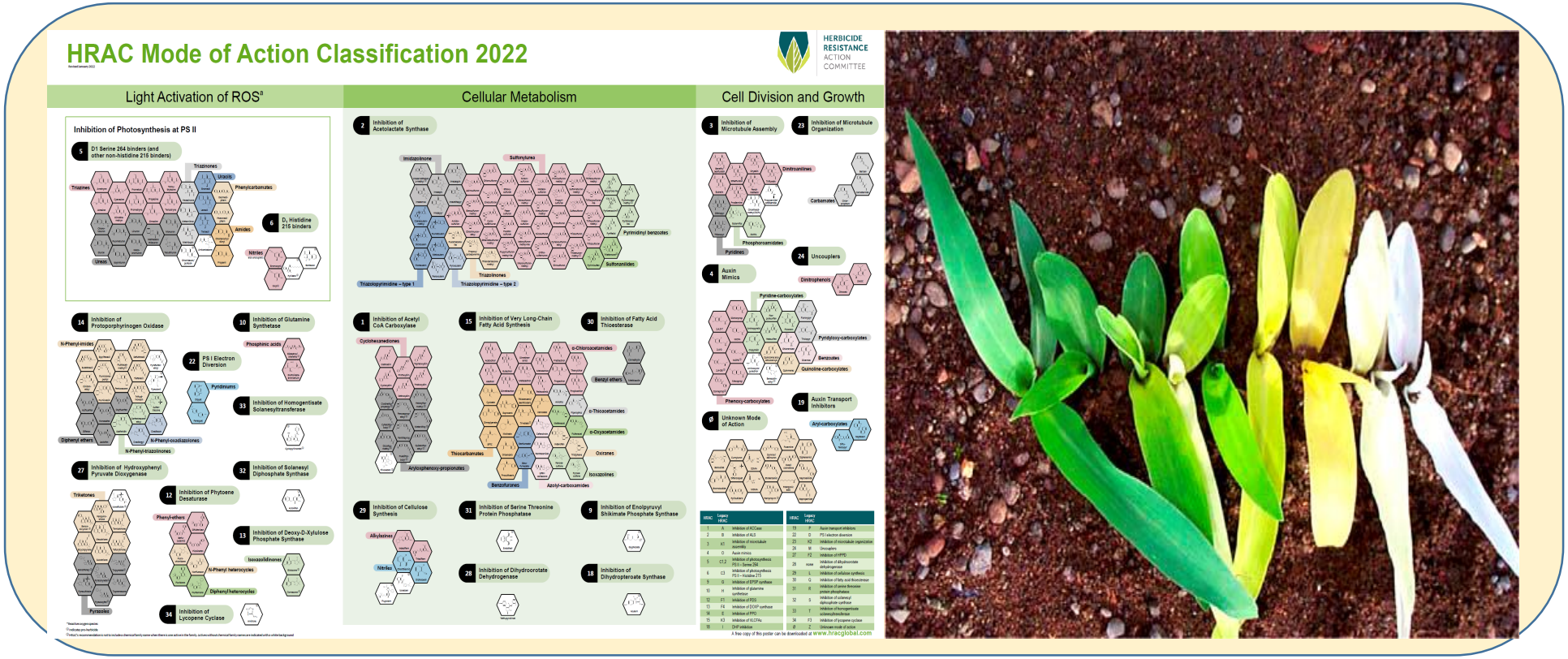
2022. 10. 27

제초제 작용기작 분류체계와 식물백화 유도 화학물질들의 작용생리



김 진 석

(한국화학연구원 친환경신물질연구센터)

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   - 연구방법 소개 및 발전현황
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5. 향후 연구방향
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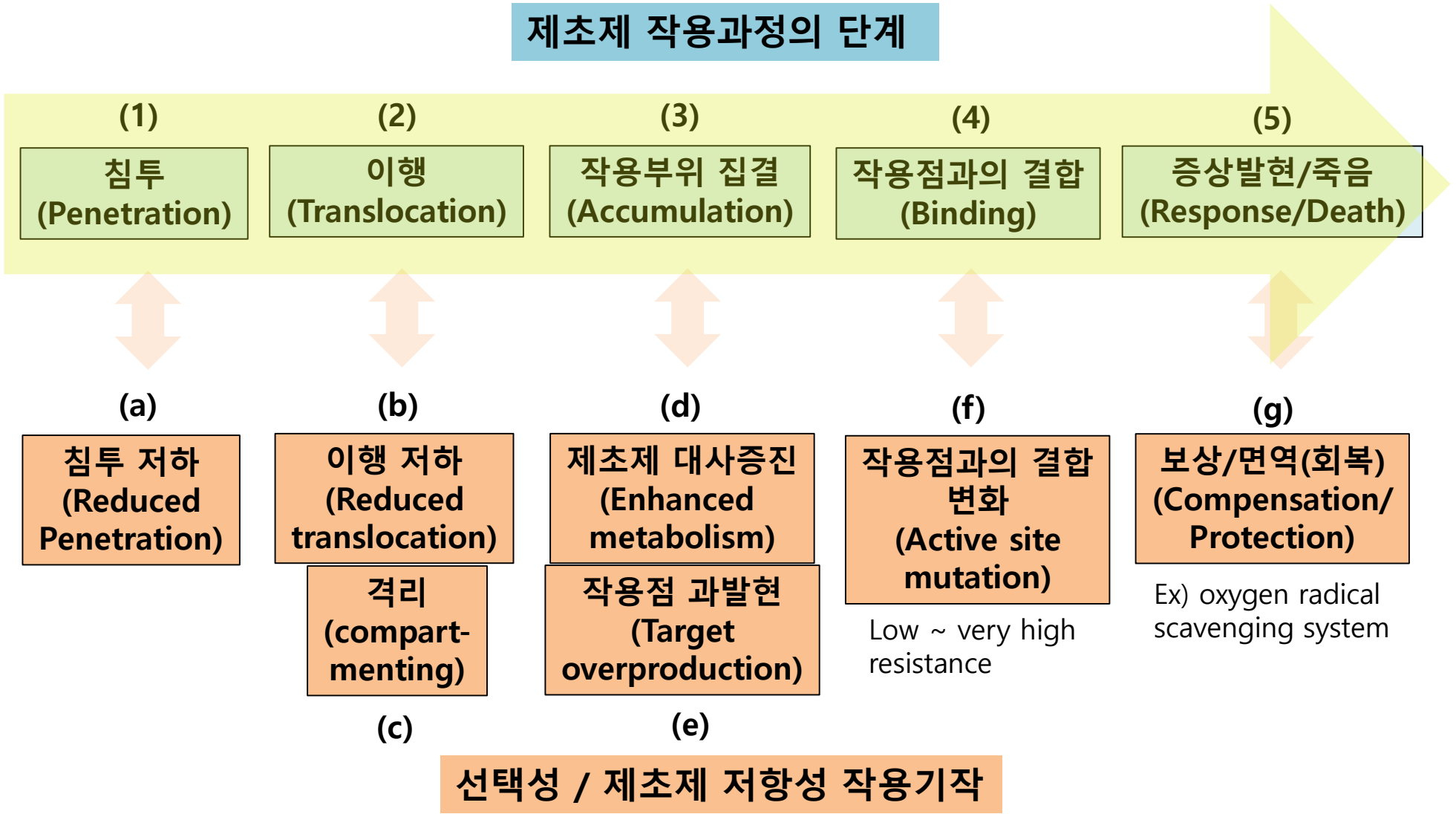
Action Physiology of Herbicide



HRAC Mode of Action Classification 2022

Revised January 2022

HERBICIDE RESISTANCE ACTION COMMITTEE

Light Activation of ROS[a]

Inhibition of Photosynthesis at PS II

5 D1 Serine 264 binders (and other non-histidine 215 binders)

Triazinones · Uracils · Phenylcarbamates · Triazines · Amides · Ureas · Nitriles

6 D_1 Histidine 215 binders

Inhibition of Protoporphyrinogen Oxidase

14 Inhibition of Protoporphyrinogen Oxidase

N-Phenyl-imides · Diphenyl ethers · N-Phenyl-oxadiazolones · N-Phenyl-triazolinones

Inhibition of Glutamine Synthetase

10 Inhibition of Glutamine Synthetase

Phosphinic acids

PS I Electron Diversion

22 PS I Electron Diversion

Pyridiniums

Inhibition of Homogentisate Solanesyltransferase

33 Inhibition of Homogentisate Solanesyltransferase

Inhibition of Hydroxyphenyl Pyruvate Dioxygenase

27 Inhibition of Hydroxyphenyl Pyruvate Dioxygenase

Triketones · Pyrazoles

Inhibition of Solanesyl Diphosphate Synthase

32 Inhibition of Solanesyl Diphosphate Synthase

Inhibition of Phytoene Desaturase

12 Inhibition of Phytoene Desaturase

Phenyl-ethers · N-Phenyl heterocycles · Diphenyl heterocycles

Inhibition of Deoxy-D-Xylulose Phosphate Synthase

13 Inhibition of Deoxy-D-Xylulose Phosphate Synthase

Isoxazolidinones

Inhibition of Lycopene Cyclase

34 Inhibition of Lycopene Cyclase

[a] Reactive oxygen species

① Indicates pro-herbicide

② HRAC's recommendation is not to include a chemical family name when there is one active in the family. Actives without chemical family names are indicated with a white background

Cellular Metabolism

Inhibition of Acetolactate Synthase

2 Inhibition of Acetolactate Synthase

Imidazolinone · Sulfonylurea · Pyrimidinyl benzoates · Sulfonanilides · Triazolinones · Triazolopyrimidine – type 1 · Triazolopyrimidine – type 2

Inhibition of Acetyl CoA Carboxylase

1 Inhibition of Acetyl CoA Carboxylase

Cyclohexanediones · Aryloxphenoxy-propionates

Inhibition of Very Long-Chain Fatty Acid Synthesis

15 Inhibition of Very Long-Chain Fatty Acid Synthesis

α-Chloroacetamides · Benzyl ethers · α-Thioacetamides · α-Oxyacetamides · Thiocarbamates · Oxiranes · Isoxazolines · Benzofuranes · Azolyl-carboxamides

Inhibition of Fatty Acid Thioesterase

30 Inhibition of Fatty Acid Thioesterase

Inhibition of Cellulose Synthesis

29 Inhibition of Cellulose Synthesis

Alkylazines · Nitriles

Inhibition of Serine Threonine Protein Phosphatase

31 Inhibition of Serine Threonine Protein Phosphatase

Inhibition of Dihydroorotate Dehydrogenase

28 Inhibition of Dihydroorotate Dehydrogenase

Inhibition of Enolpyruvyl Shikimate Phosphate Synthase

9 Inhibition of Enolpyruvyl Shikimate Phosphate Synthase

Inhibition of Dihydropteroate Synthase

18 Inhibition of Dihydropteroate Synthase

Cell Division and Growth

Inhibition of Microtubule Assembly

3 Inhibition of Microtubule Assembly

Dinitroanilines · Phosphoramidates · Pyridines

Inhibition of Microtubule Organization

23 Inhibition of Microtubule Organization

Carbamates

Uncouplers

24 Uncouplers

Dinitrophenols

Auxin Mimics

4 Auxin Mimics

Pyridine-carboxylates · Pyridyloxy-carboxylates · Benzoates · Quinoline-carboxylates · Phenoxy-carboxylates

Auxin Transport Inhibitors

19 Auxin Transport Inhibitors

Aryl-carboxylates

Unknown Mode of Action

Ø Unknown Mode of Action

HRAC	Legacy HRAC	
1	A	Inhibition of ACCase
2	B	Inhibition of ALS
3	K1	Inhibition of microtubule assembly
4	O	Auxin mimics
5	C1,2	Inhibition of photosynthesis PS II – Serine 264
6	C3	Inhibition of photosynthesis PS II – Histidine 215
9	G	Inhibition of EPSP synthase
10	H	Inhibition of glutamine synthetase
12	F1	Inhibition of PDS
13	F4	Inhibition of DOXP synthase
14	E	Inhibition of PPO
15	K3	Inhibition of VLCFAs
18	I	DHP inhibition

HRAC	Legacy HRAC	
19	P	Auxin transport inhibitors
22	D	PS I electron diversion
23	K2	Inhibition of microtubule organization
24	M	Uncouplers
27	F2	Inhibition of HPPD
28	none	Inhibition of dihydroorotate dehydrogenase
29	L	Inhibition of cellulose synthesis
30	Q	Inhibition of fatty acid thioesterase
31	R	Inhibition of serine threonine protein phosphatase
32	S	Inhibition of solanesyl diphosphate synthase
33	T	Inhibition of homogentisate solanesyltransferase
34	F3	Inhibition of lycopene cyclase
Ø	Z	Unknown mode of action

A free copy of this poster can be downloaded at www.hracglobal.com

HRAC Mode of Action Classification 2022

28 group, 25 action sites

HRAC /WSSA	Legacy HRAC	Site of action
1	A	Inhinition of ACCase
2	B	Inhinition of ALS
3	K1	Inhinition of microtubule assembly
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14	E	Inhinition of PPO
15	K3	Inhinition of VLCFAs
18	I	DHP inhibition
19	P	Auxin transport inhibitors

HRAC /WSSA	Legacy HRAC	Site of action
22	D	PS I electron diversion
23	K2	Inhibition of microtubule organization
24	M	Uncouplers
27	F2	Inhibition of HPPD
28	none	Inhibition of dihydroorotate dehydrogenase
29	L	Inhibition of cellulose synthesis
30	Q	Inhibition of fatty acid thioesterase
31	R	Inhibition of serine threonine protein phosphatase
32	S	Inhibition of solanesyl diphosphate synthase
33	T	Inhibition of homogentisate solanesyltransferase
34	F3	Inhibition of lycopene cyclase
4/29	O/L	Auxin mimics/Cellulose synthesis
6/24	C3/M	PS II-Histidine 215/Uncouplers
ø	Z	Unknown mode of action

