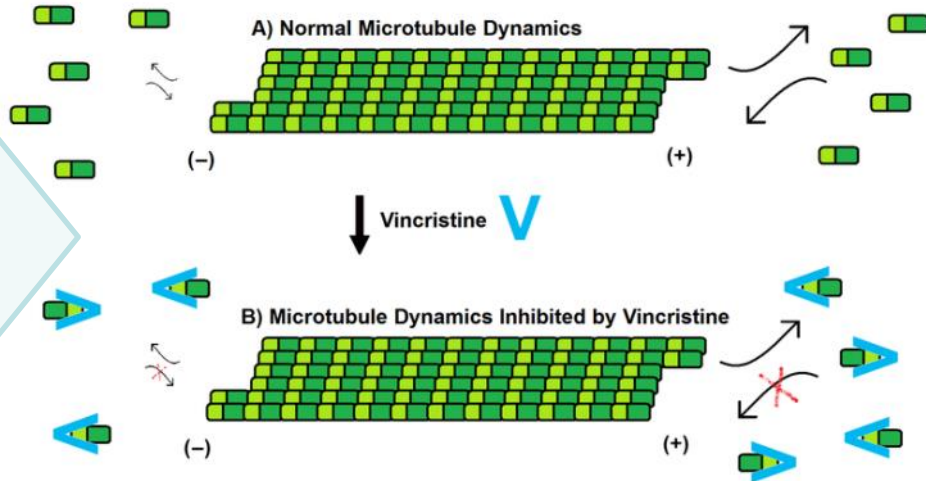
Vinblastine



Vincristine

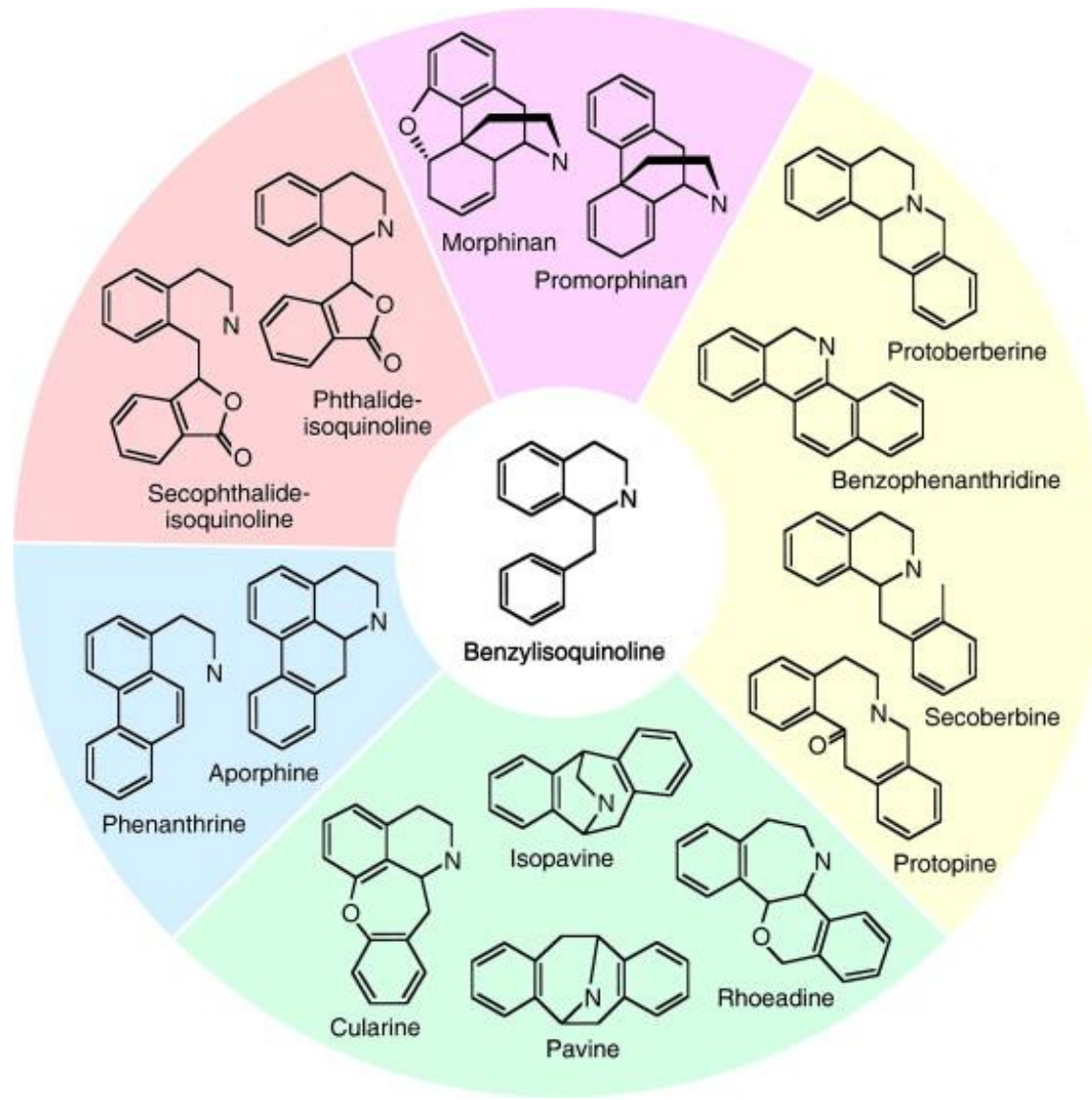


Vinca alkaloids bind free tubulin dimers and interfere with microtubule assembly, therefore blocking cell division