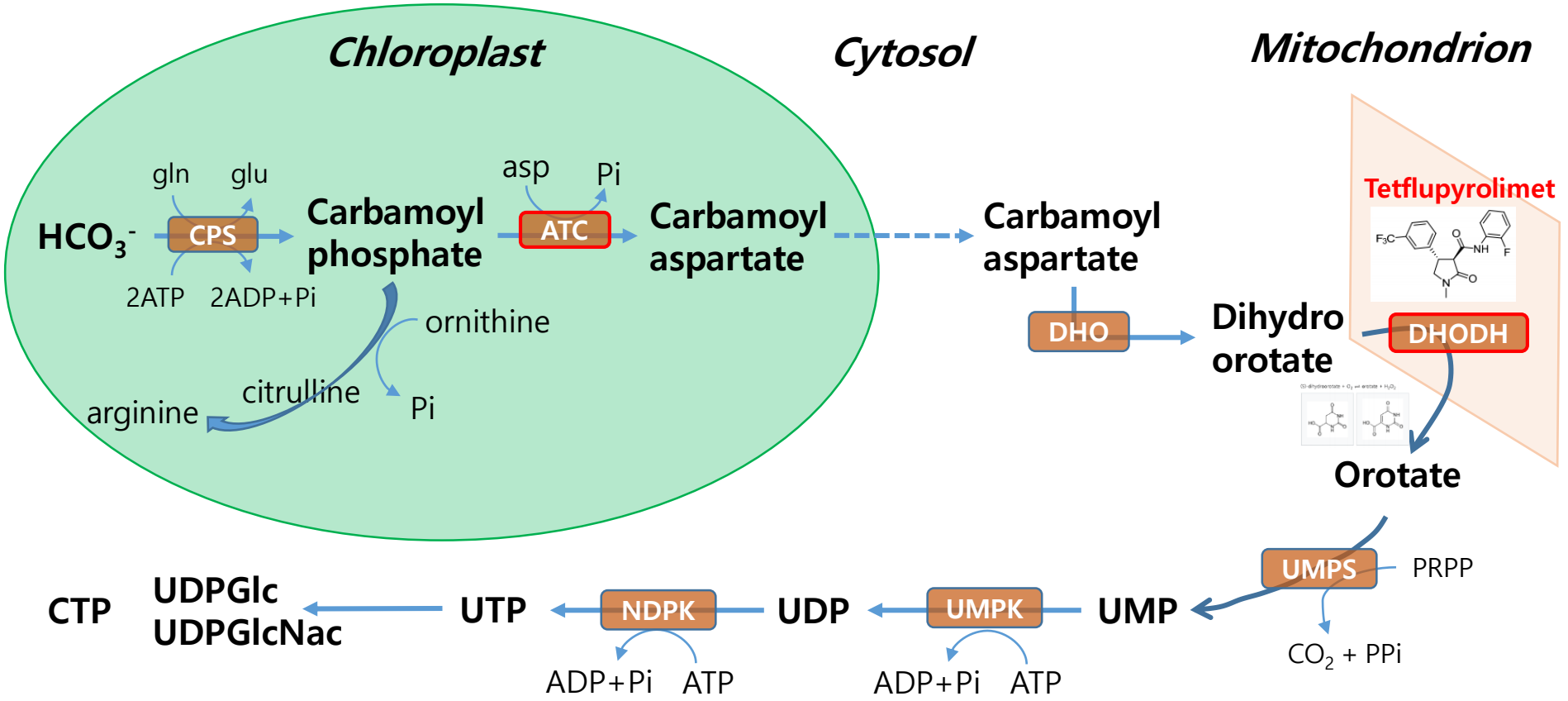
The most recent updates of herbicide site of action (SOA) classification list (05 May, 2021)

Herbicide	WSSA/ HRAC Code	Old WSSA	Site of Action
Benazolin-ethyl	4	NC	Auxin Mimics
Metoxuron, Chloranocryl=dicryl, Pentanochlor, Propanil, Benzthiazuron, Bromuron, Buturon, Chlorbromuron, Chlorotoluron, Chloroxuron, Difenoxuron, Dimefuron, Diuron, Ethidimuron, Fenuron, Fluometuron, Fluothiuron, Isoproturon, Isouron, Linuron, Metobenzuron, Metobromuron, Methabenzthiazuron, Metoxuron, Monolinuron, Monuron, Neburon, Parafluron, Siduron, Tebuthiuron, Thiazafluron	5	7	Inhbition of Photosynthesis at PSII - Serine 264 Binders
Ethofumesate, Benfuresate, Butylate, Cycloate, Dimepiperate, EPTC, Esprocarb, Molinate, Orbencarb, Pebulate, Prosulfocarb, Thiobencarb (=Benthiocarb), Tiocarbazil, Tri-allate, Vernolate	15	8	Inhibition of Very Long-Chain Fatty Acid Synthesis
Tetflupyrolimet	28	NC	Inhibition of Dihydroorotate Dehydrogenase
Dichlobenil	29	20	Inhibition of Cellulose Synthesis
Isoxaben	29	21	Inhibition of Cellulose Synthesis
Cinmethylin, Methiozolin	30	30	Inhibition of Fatty Acid Thioesterase
Endothal	31	NC	Inhibition of Serine-Threonine Protein Phosphatase
Aclonifen	32	11	Inhibition of Solanesyl Diphosphate Synthase
Cyclopyrimorate	33	NC	Inhibition of Homogentisate Solanesyltransferase
Amitrole	34	11	Inhibition of Lycopene Cyclase
Quinclorac	4/29	4	Auxin mimics/Cellulose synthesis
Bromofenoxim, Bromoxynil, Ioxynil	6/24	6	PS II-Histidine 215/Uncouplers
Bensulide	0	8	Unknown
Napropamide, Diphenamid, Naproanilide	0	15	Unknown

최근에 소개된 신규 제초작용점 5가지

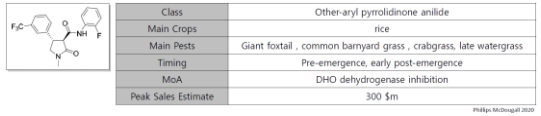
- Dihydroorotate dehydrogenase
- Fatty acid thioesterase
- Serine-threonine protein phosphatase
- Solanesyl diphosphate synthase
- Homogentisate solanesyl transferase

Inhibition of dihydroorotate dehydrogenase



UDP: Glycogen 생성에 사용
UTP: RNA 생성의 기질로 사용
CTP: RNA 합성의 기질,
Glycerophospholipid 합성의 coenzyme

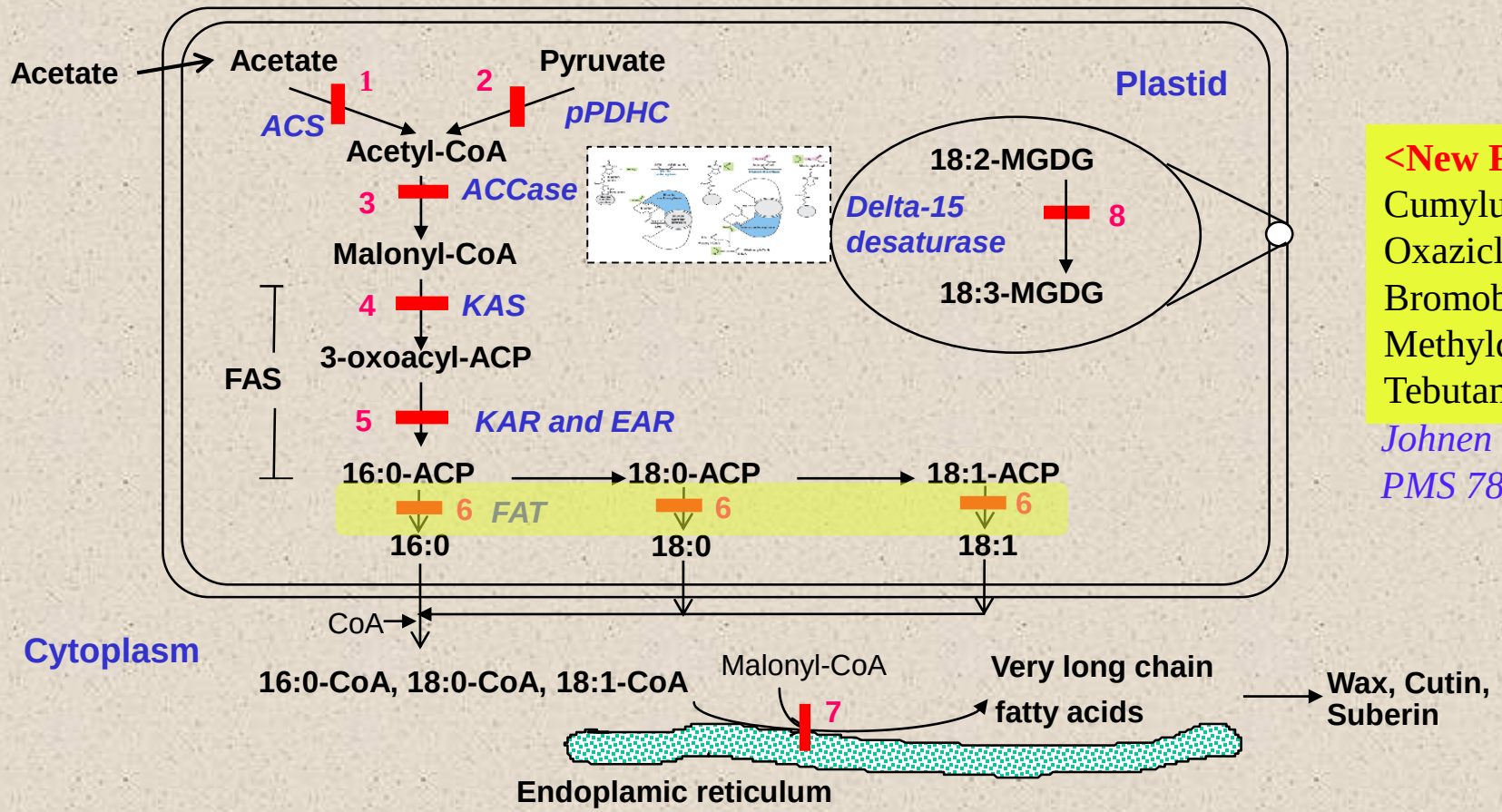
CPS: Carbamoyl phosphate synthetase, **ATC**: Aspartate transcarbamoylase, **DHO**: Dehydroorotase,
DHODH: Dihydroorotate dehydrogenase, **UMPS**: Uridine monophosphate synthase, **UMPK**: UMP kinase,
NDPK: Nucleoside diphosphate kinase



Class	Other-aryl pyrrolidinone anilide
Main Crops	rice
Main Pests	Giant foxtail , common barnyard grass , crabgrass, late watergrass
Timing	Pre-emergence, early post-emergence
MoA	DHO dehydrogenase inhibition
Peak Sales Estimate	300 $m

Biosynthetic pathway of pyrimidine nucleotides in plants

Inhibition of fatty acid thioesterase (FAT)



<New FAT inhibitors>
Cumyluron
Oxaziclomefone
Bromobutide
Methyldymron
Tebutam

Johnen et al.,
PMS 78:3620-3629 (2022)

(Abbreviations)
FAT, fatty acid thioesterase; ACS, acetyl-CoA synthetase;
pPDHC, plastidic pyruvatedehydrogenase complex;
ACCase, acetyl-CoA carboxylase; FAS, fatty acid synthase;
KAS, ketoacyl-ACP synthase; KAR, ketoacyl-ACP reductase;
EAR, enoyl-ACP reductase; MGDG, monogalactosyldiacylglycerol;
ACP, acyl carrier protein

(Inhibitors)
1: ethyl-adenylate, 2: acetylmethyl-phosphinate,
3: sethoxydim, diclopop, fenoxaprop, ets
4: cerulenin (KAS I), thiolactomycin (KAS I and KAS III), 5: diflufenican, 6: cinmethylin, methiozolin
7: carbamothioates,
8: substitited pyridazinones