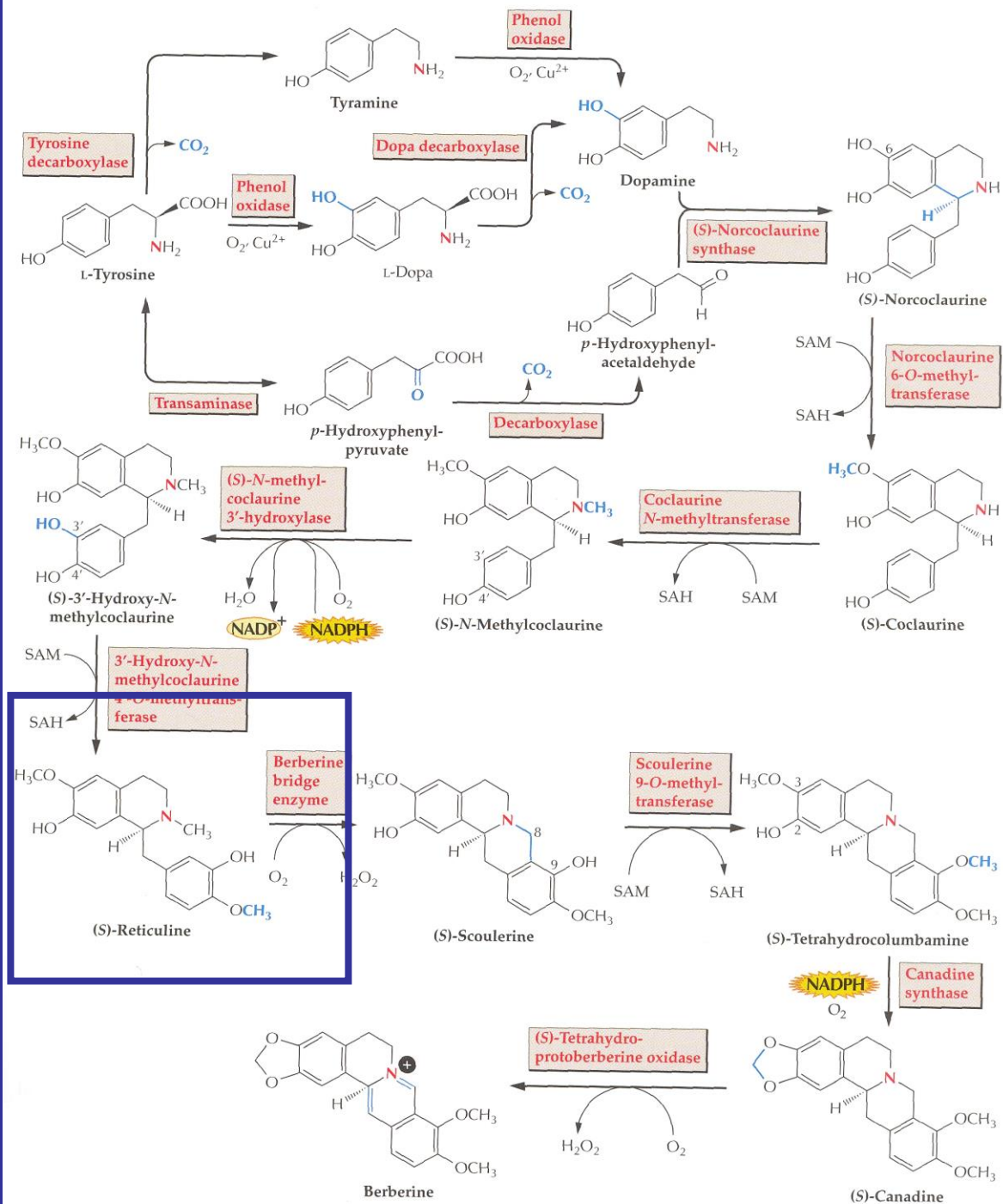


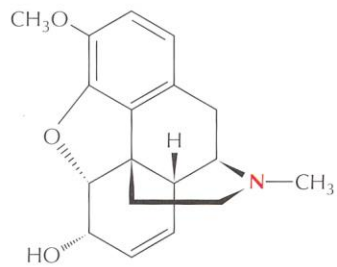
Αλκαλοειδή Benzylisoquinoline (BIAs)

>2500 ενώσεις
που όλα
προέρχονται από
τροποποιήσεις
ενός βασικού
σκελετού

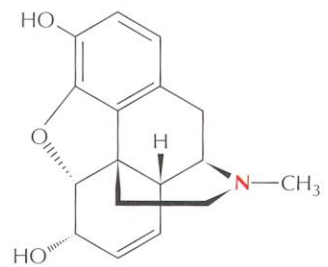


Reprinted from Liscombe, D.K., MacLeod, B.P., Loukanina, N., Nandi, O.I. and Facchini, P.J. (2005). Evidence for the monophyletic evolution of benzylisoquinoline alkaloid biosynthesis in angiosperms. *Phytochemistry*. 66: [1374-1393](#) with permission from Elsevier; [Richard Old](#), XID Services, Inc.