Perfluidone: Inhibition of 3-ketoacyl-CoA synthase in VLCFAs

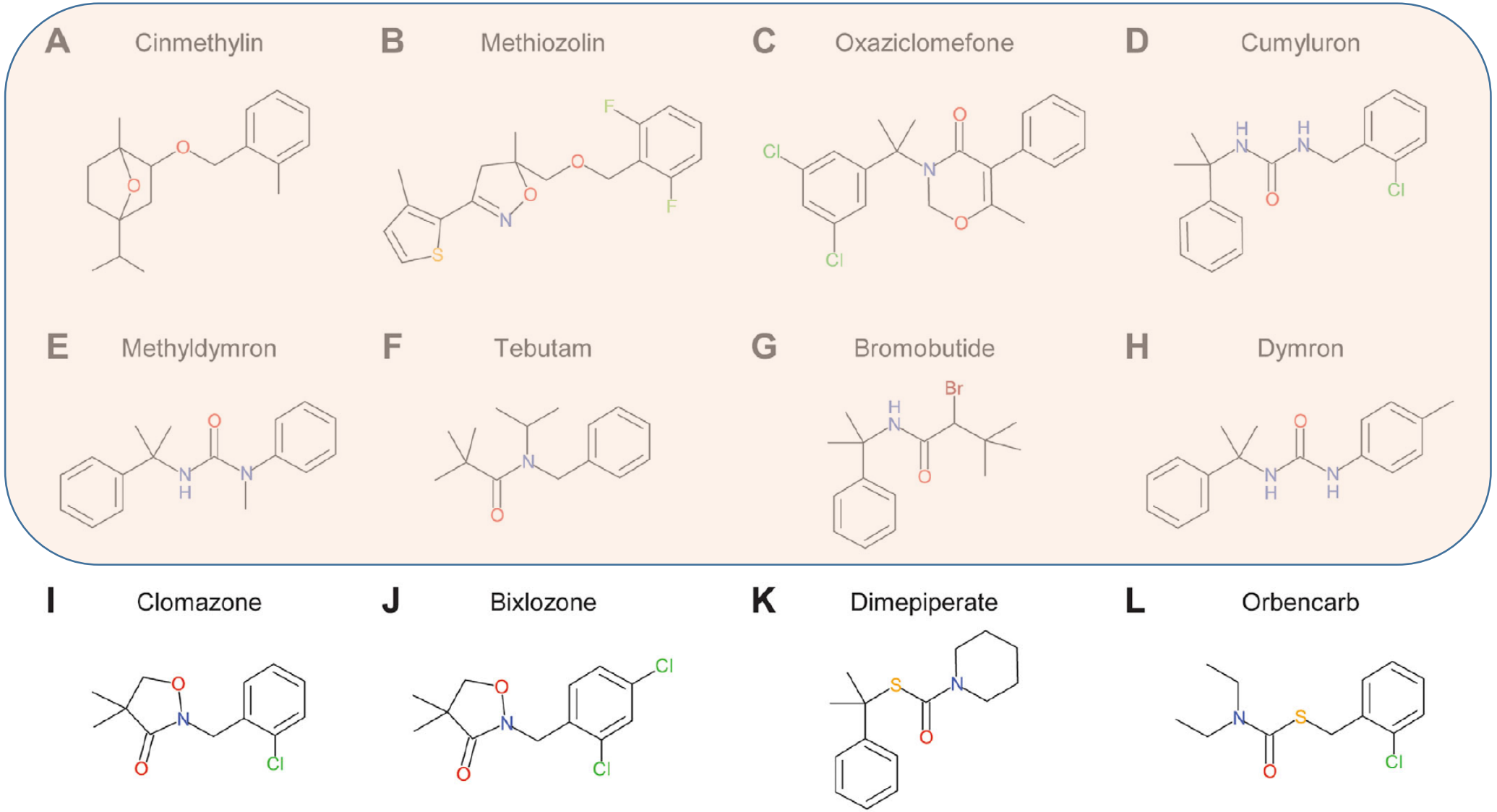
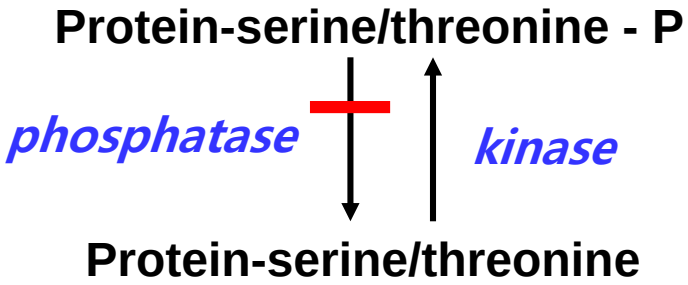
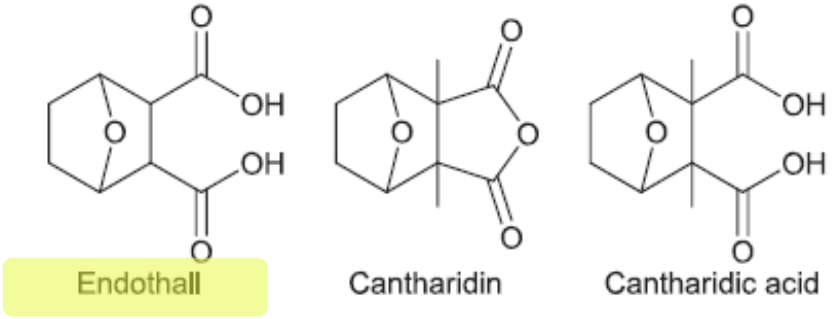


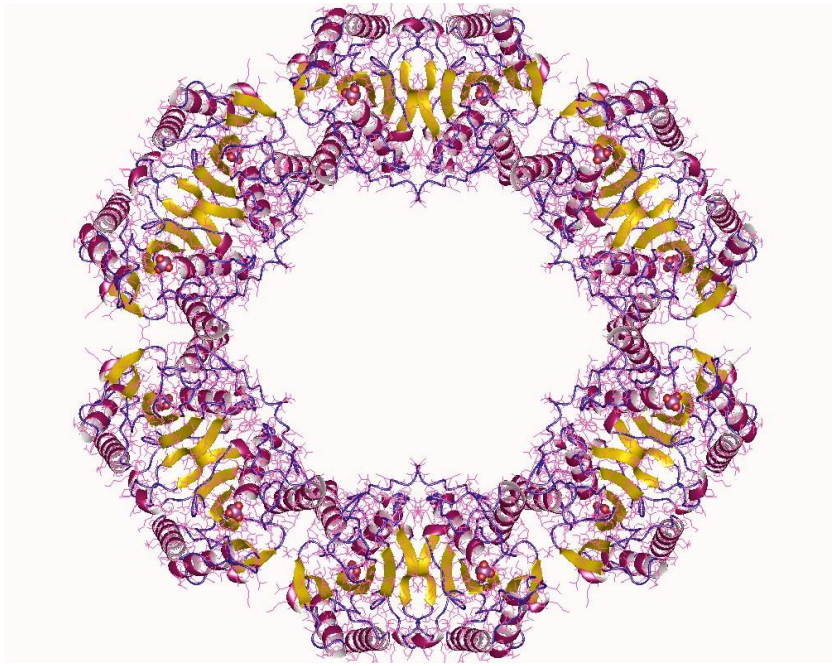
Figure 3. Overview of chemical structure of compound selection. Chemical structures of (A) cinmethylin, (B) methiozolin, (C) oxaziclomefone, (D) cumyluron, (E) methyldymron, (F) tebutam, (G) bromobutide, (H) dymron, (I) clomazone, (J) bixlozone, (K) dimepiperate and (L) orbencarb are shown.

Johnen et al., I2022. nhibition of acyl-ACP thioesterase as site of action of commercial herbicides cumyluron, oxaziclomefone, bromobutide, methyldymron and tebutam. PMS 78:3620-3629.

Inhibition of protein-serine/threonine phosphatases





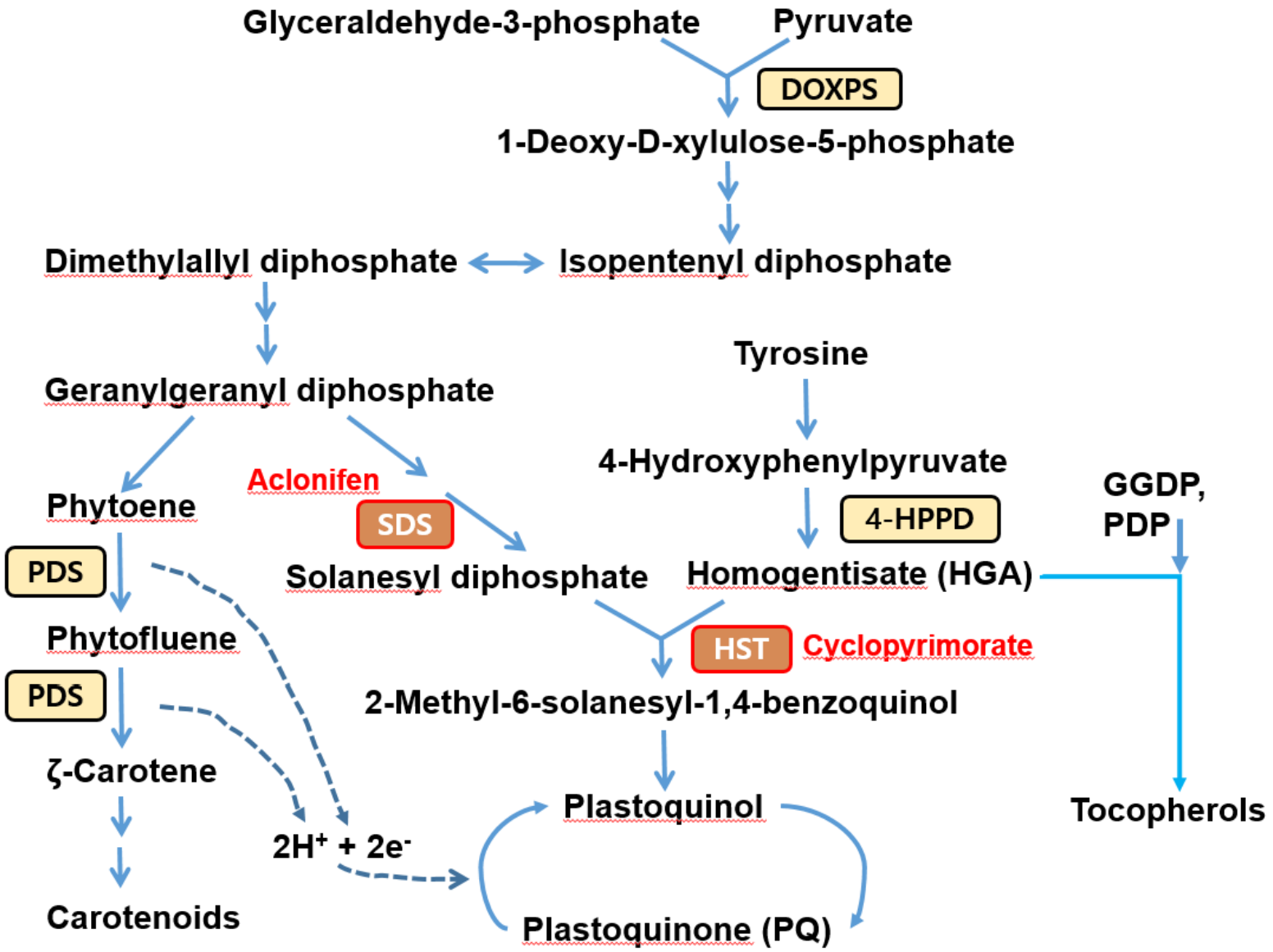


The addition and removal of phosphate groups regulates many cellular pathways involved in cell proliferation, cell differentiation, programmed cell death (apoptosis) and embryonic development.

There are more than 20 serine/threonine PPs in *A. thaliana*

Bajsa et al. 2012. Pest. Biochem. Physiol. 102:38-44

Inhibition of SDS and HST



SDS: Solanyl diphosphate synthase, HST: Homogentisate solanesyl transferase

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Phosphinic acids

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Benzyl ethers

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3 Inhibition of Microtubule Assembly

Dinitroanilines · Phosphoroamidates · Pyridines

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Carbamates

24 Uncouplers

Dinitrophenols

4 Auxin Mimics

Pyridine-carboxylates · Pyridyloxy-carboxylates · Benzoates · Quinoline-carboxylates · Phenoxy-carboxylates

19 Auxin Transport Inhibitors

Aryl-carboxylates

Ø Unknown Mode of Action

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HRAC	Legacy HRAC	
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24	M	Uncouplers
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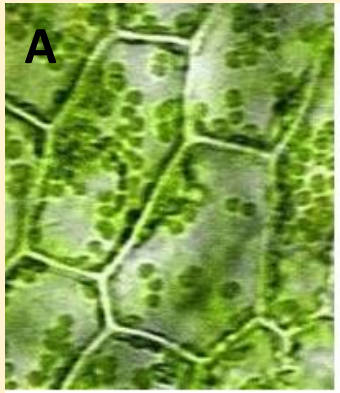
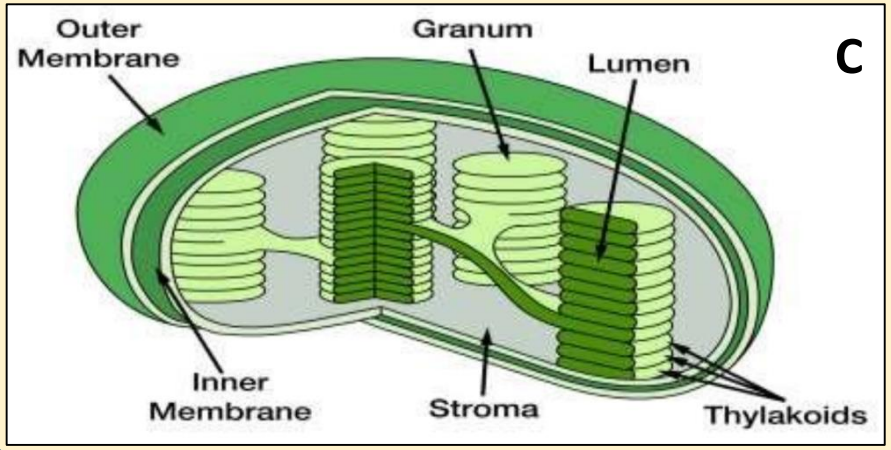
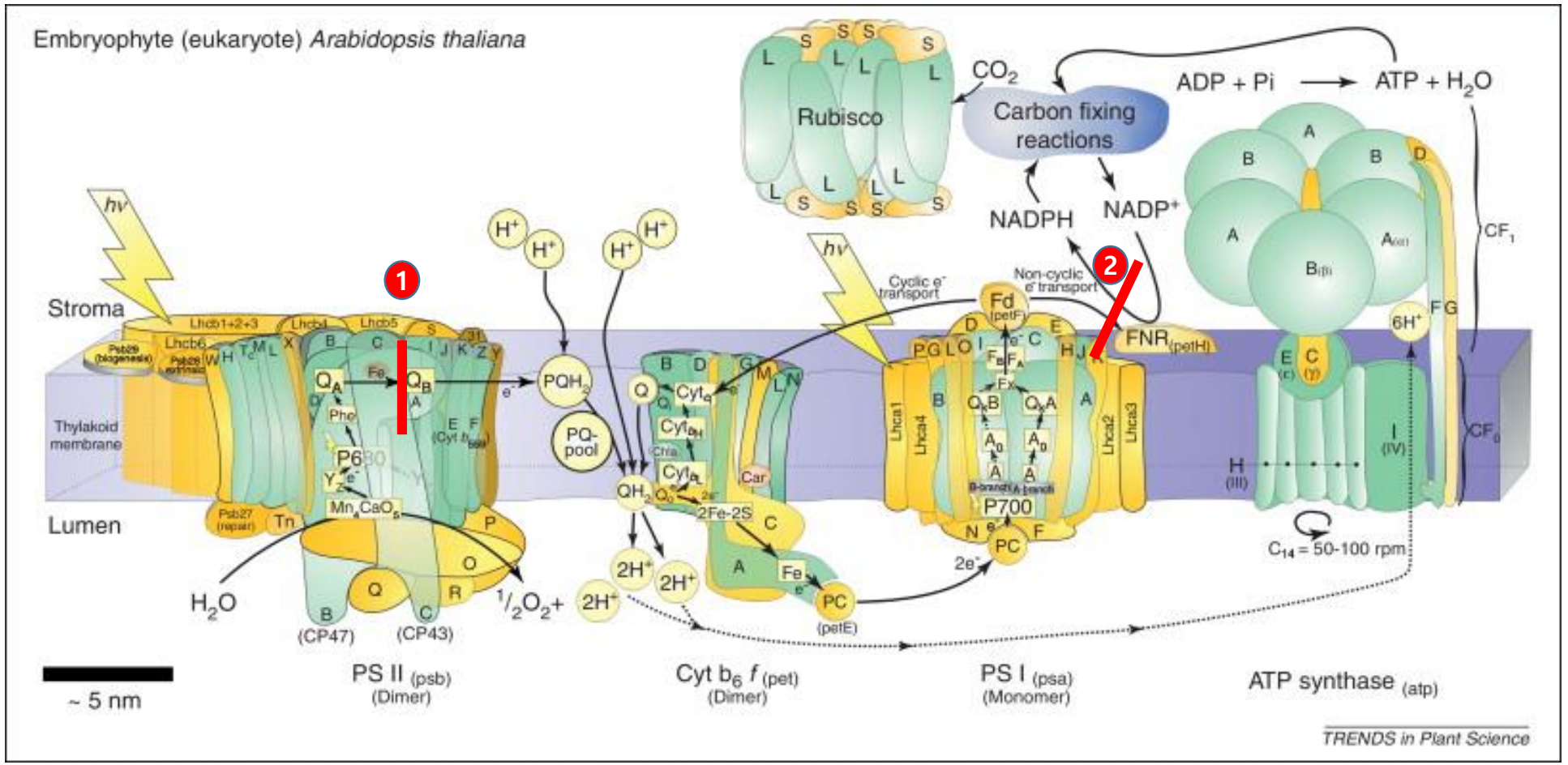
식물백화 유도 화학물질들의 여러 가지 작용생리