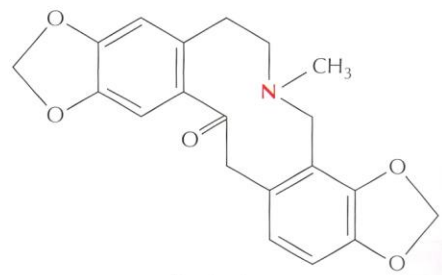




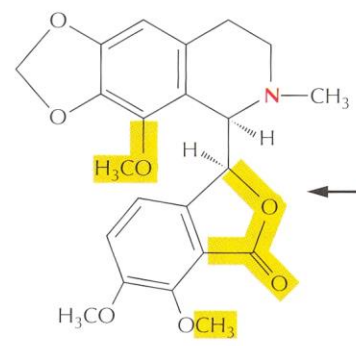
Codeine
Papaver somniferum



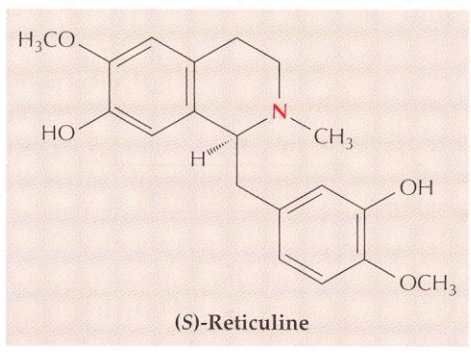
Morphine
Papaver somniferum



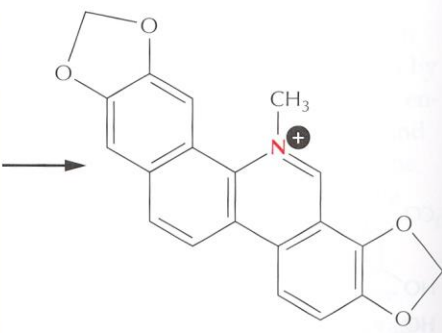
Protopine
Fumaria officinalis



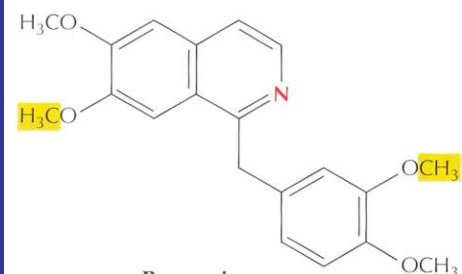
Noscapine
Papaver somniferum



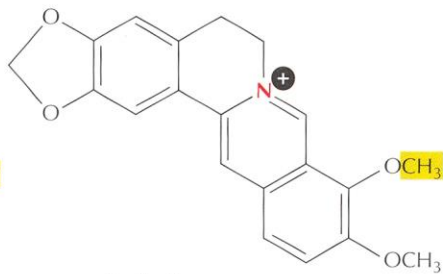
(S)-Reticuline



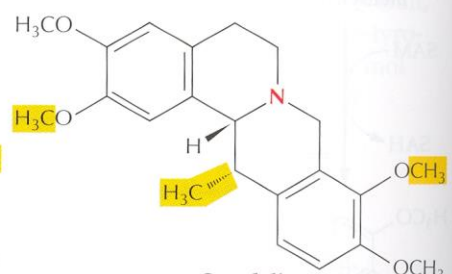
Sanguinarine
Sanguinaria canadensis



Papaverine
Papaver somniferum

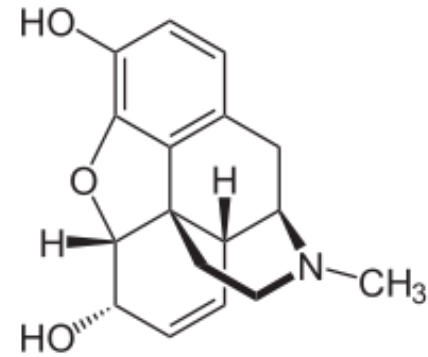


Berberine
Berberis vulgaris

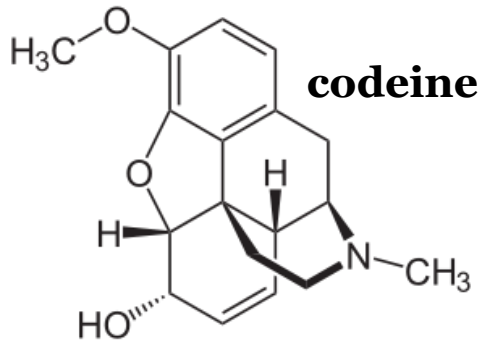


Corydaline
Corydalis cava

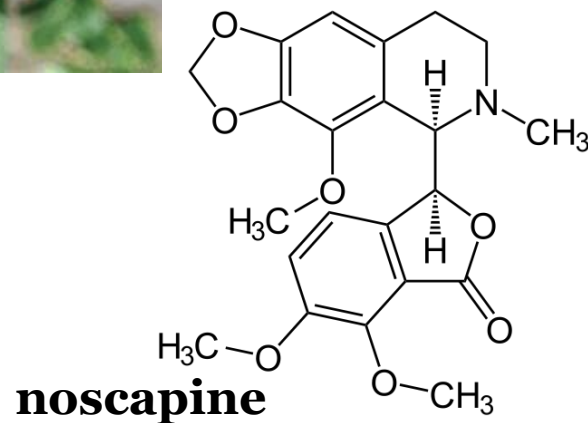
Μορφίνη από *Papaver somniferum*



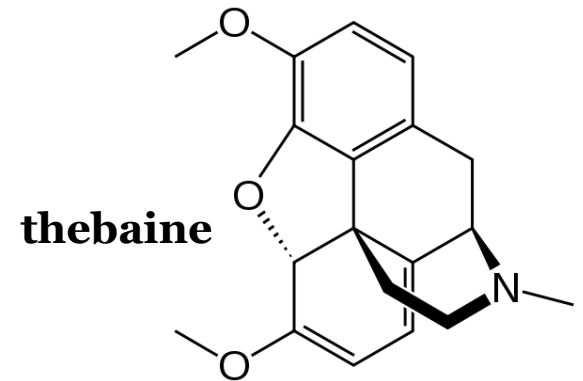
morphine



codeine



noscapine



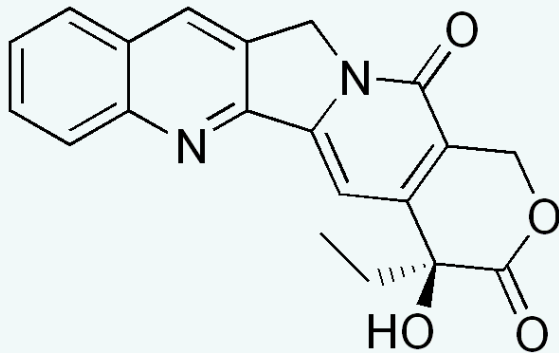
thebaine

Camptothecin, αντικαρκινική δράση από το *Camptotheca acuminata* quinoline alkaloid