Inhibition of photosystem II or photosystem I

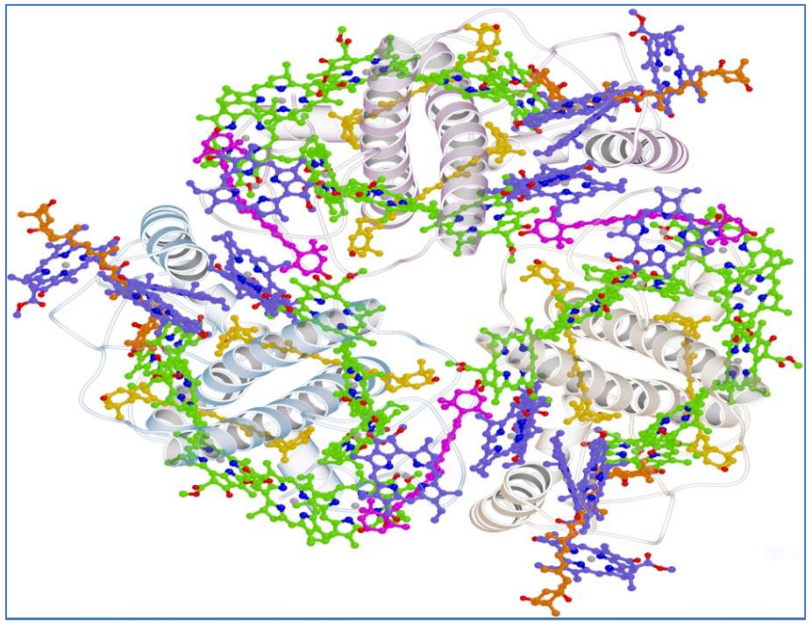


1 **Diuron, Atrazine, Propanil, Bromoxynil, Bentazon, etc**

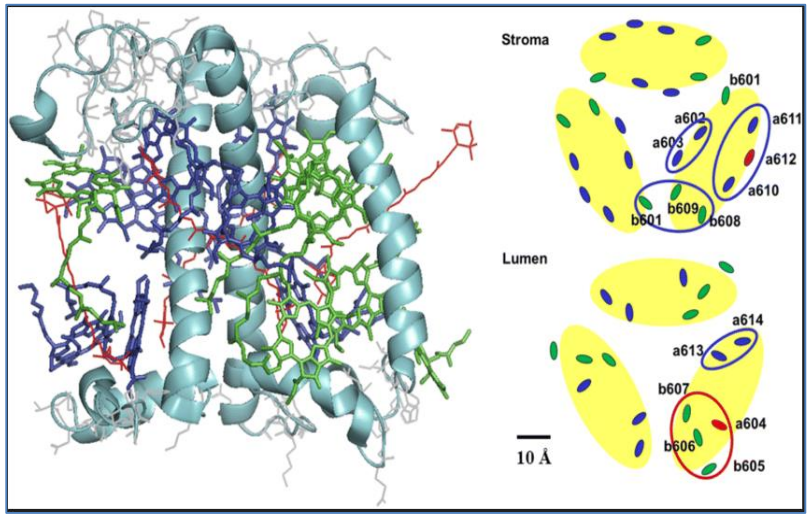
2 **Paraquat, Diquat**

- ✓ Oxygen radical → pigment destruction & membrane peroxidation
- ✓ Reduction of chemical energy production

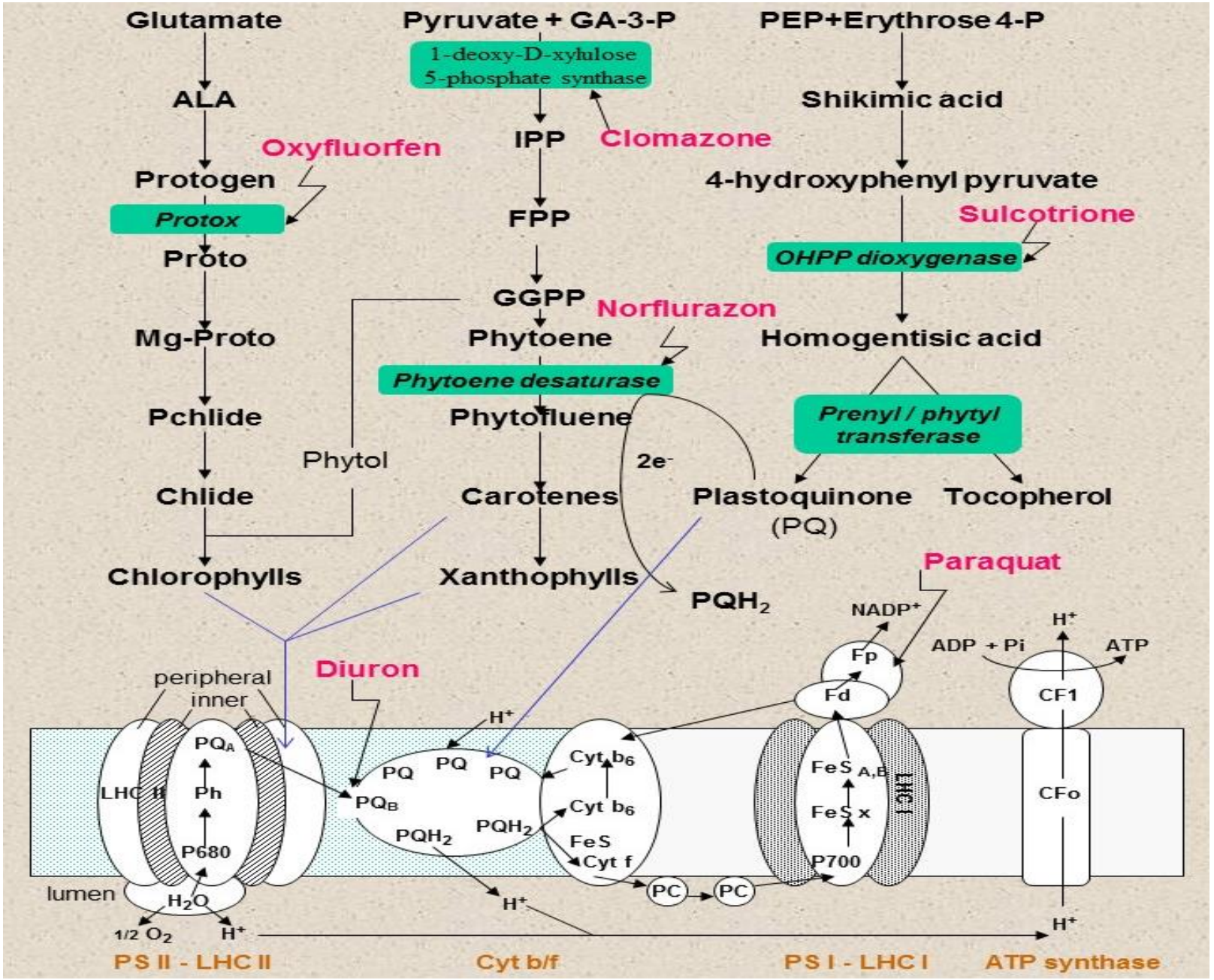
Herbicide action sites on PET and pigment biosynthesis



Crystal structure of spinach major light-harvesting complex LHC-II.



Crystal structure of a monomeric subunit of LHC II. Chl a in blue, Chl b in green, and carotenoids in purple color.



A **B** **C**

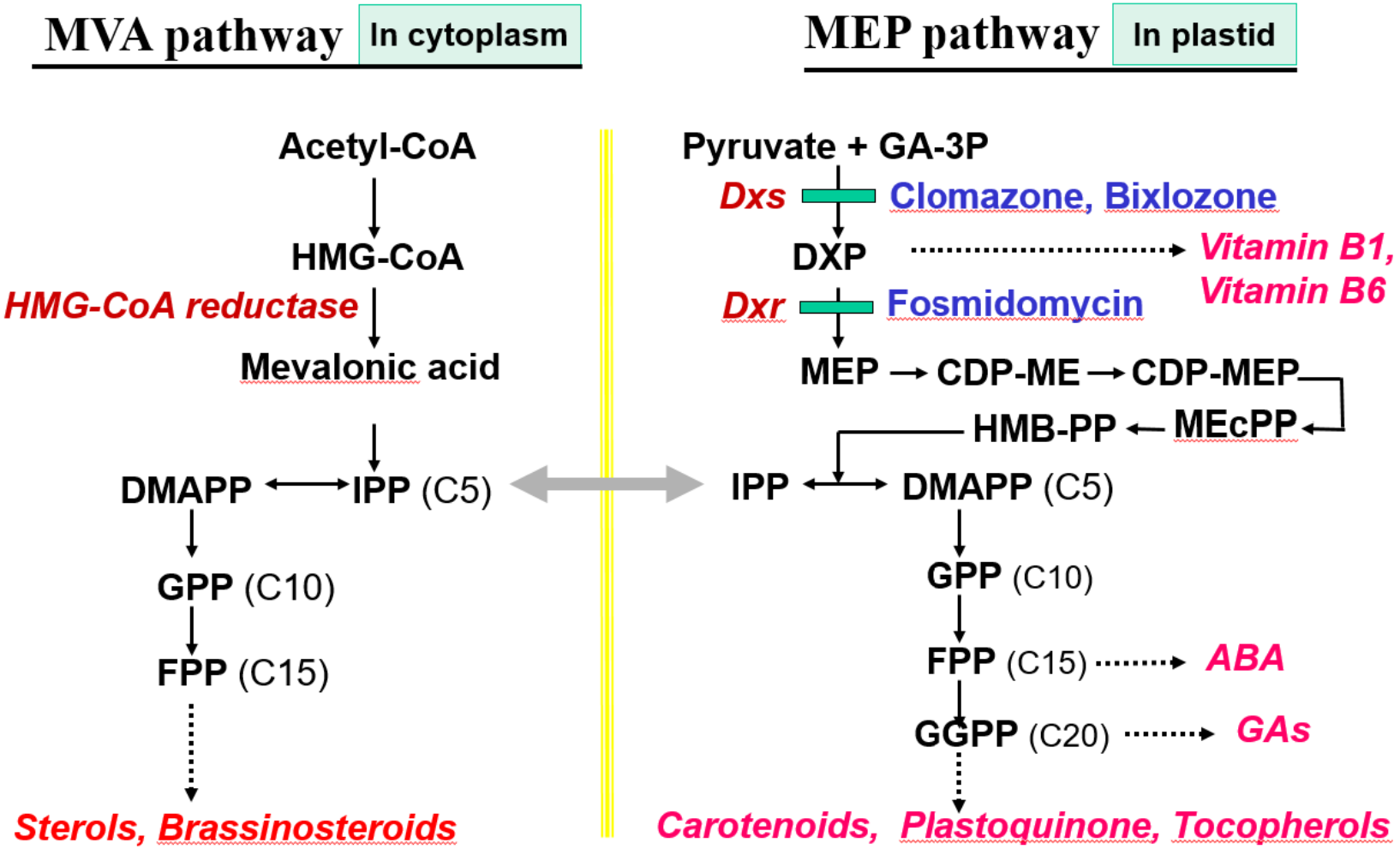
Complete or partial white corn induced by fluridone, phytoene desaturase inhibitor.

A: Untreated, **B**: Cultivation in greenhouse after soaking treatment of corn seed in fluridone solution,
C: Cutivation in greenhouse after soil-drenching(or foliar treatment) of fluridone solution at seedling stage of corn.

Classification of mode of action of bleaching (whitening) compounds.