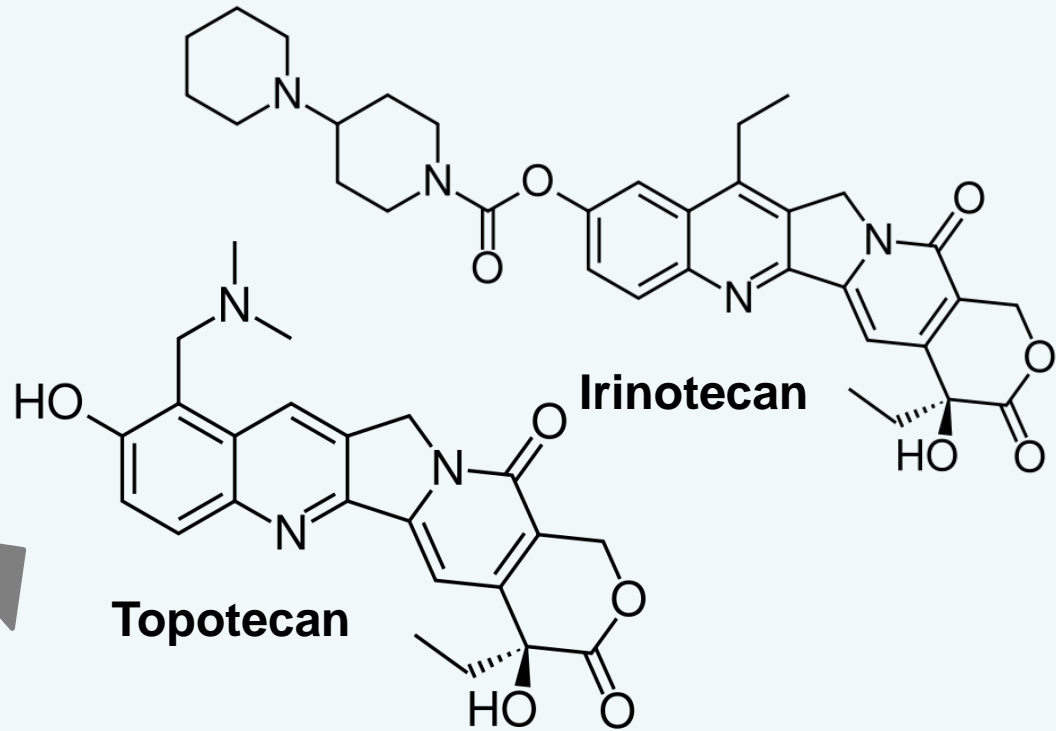


the “happy tree” 喜树
xi shu

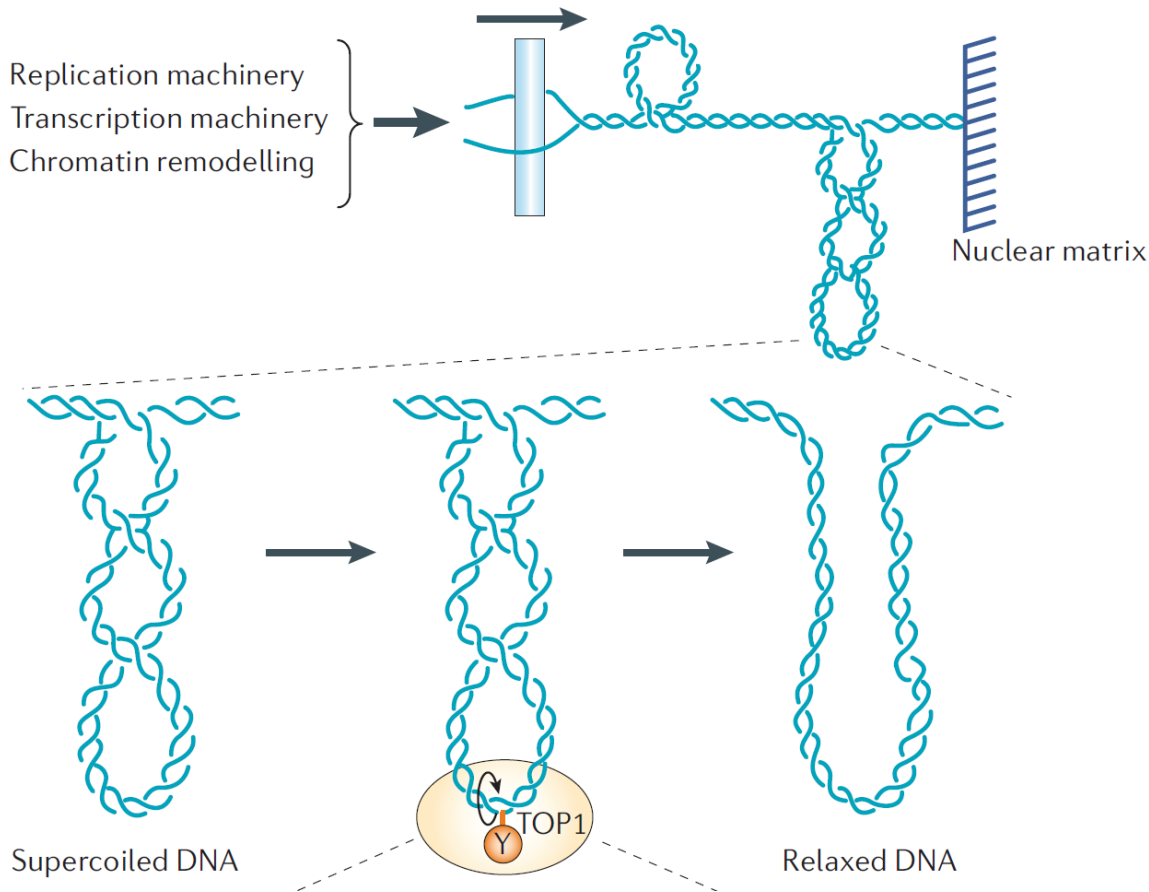
Ημισυνθετικά παράγωγα



Camptothecin



Camptothecins block DNA replication via topoisomerase



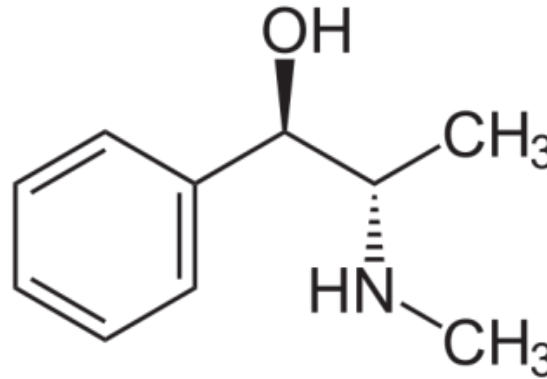
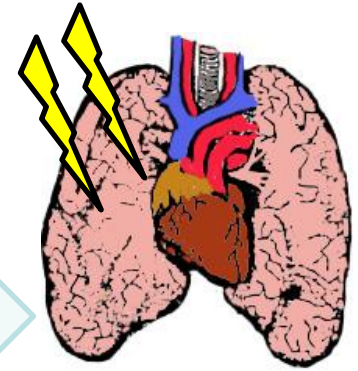
Camptothecin arrests cancer cell growth by targeting topoisomerase I, and identified a new cellular target for chemotherapy agents