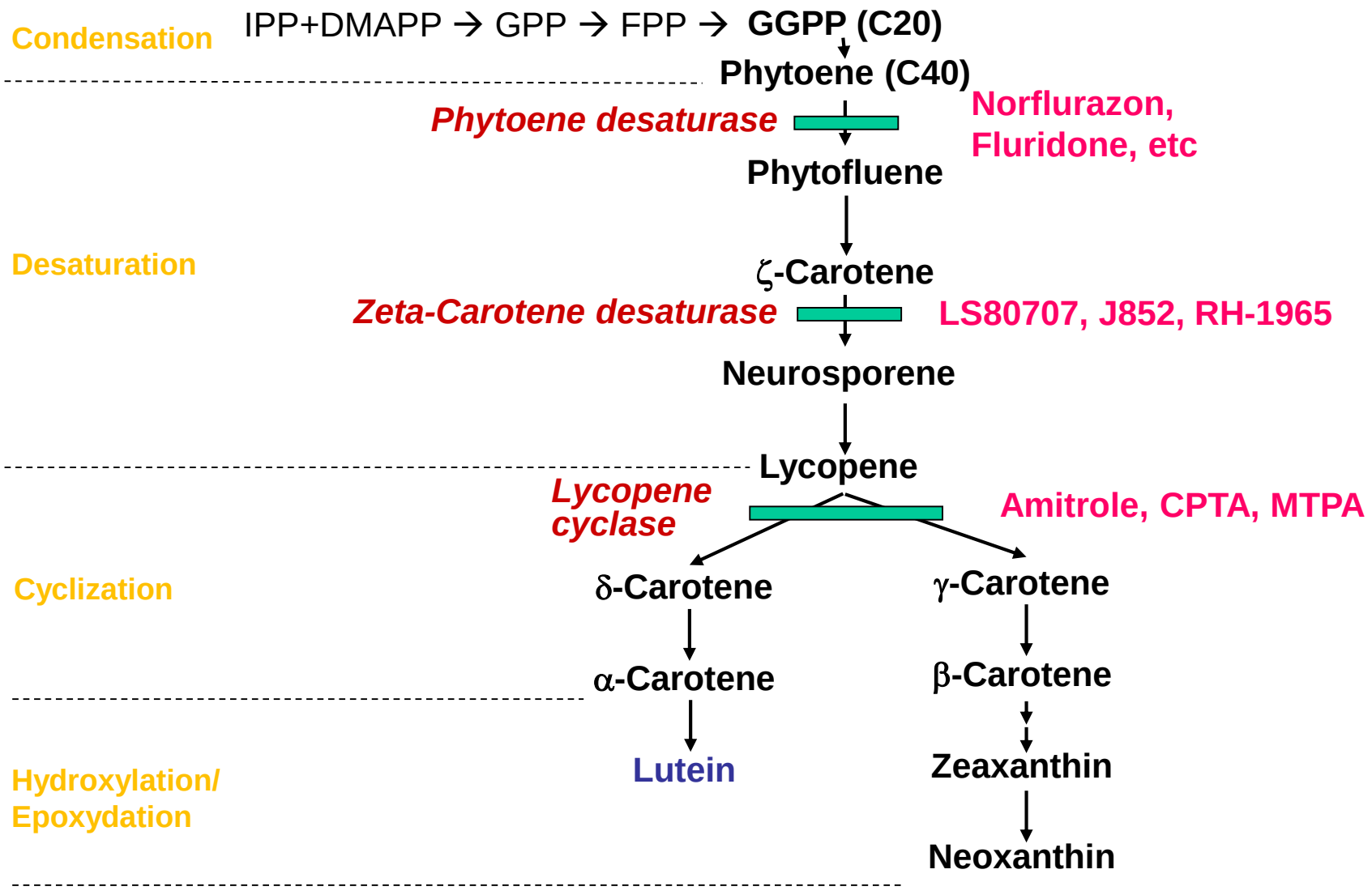
Commercial herbicides: 6 action sites

HRAC/WSSA group	HRAC group	Action sites	Chemical family	Herbicides
12	F1	Inhibition of phytoene desaturase (PDS)	Diphenyl heterocycles	Fluridone, Flurtamone
			N-Phenyl heterocycles	Flurochloridone, Norflurazon
			Phenyl ethers	Beflubutamid, Diflufenican, Picolinafen
13	F4	Inhibition of deoxy-d-xyulose phosphate synthase (DXS)	Isoxazolidinone	Bixlozone, Clomazone
27	F2	Inhibition of hydroxyphenyl pyruvate dioxygenase (HPPD)	Isoxazoles	Isoxaflutole
			Pyrazoles	Pyrasulfotole, Tolpyralate, Topramezone
			Pyrazoles (procide)	Benzofenap, Pyrazolynate, Pyrazoxyfen
			Triketones	Bicyclopyrone, Fenquinotrione, Mesotrione, Sulcotrione, Tefuryltrione, Tembotrione
			Triketones (procide)	Benzobicyclon
32	S	Inhibition of solanesyl diphosphate synthase (SDS)	Diphenyl ether	Aclonifen
33	T	Inhibition of homogentisate solanesyltransferase (HST)	Phenoxypyridazine	Cyclopyrimorate
34	F3	Inhibition of lycopene cyclase	Triazole	Amitrole

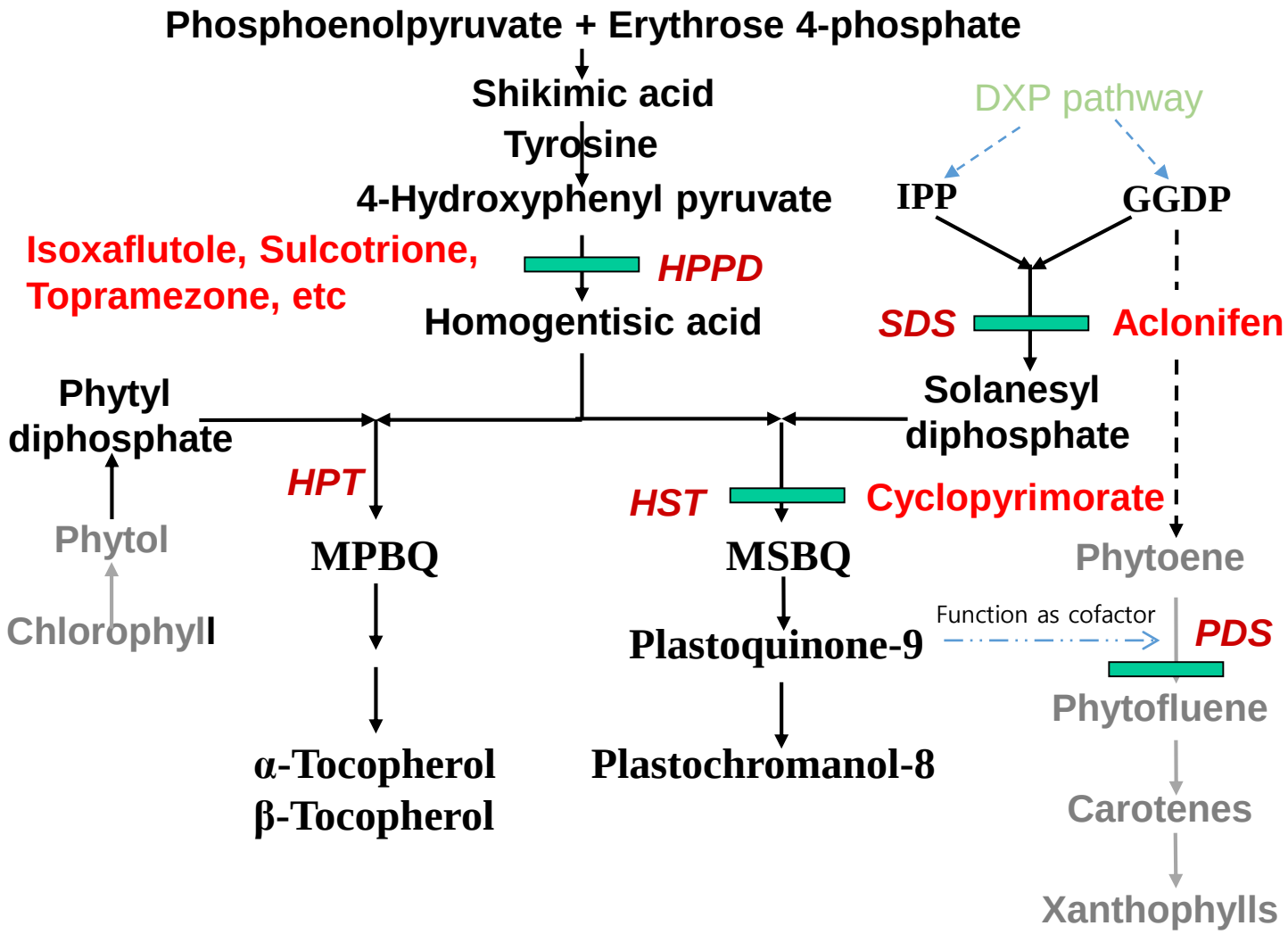


Isoprenoid biosynthesis pathway in plants and the action sites of several inhibitors.

CDP-ME: 4-diphosphocytidyl-2-C-methylerythritol, CDP-MEP: 4-diphosphocytidyl-2-C-methyl-D-erythritol 2-phosphate, DMAPP: dimethylallyl pyrophosphate, DXP: 1-deoxy-D-xylulose 5-phosphate, Dxr: DXP reductoisomerase, Dxs; DXP synthase, FPP: farnesyl pyrophosphate, GA-3P: glyceraldehyde 3-phosphate, GPP: geranyl pyrophosphate, GGPP: geranylgeranyl pyrophosphate, HMB-PP: (E)-4-hydroxy-3-methyl-but-2-enyl pyrophosphate, IPP: isopentenyl pyrophosphate, MEcPP: 2-C-methyl-D-erythritol 2,4-cyclodiphosphate, MEP: 2-C-methylerythritol 4-phosphate, MVA: Mevalonate,



Carotenoid biosynthesis pathway and its inhibitors

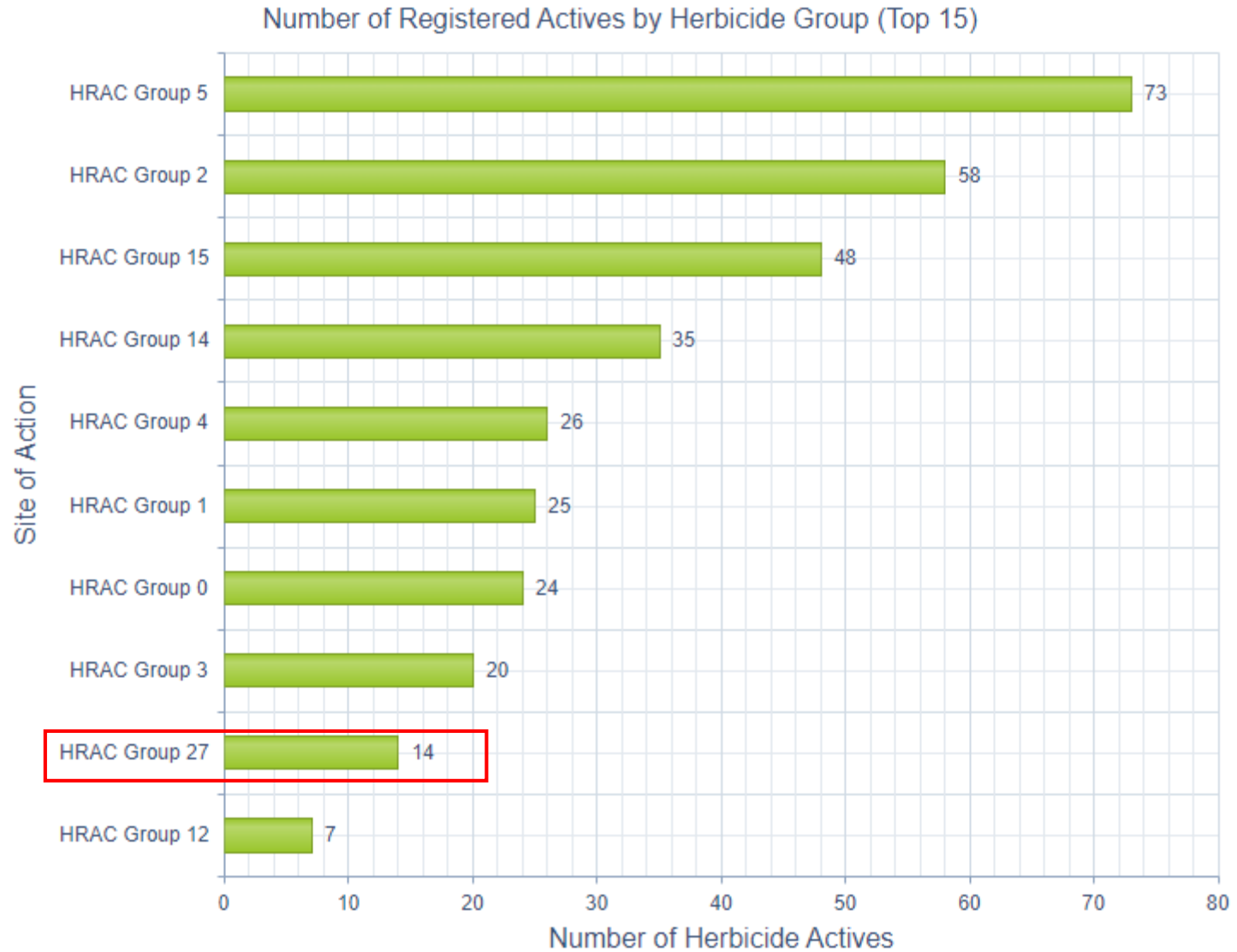


Plastoquinones and tocopherols biosynthesis pathway in plants and the action sites of several inhibitors.