Εφεδρίνη από *Ephedra sinica*

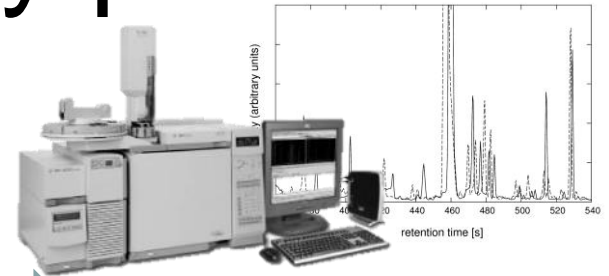


Ασθμα και αναπνευστικά
προβλήματα

Αύξηση
μεταβολικού
ρυθμού

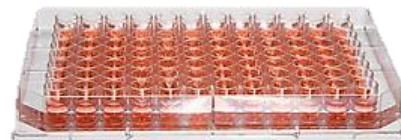


Bioprospecting: Drugs and medicines found by plant screening

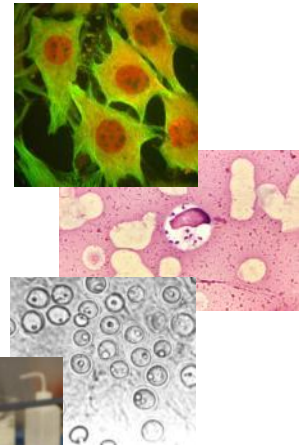


Chemical assays

Plant samples are collected and extracted

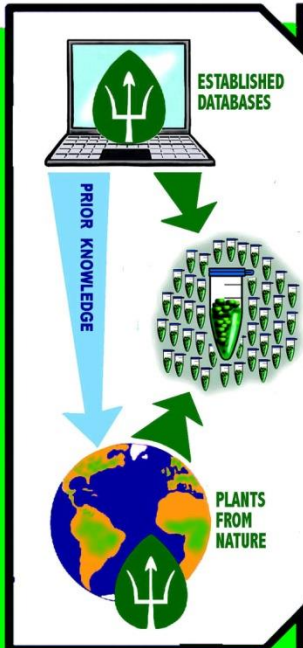