GGPP: geranylgeranyl pyrophosphate, HPPD: hydroxyphenylpyruvate dioxygenase, HPT: homogentisate phytyl diphosphate transferase, HST: homogentisate solanesyl diphosphate transferase, IPP: isopentenyl pyrophosphate, MPBQ: 2-methyl-6-phytyl-1,4-benzoquinol, MSBQ: 2,3-dimethyl-6-solanesyl-1,4-benzoquinol, PDS: phytoene desaturase. SDS: Solanesyl diphosphate synthase

Most Representative Commercial HPPD-based Herbicides

Herbicides	Year	Chemical family	Usage (Applications)	Treatment	Selectivity / Others
Benzobicyclon	2001	Triketones (procide)	Rice	Pre/Post	Metabolism
Benzofenap	1987	Pyrazoles (procide)	Rice	Pre/Post	Metabolism
Bicyclopyrone	2015	Triketones	Corn, Sugarcane	Pre/Post	
Fenquinotrione	2018	Triketones	Rice, Cereal	Pre/Post	Metabolism
Isoxaflutole	1998, 2013	Isoxazoles (procide)	Corn, Sugarcane, Soybean	Pre	Rate of diketonitrile degradation
Mesotrione	2001	Triketones	Corn	Pre/Post	
Pyrasulfotole	2008	Isoxazoles	Cereal grains	Post	
Pyrazolynate	1980	Pyrazoles (procide)	Rice	Pre/Post	
Pyrazoxyfen	1985	Pyrazoles (procide)	Rice	Pre/Post	
Sulcotrione	1991	Triketones	Corn, Soybean, Wheat and others	Post	
Tefuryltrione	2010	Triketones	Rice	Post	Millet, Flatsedges (e.g. those of the Cyperus microiria Steud family)
Tembotrione	2007	Triketones	Corn	Post	
Tolpyralate	2019	Pyrazoles	Corn	Post	Metabolism
Topramezone	2006	Pyrazoles	Corn, Soybean	Post	Carry-over issues



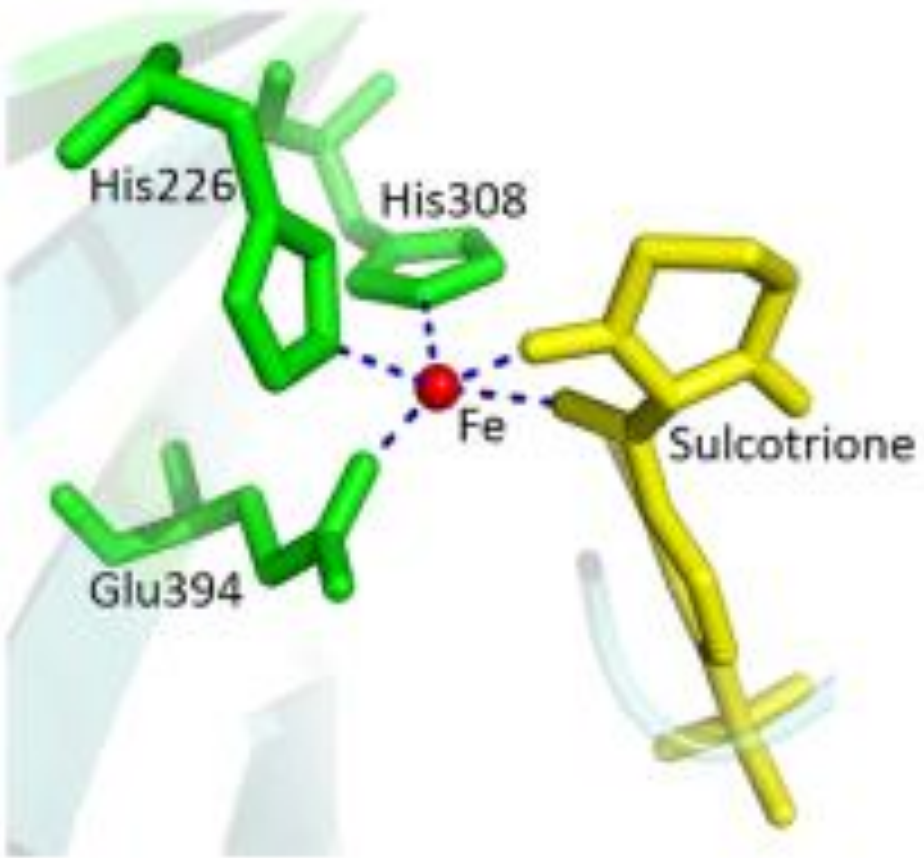
Herbicide-Resistant Weeds by Site of Action

This table lists the number of species resistant to each site of action. Please note that **many species have evolved resistance to more than one site of action**, so the grand total represents unique cases of resistance, not the number of species.
(click on a column header to sort, hover mouse over links for more information or click on a links for details)

HRAC Group	Legacy HRAC Group	Site of Action	Example Herbicide	Dicots	Monocots	Total
2	B	Inhibition of Acetolactate Synthase	Chlorsulfuron	105	65	**170**
5	C1 C2	PSII inhibitors - Serine 264 Binders	Chlorotoluron	53	34	**87**
9	G	Inhibition of Enolpyruvyl Shikimate Phosphate Synthase	Glyphosate	27	29	**56**
1	A	Inhibition of Acetyl CoA Carboxylase	Sethoxydim	0	50	**50**
4	O	Auxin Mimics	2,4-D	33	8	**41**
22	D	PS I Electron Diversion	Paraquat	22	10	**32**
14	E	Inhibition of Protoporphyrinogen Oxidase	Oxyfluorfen	10	4	**14**
15	K3 N	Very Long-Chain Fatty Acid Synthesis inhibitors	Butachlor	2	11	**13**
3	K1	Inhibition of Microtubule Assembly 2	Trifluralin	2	10	**12**
34	F3	Inhibition of Lycopene Cyclase	Amitrole	1	5	**6**
10	H	Inhibition of Glutamine Synthetase	Glufosinate-ammonium	1	5	**6**
12	F1	Phytoene Desaturase inhibitors	Diflufenican	4	1	**5**
6	C3	PSII inhibitors - Histidine 215 Binders	Bromoxynil	3	1	**4**
29	L	Inhibition of Cellulose Synthesis	Dichlobenil	0	4	**4**
27	F2	Inhibition of Hydroxyphenyl Pyruvate Dioxygenase	Isoxaflutole	3	0	**3**
13	F4	Inhibition of Microtubule Assembly	Clomazone	0	3	**3**
0	Z	Antimicrotubule mitotic disrupter	Flamprop-methyl	0	3	**3**
23	K2	Inhibition of Microtubule Organization	Propham	0	1	**1**
0	Z	Nucleic acid inhibitors	MSMA	1	0	**1**
0	Z	Unknown	Endothall	0	1	**1**
0	Z	Cell elongation inhibitors	Difenzoquat	0	1	**1**
				267	**246**	**513**

Target sites of HPPD inhibitors

Crystal structure of AtHPPD complexed with Benquitrione



Crystal structure of *Arabodopsis thaliana* HPPD (AtHPPD) complexed with sulcotrione (yellow). The facial triad (green) binds to Fe(II).

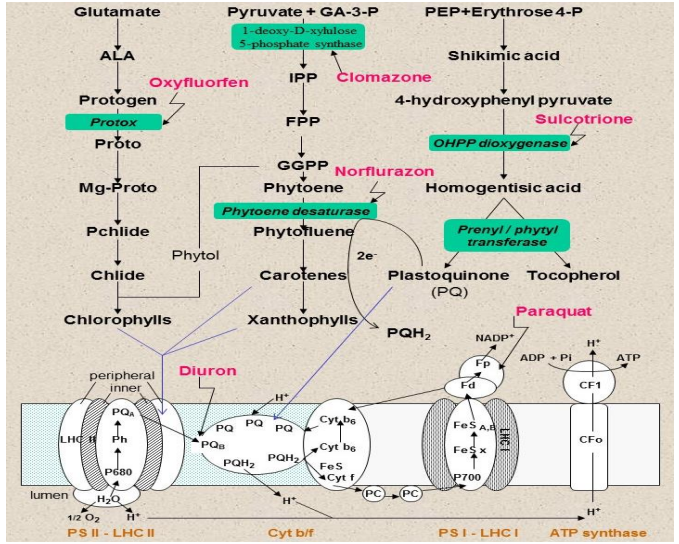
Ndikuryayo et al. 2017. J. Agric. Food Chem. 65:8523−8537

HPPD 저해제의 제초작용생리 (Sekino 2002의 변형)

Target site	Primary effect	Secondary effect (Catastrophic effect)

Inhibition of HPPD

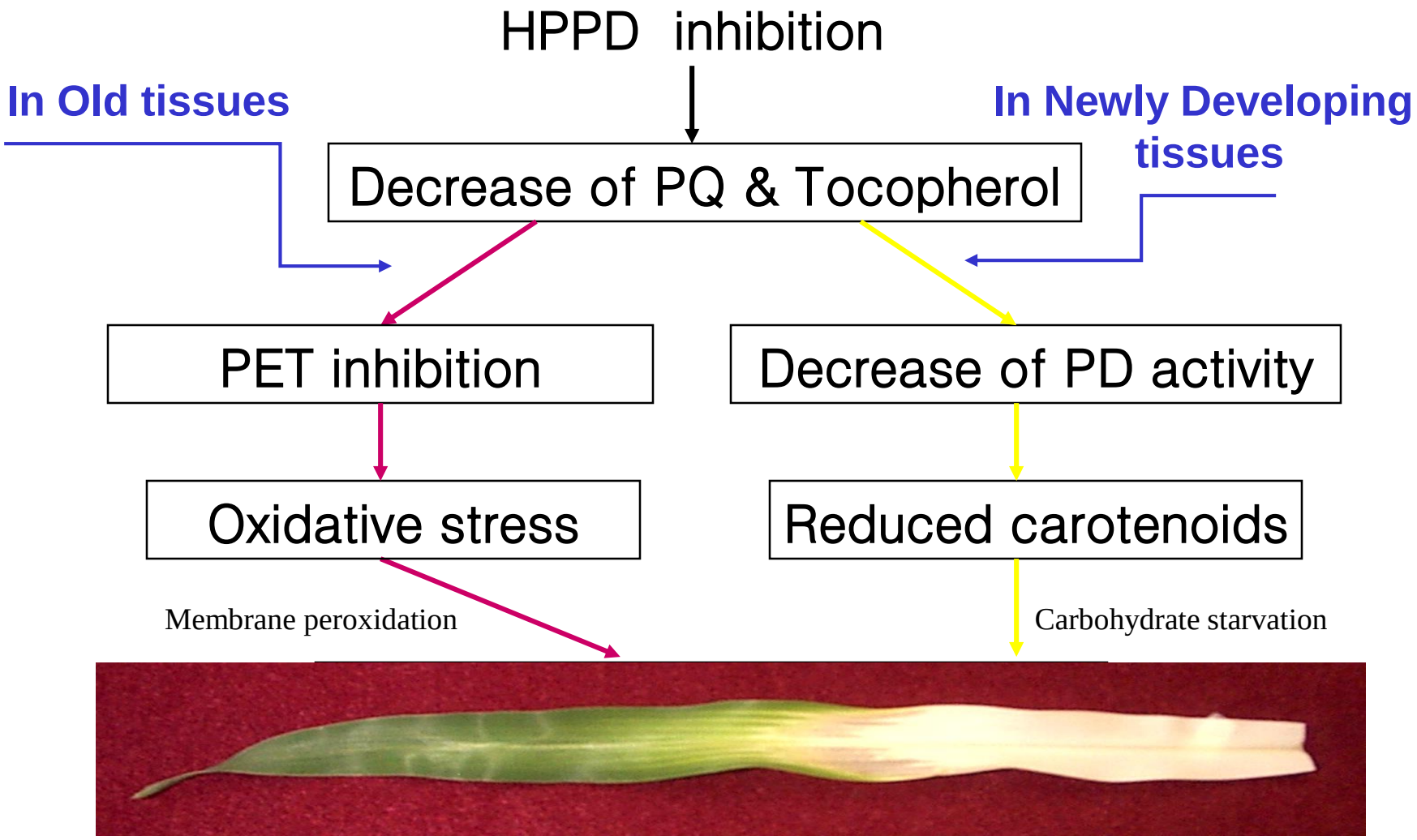
Inhibition of HGA biosynthesis



- **Depleted PQ cofactor of PDS**
  - → Reduced expression of CP genes → Reduced PS II activity
  - → Reduced PS electron transport → Reduced PS II activity
  - → PDS inhibition → Decrease in carotenoids → Chl. loss, Reduced CP development
- **Depleted tocopherols**
  - → Reduced free radical quenching → Lipid peroxidation
  - → Reduced free radical quenching → Disrupted PS II structure → Reduced PS II activity
- **Accumulated free tyrosine** → Disturbed amino acid metabolism

Bleaching (whitening), Necrosis, Wilting, Growth inhibition

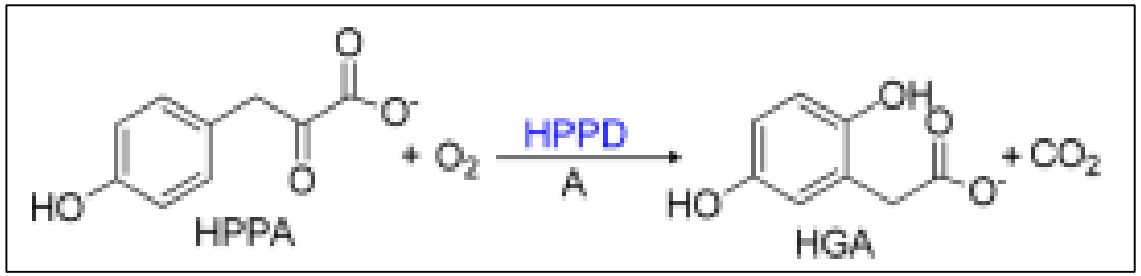
Death mechanism of weed treated with sulcotrione



Various methods for detecting HPPD inhibition

=== HPPD 저해제 탐색 관련 연구기법 ===

- *In vivo* functional bioassay
- Isotope labeling: CO_2, O_2
- HPLC: HPPA, HPPD
- Coupling UV method (HTS): homogentisate oxidase, MAA(A380nm)
- *In vivo* cell visualization(VIS method): *E. coli*, cell brown color
- Fluorescent screening: HP-1 probe



Fu et al. 2022. *In vivo* fluorescent screening for HPPD-targeted herbicide discovery. Pest Manag. Sci., 7 Aug. 2022, DOI 10.1002/ps.7117

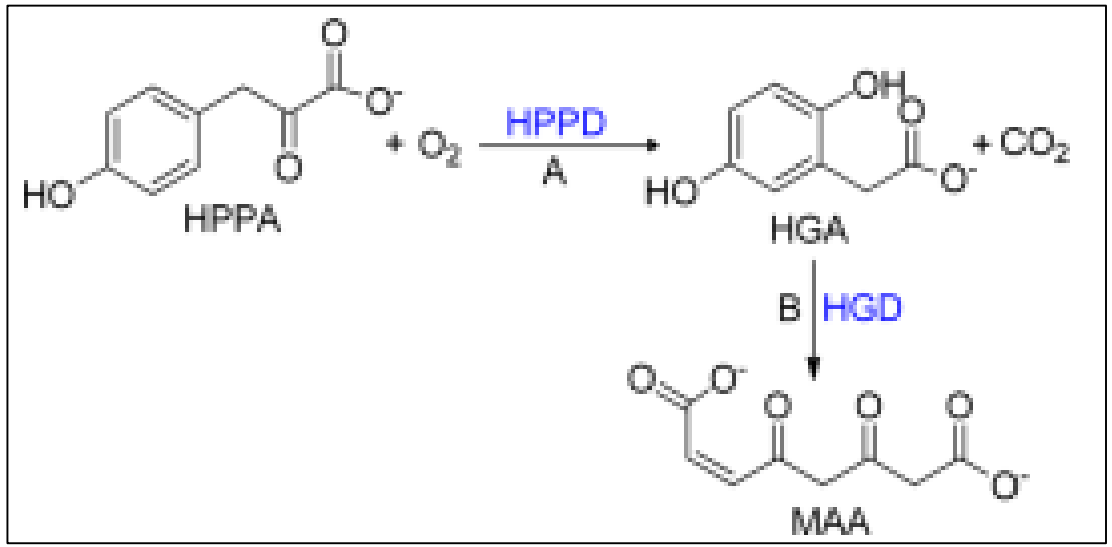
In vivo functional bioassay

<Cucumber Greening Assay>

Pchl(ide) in darkness (A)	Chlorophyll after illumination (B)	Mode of action
		Clomazone type
		Norflurazon type
		Sulcotrione type

Kim et al. (2000) Differential influence of albino-inducing chemicals on the photosynthetic pigments biosynthesis in etiolated cucumber (*Cucumis sativus* L). Kor. J. Weed Sci. 20(2): 140-148.