Biological assays

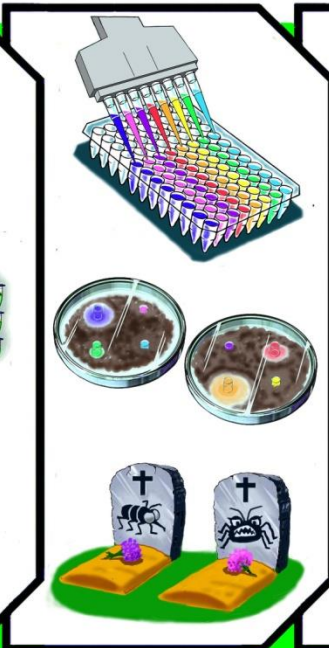


TRIFORC

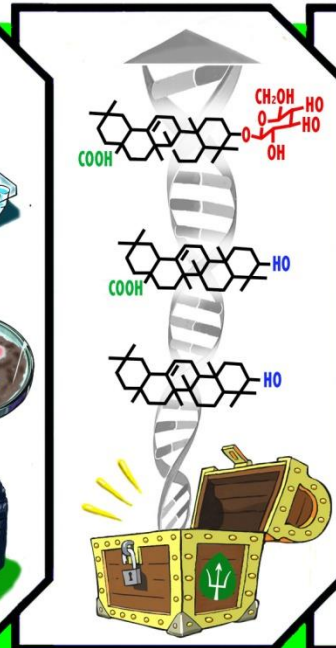
BIOPROSPECTING



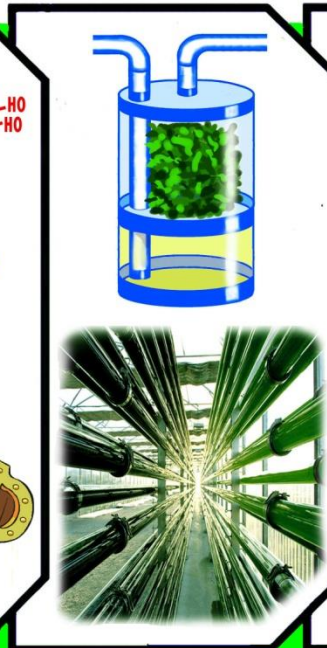
ACTIVITY SCREENING



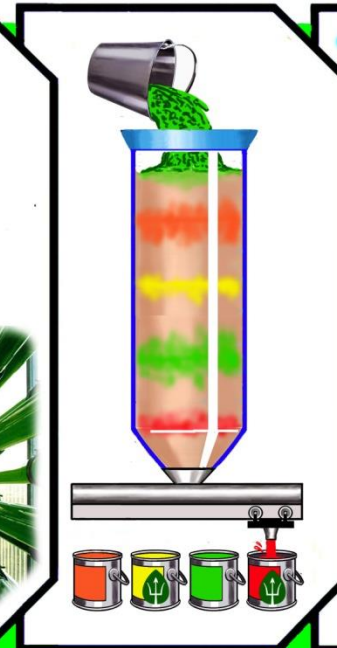
TRIFORC TOOLBOX



BIO-PRODUCTION



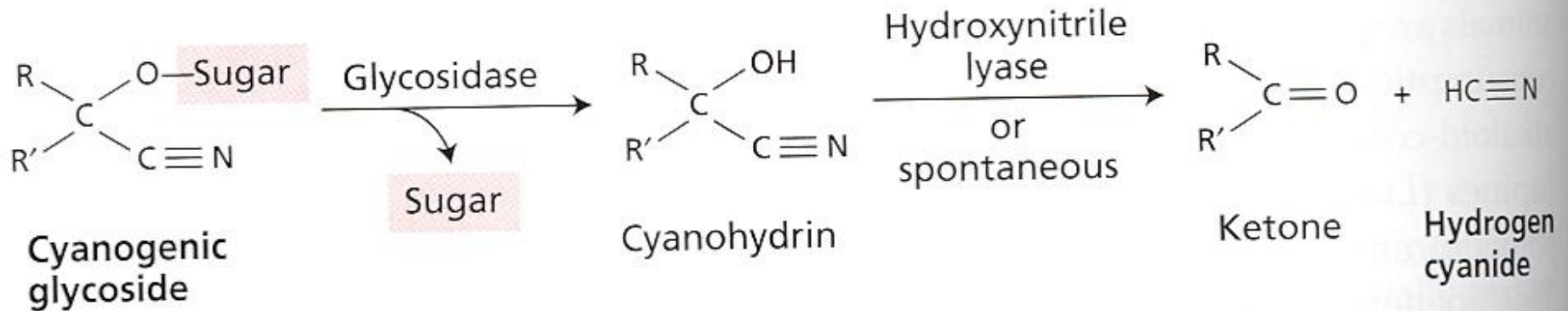
BIO-REFINERY



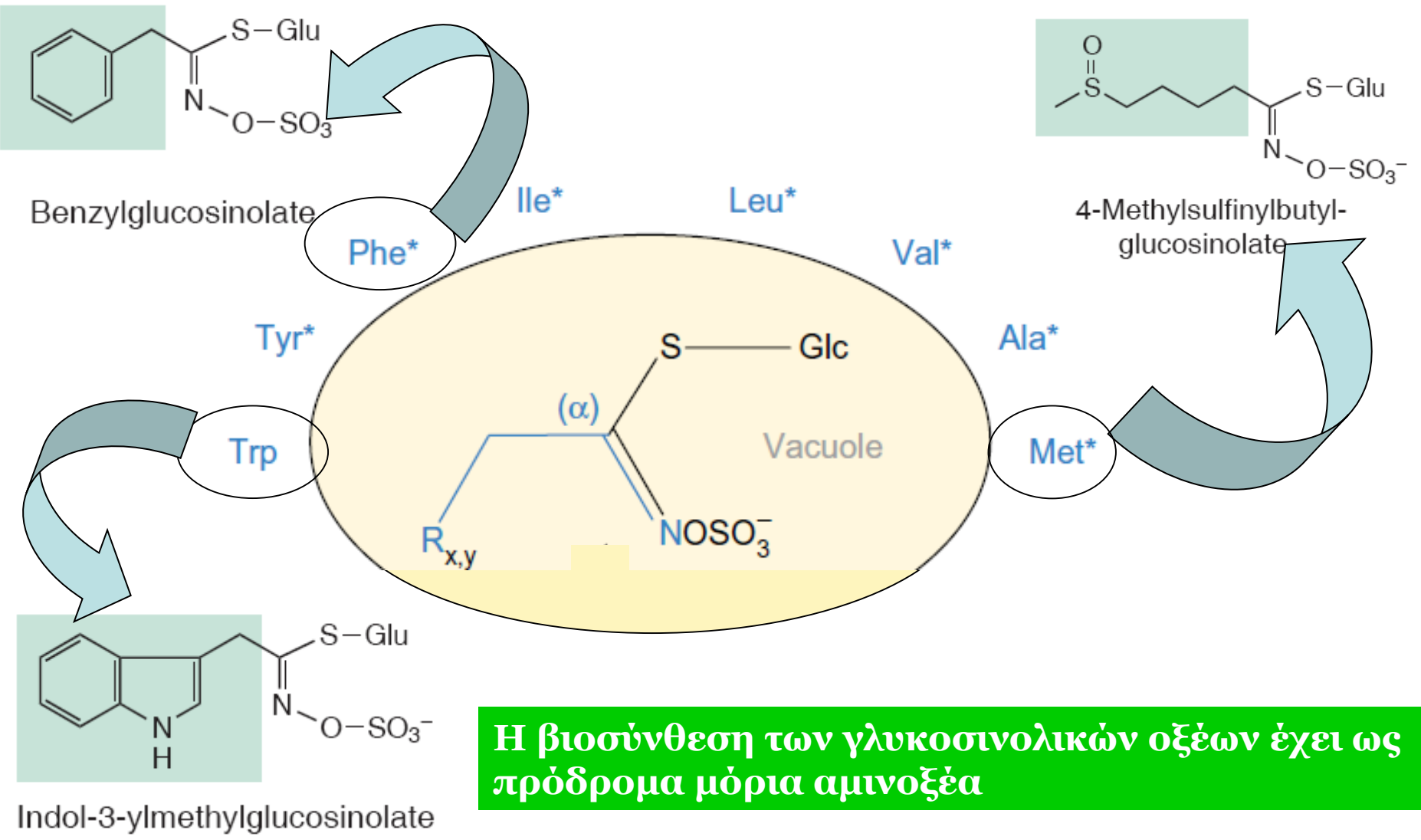
COMMERCIALIZATION



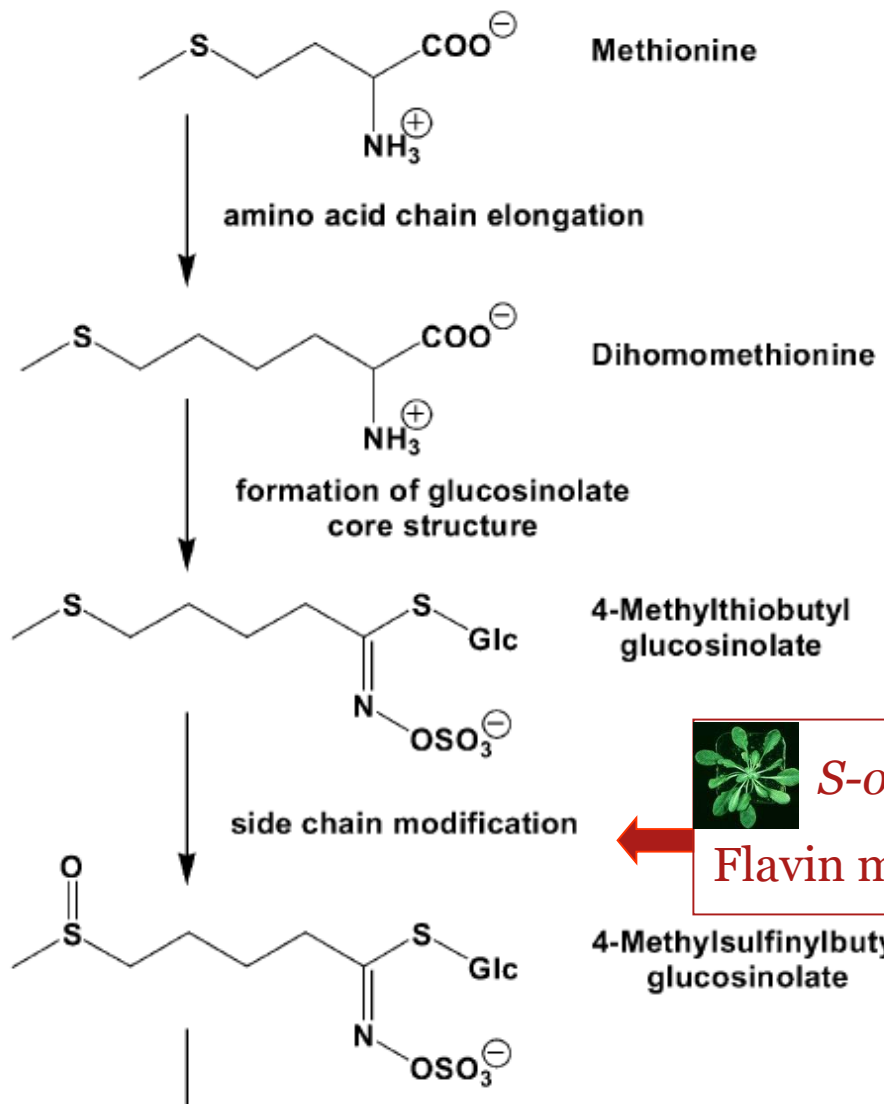
Κυανογόνα γλυκοζίδια (cyanogenic glycosides)



Θειογλυκοζίδια- Γλυκοσινολικά οξέα (glucosinolates)



Η βιοσύνθεση των γλυκοσινολικών οξέων έχει ως πρόδρομα μόρια αμινοξέα

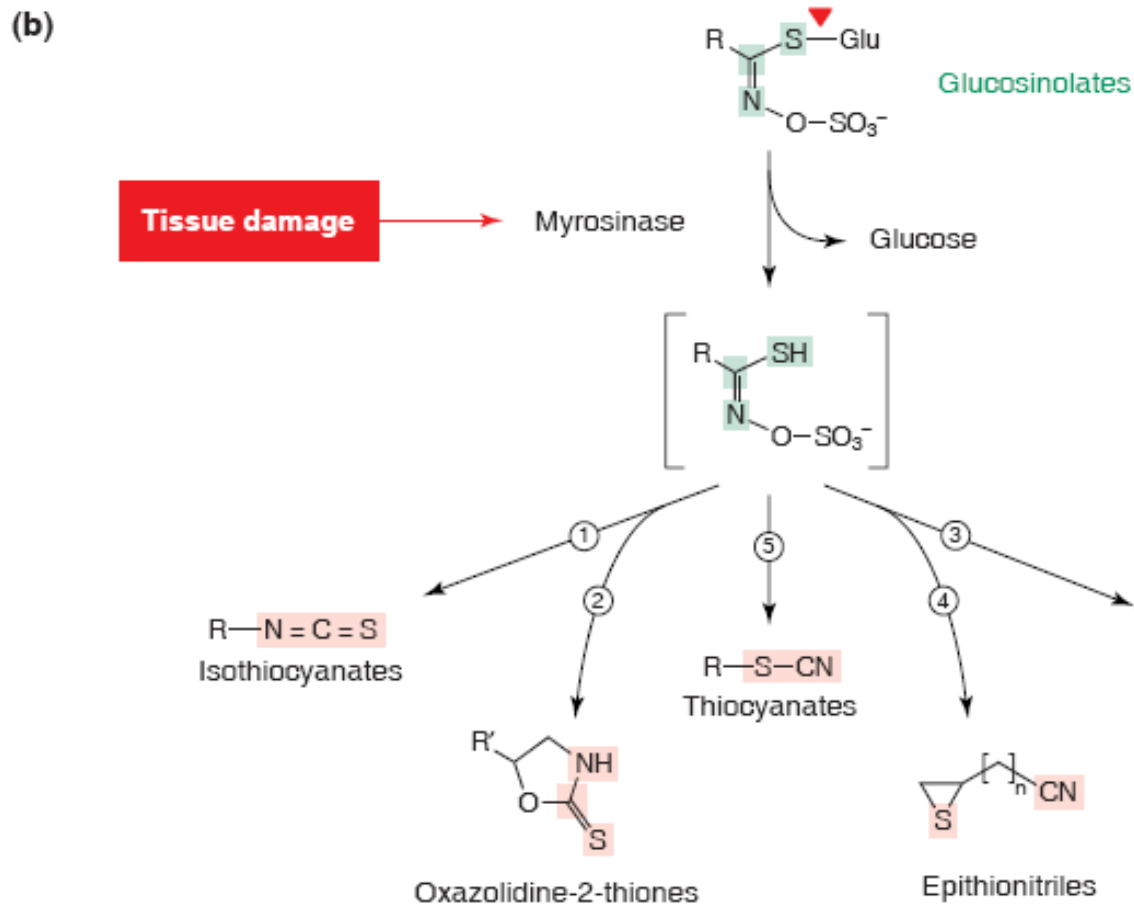
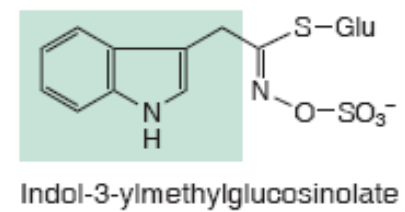
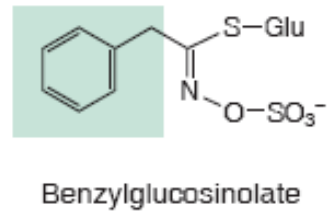
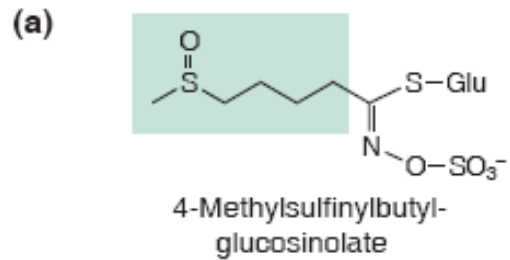