Target enzyme assay (Coupling UV method)



HPPD +
Homogentisate 1,2-dioxidase (HGD),

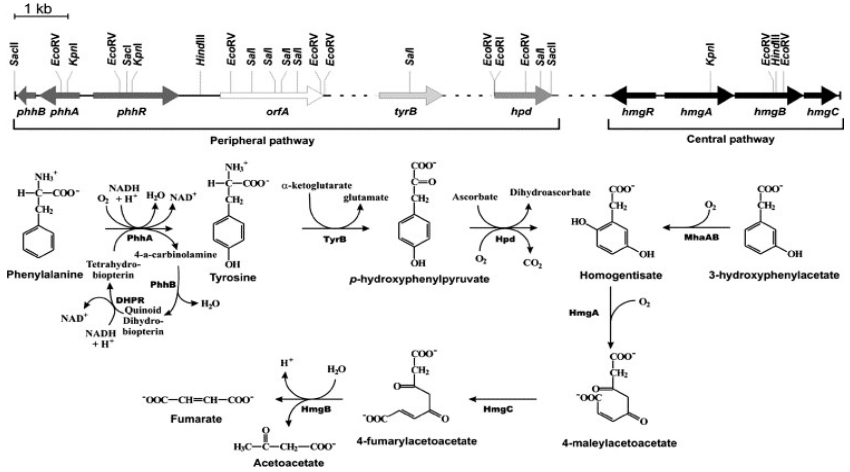
MAA(maleylacetoacetate),
Detection at 318nm

<Two enzyme coupling UV method>

장점	단점
- Applicable for HTS - Simple instruments	- Homogentisate oxidase - Unstable MAA even at moderate condition - Spotaneous oxidation of HPPA - Substrate inhibition of HPPD

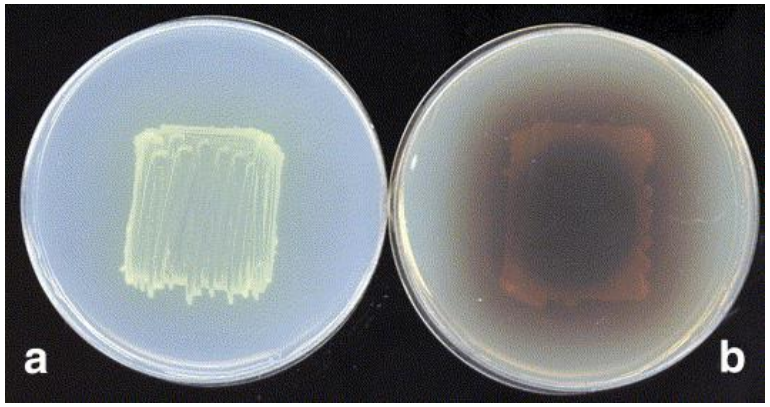
Cell-based HTS system using a genetically engineered strain of bacteria

- *In vivo* colorimetric bioassay using *P. pudita* , brown pigments, Arias-Barrau et al. (2005)



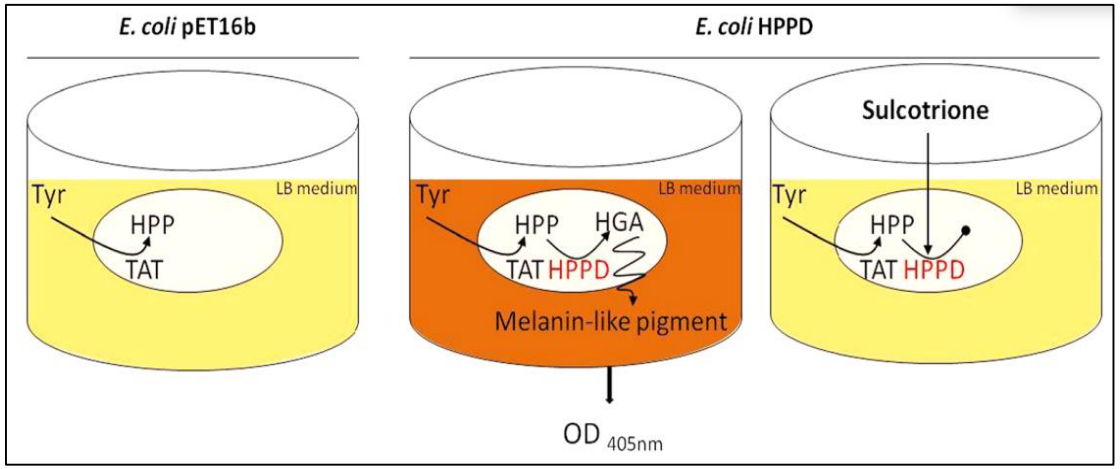
Arias-Barrau et al. 2005. FEMS Microbiology Letters 249(2): 297-302

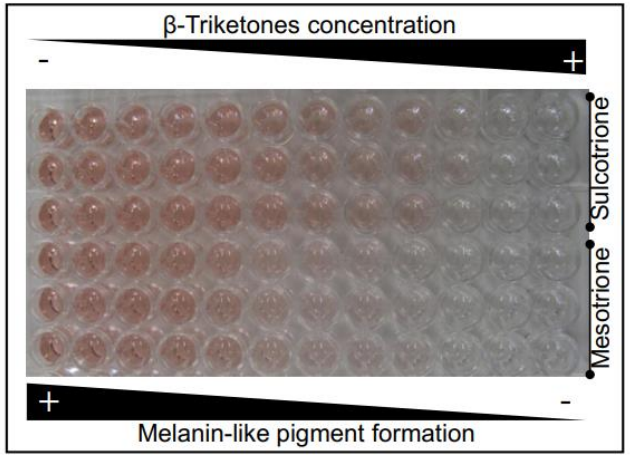
Pseudomonas pudita U Δhmg

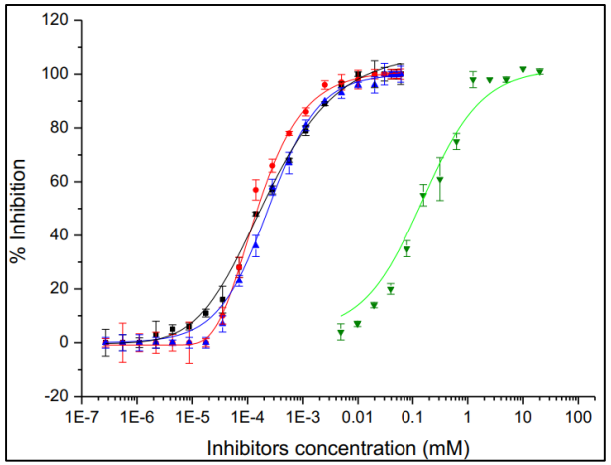


The presence (a) or in the absence (b) of sulcotrione

- *In vivo* colorimetric bioassay using *E. coli* , melanin-like pigment, Rocaboy-Faquet et al. (2014)

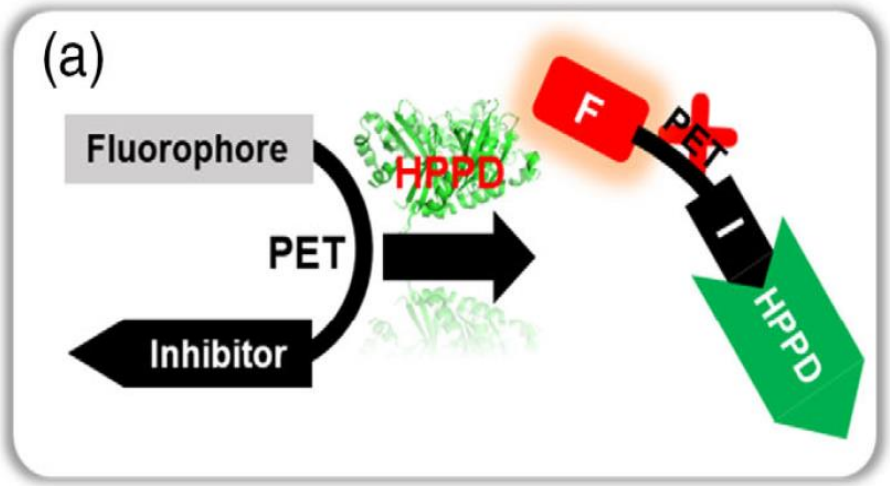




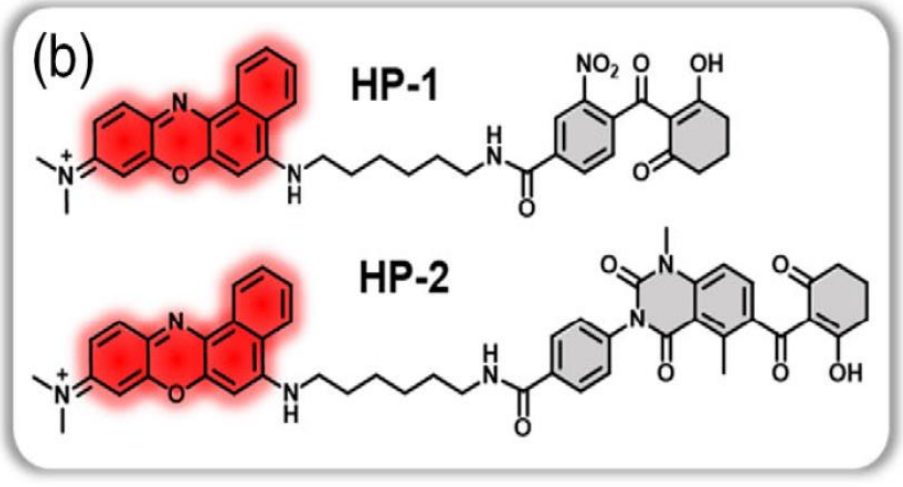


In vitro & In vivo fluorescent screening for HPPD-targeted herbicide discovery

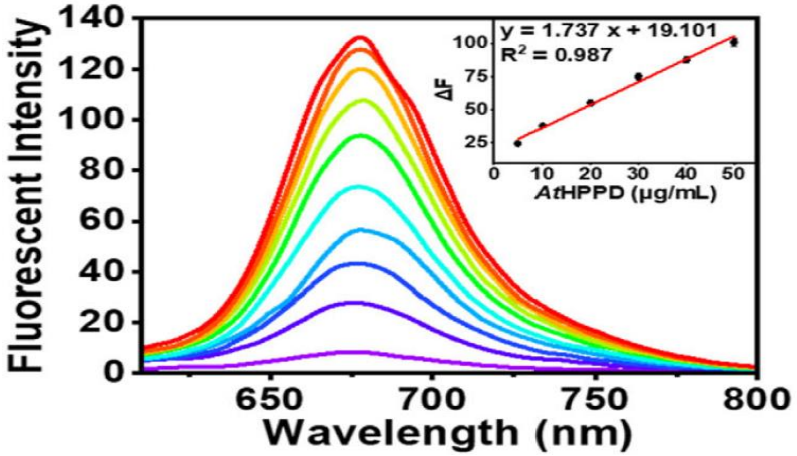
Fu et al. 2022. PMS, DOI 10.1002/ps.7117



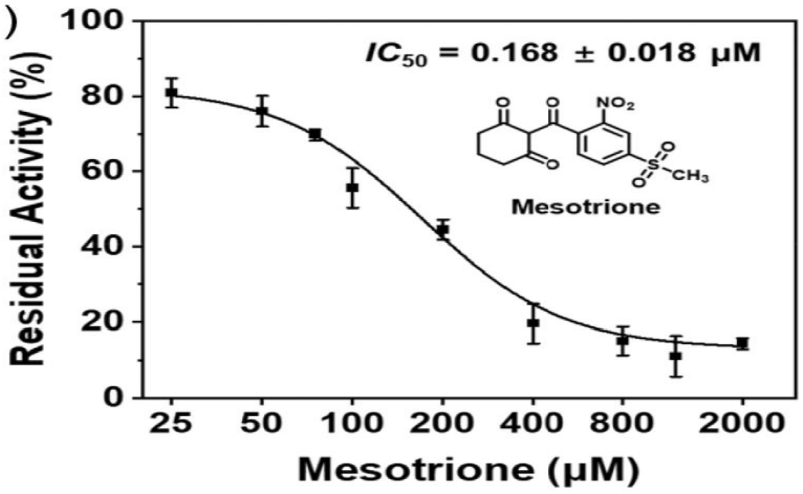
Design of HPPD-targeted sensors



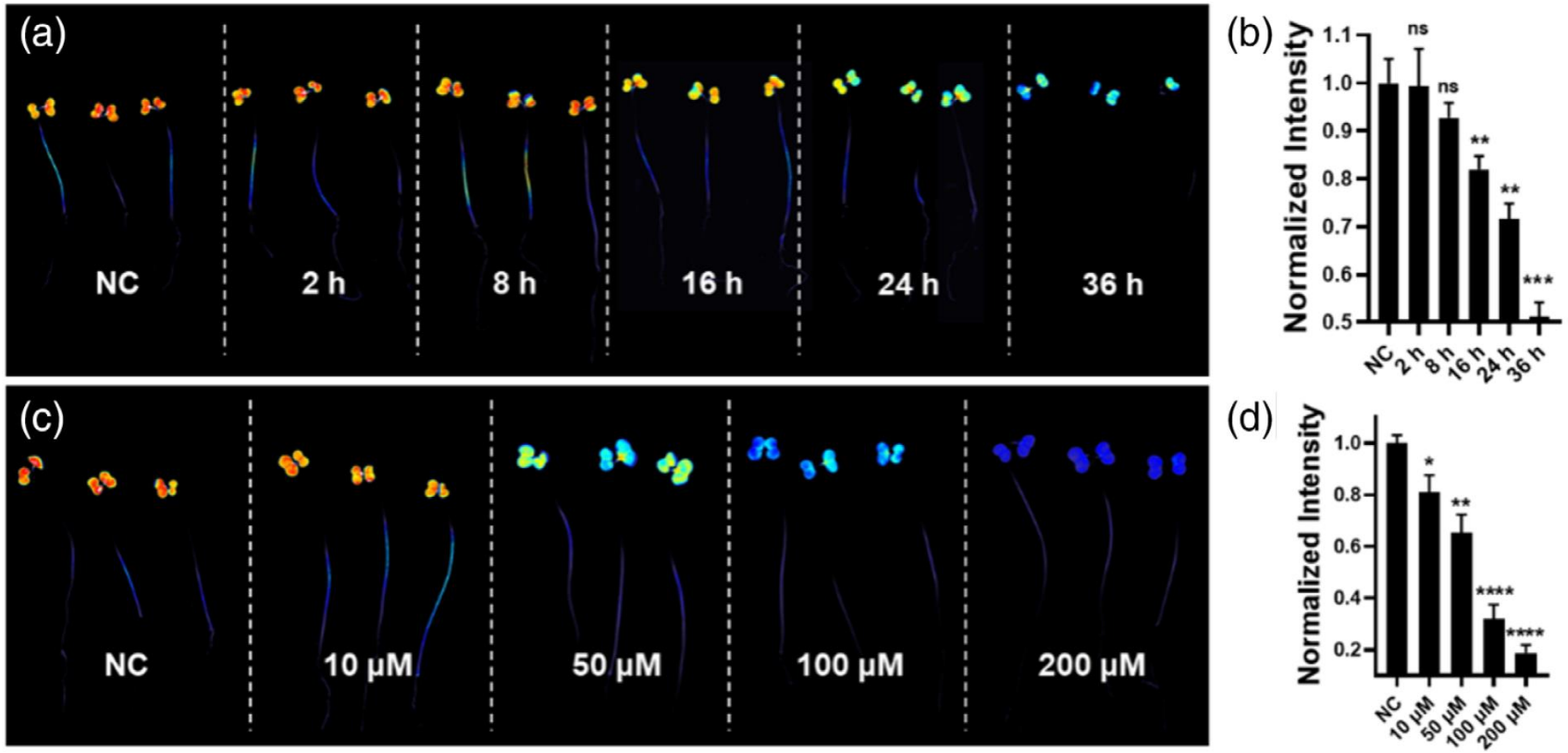
The structures of fluorescent probes



Fluorescence response change of HP-1 with A*t*HPPD (Ex=580 nm, Em=675 nm)



Inhibition of A*t*HPPD by mesotrione.

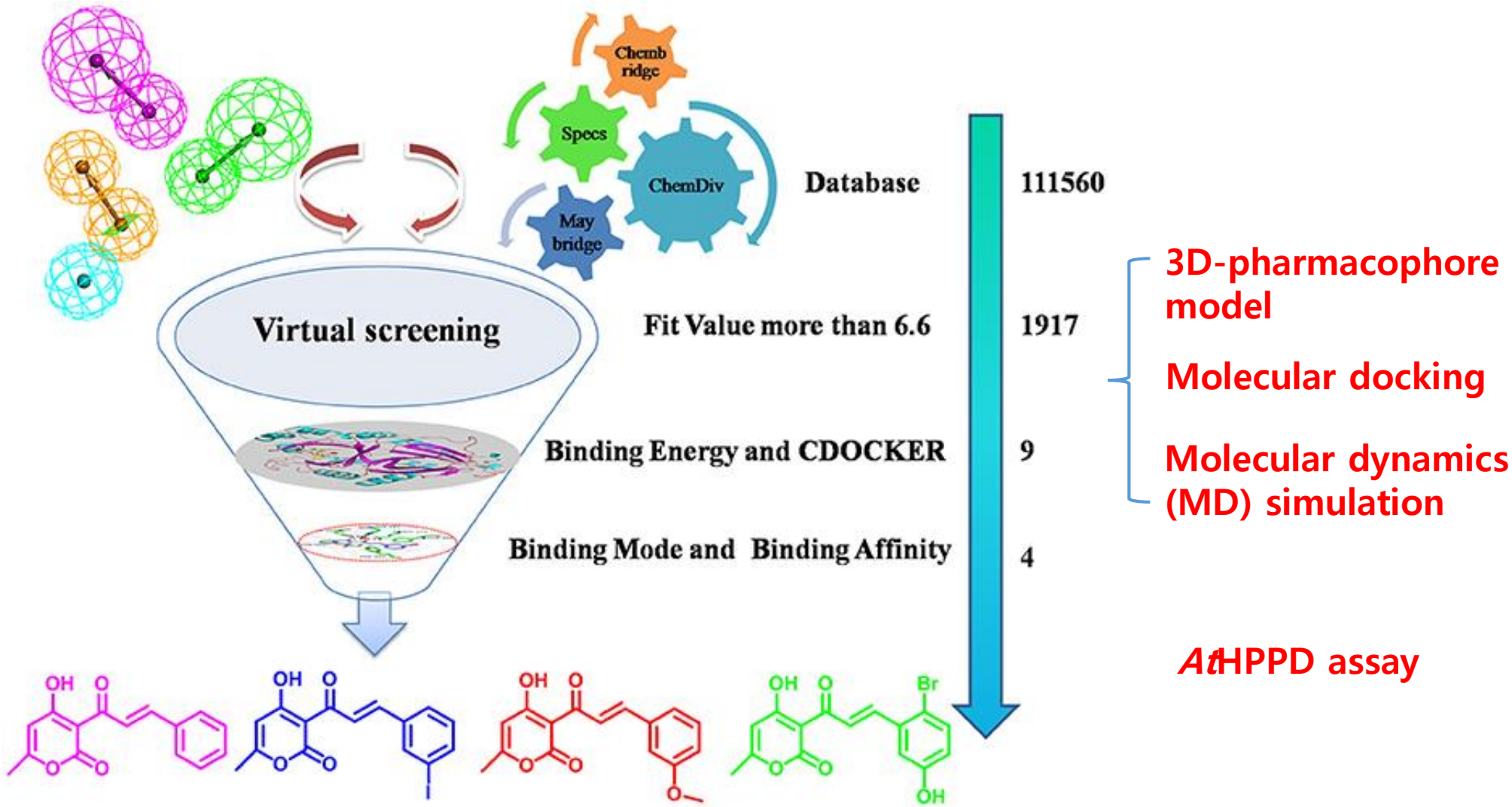


Fluorescence image of *Brassica napus* treated with HP-1 and mesotrione

장점	단점
- Coupling UV method 단점 보완 - *In vitro* & *In vivo* assay 가능(둘간의 inconsistency를 극복) - Highly efficient in vivo screening platform, 2d 이내 완료 (Bleaching 증상에 기준한 온실검정에 비해 검정시일 단축)	- NTBC보다 binding affinity가 높은 화합물만 검정가능 - 고가의 장비 사용

Integrated *in silico* Structure-based Virtual Screening

=== HPPD 저해제 개발 패러다임 변화 ===



3D-pharmacophore model

Molecular docking

Molecular dynamics (MD) simulation

*At*HPPD assay

Fu et al., 2018. Front. Chem. 6:14. doi: 10.3389/fchem.2018.00014

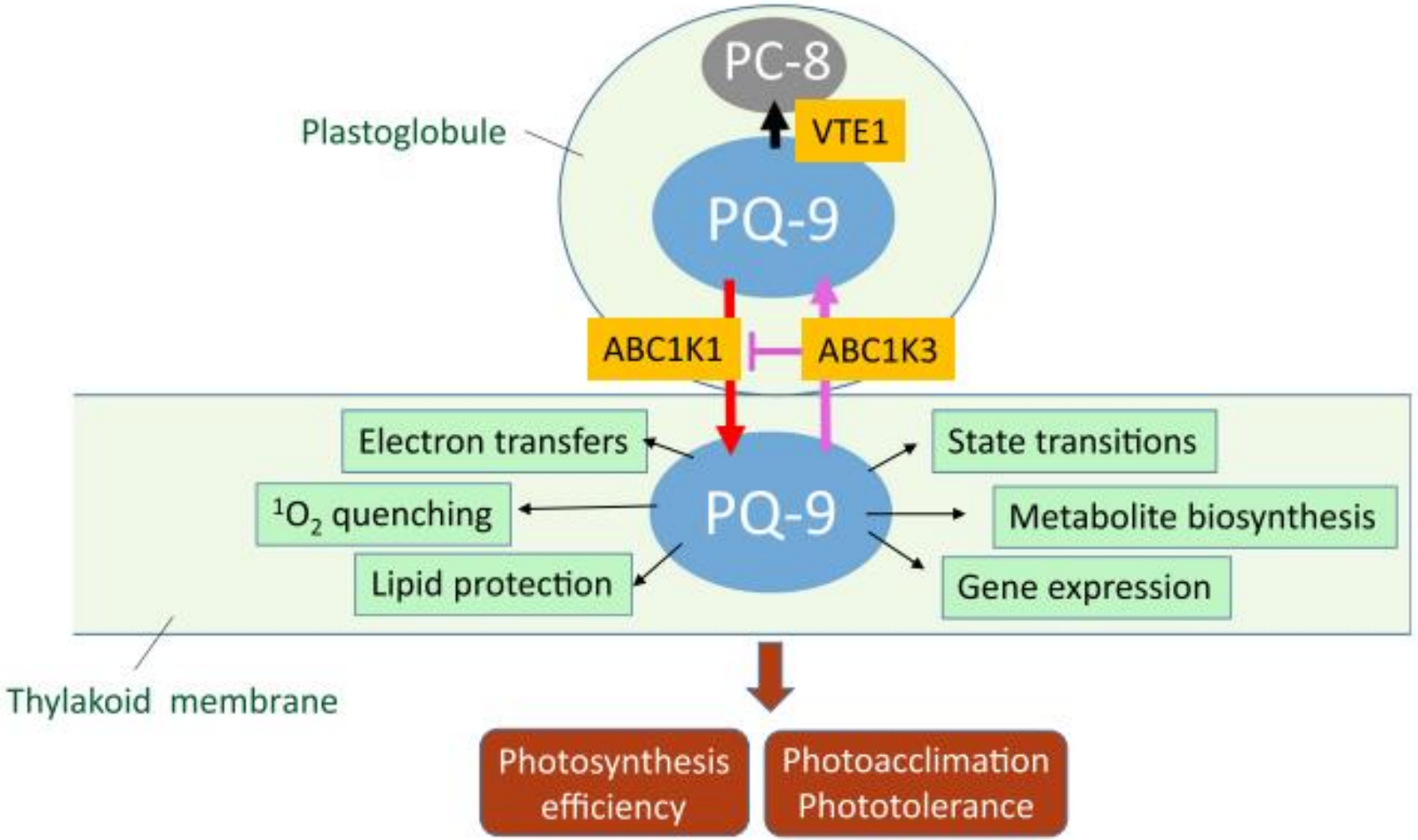


Figure 4. Scheme Illustrating the Functions of PQ-9 in Plants Modulated by the Dynamic Partitioning of PQ-9 Molecules between the Photochemically Active Pool in the Thylakoid Membranes and the Photochemically Nonactive Pool Stored in the Plastoglobules. Abbreviations, PC-8, plastochromanol 8; PQ-9, plastoquinone-9.

Havaux, M. 2020. Plastoquinone in and beyond photosynthesis. Trends in Plant Science 25(12):1252-1265

향후 연구방향

- ❖ 신규작용점 화합물 개발: 예) PQ regulation
- ❖ 단백질 구조와 화합물 결합: *In silico* assay
- ❖ 제초효과 상승 (catastrophic/pleiotypic effect) 기술 개발
- ❖ 작용생리: 작용기작 --> 선택성 기작
- ❖ 백색(white color) 식물 연구




Availability of herbicide MoA information

❖제초제/살생물제 개발과 등록에 활용

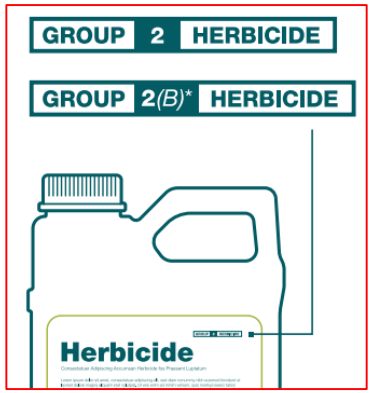
❖제초제 저항성 관리에 필수적인 정보

❖합제 개발에 유익한 정보 제공

❖새로운 제초활성검정법 개발에 활용

❖Molecular breeding (genetically modified crops)

❖Herbicides as probes in plant biology



New MoA label icon