glucoerucin

S-oxygenating enzyme:
Flavin monooxygenase FMO_{GS-OX1}

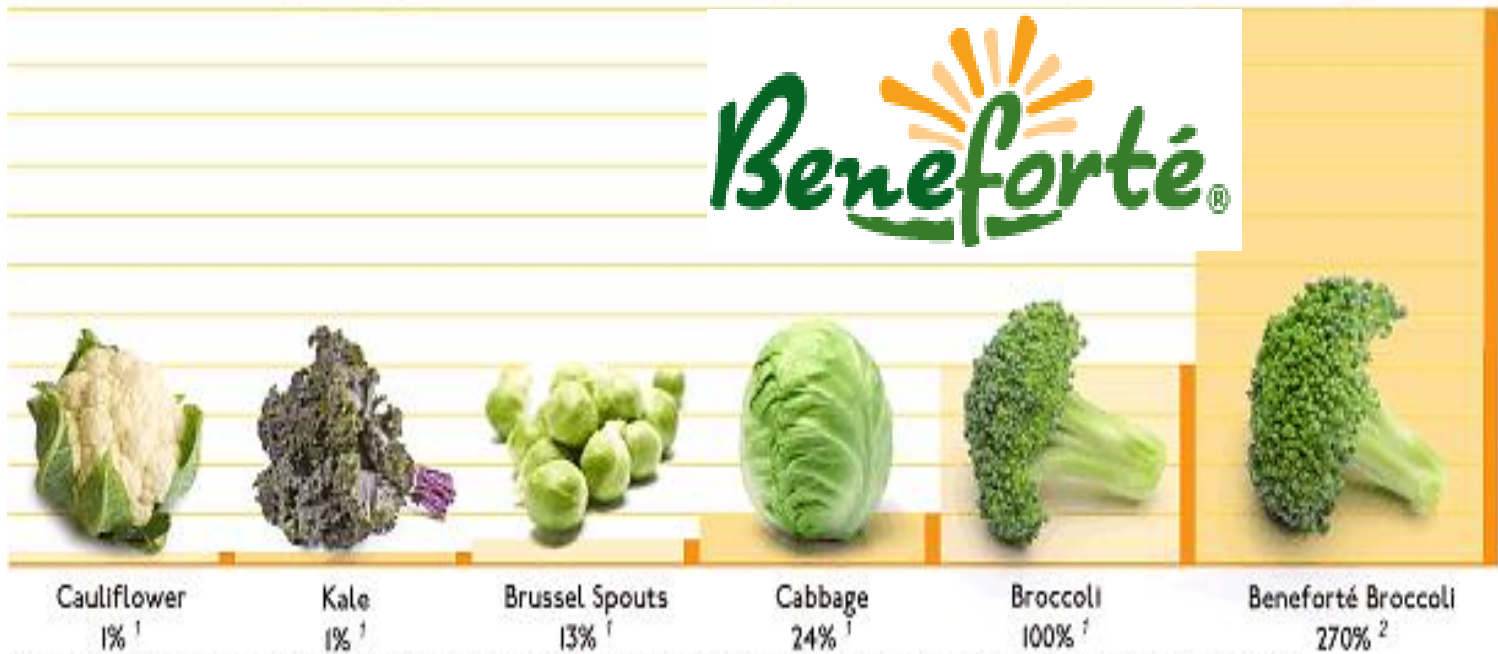
glucoraphanin

Θειογλυκοζίδια (glucosinolates)



Beneforté®

Relative percentages of glucoraphanin per serving of cruciferous vegetables, including broccoli:



¹ Journal of the Science of Food and Agriculture 85:681 (2005) – relationship of climate and genotype to seasonal variation in the glucosinolate-myrosinase system.

² Average glucoraphanin content in Beneforté® broccoli relative to market standard broccoli varieties assessed over 3 years in 23 locations.