

## Chemistry on Plant Growth Regulators: An overview

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### ABSTRACT

A natural substance that acts to control plant activities are Plant growth regulators and often called phytohormones to regulate growth, development and responses to stimuli. Which includes hormones and non-nutrient chemicals not found naturally in plants that when applied in plants, influence their growth and development. Changes in phytohormone levels result in gene activation shifts. This paper accomplishes the review article on chemistry of the novel plant growth regulators according to their medications, and has been discussed according to the types of plant growth regulators.

**Keywords:** Plant Growth Regulators, Anti-Auxins, Cytokinins, Defoliant, Ethylene Inhibitors

### INTRODUCTION

Plant growth regulators/plant hormones are chemicals which are related to the growth of the plant are known as 'plant growth substances'. Low concentrated signal molecules are produced in the plant where the hormone cells regulate the cells locally and moved to other locations<sup>[1,2]</sup>. Two types of plant growth regulators are used in the nature named as Natural and Synthetic types:

Natural PGH= generated by the plant

Synthetic PGH= Development done by the humans

### Both the groups regulate:

- Cell division
- Cell differential
- Root and shoot growth
- Plant aging

The following are the classification of Plant Growth Regulators:

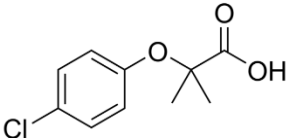
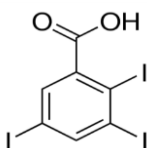
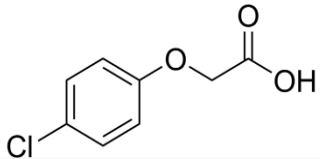
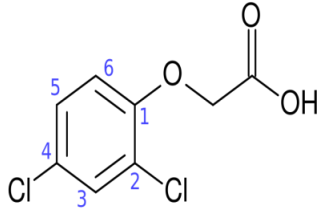
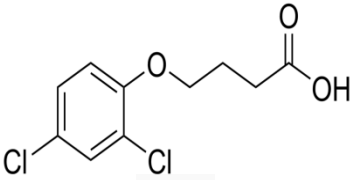
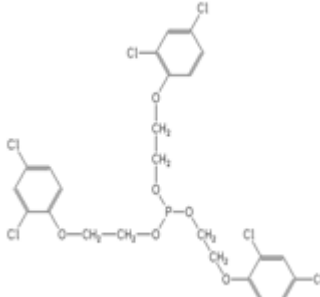
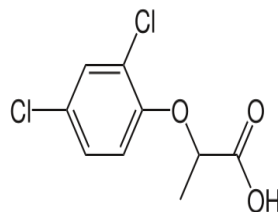
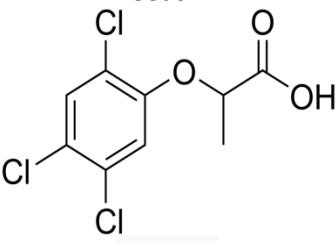
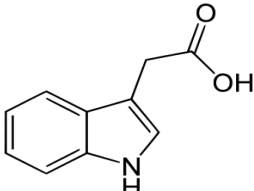
- Auxins
- Gibberilins
- Cytokinenins
- Abscisic acid
- Ethylene

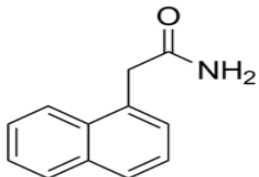
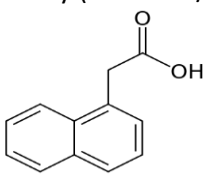
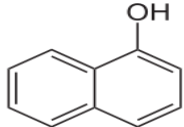
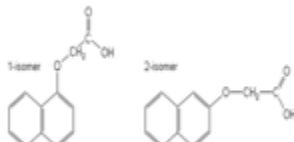
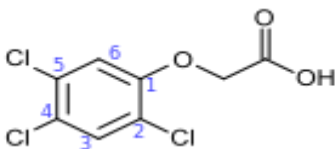
The following are the chemistry of the classified plant growth regulators:

### ANTI-AUXINS

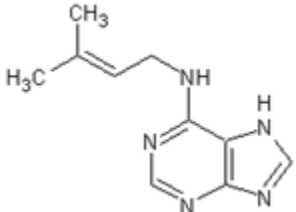
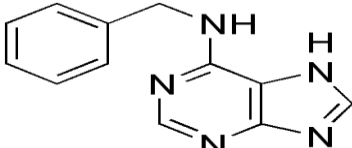
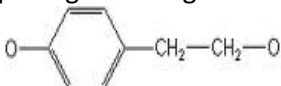
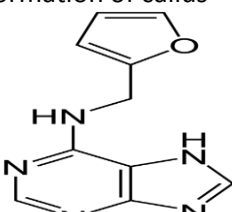
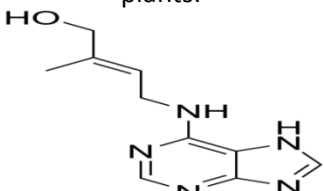
<p><b>Clofibric acid:</b> It is the form of herbicide, related to the plant growth it is a metabolite of the cholesterol-lowering pharmaceutical. And reduce the level of VLDL. It can</p>	<p><b>2,3,5-tri-iodobenzoic acid:</b> It is an inhibitor of polar auxin transport and more commonly known as TIBA. Uses : plant growth regulator and controller. It suppresses somatic embryo</p>	<p>4-CPA:4-chlorophenoxy acetic acid Synthetic pesticide similar to chemicals in a group of plant hormones called auxins Esterized with dimethylet</p>
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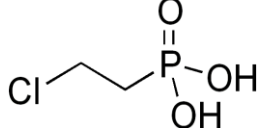
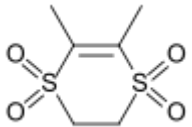
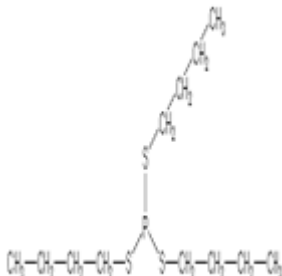
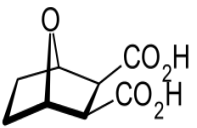
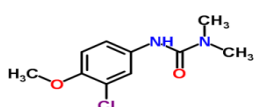
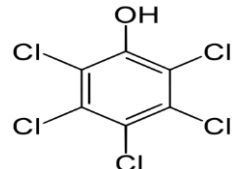
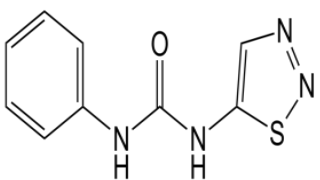
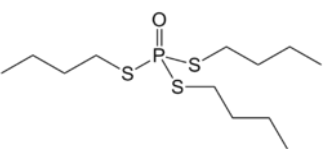
<p>increase the level of HDL as well<sup>[3]</sup>.</p>  <p>2-(4-chlorophenoxy)-2-methylpropanoic acid</p>	<p>formation and postembryonic shoot / root development in <i>Eleutherococcus senticosus</i><sup>[4]</sup>.</p>  <p>2,3,5-triodobenzoic acid</p>	<p>hanolamine (DMAE) it forms centrophenoxine<sup>[5]</sup>.</p>  <p>2-(4-Chlorophenoxy)acetic acid</p>
<p><b>2,4-D: Dichloro phenoxy acetic acid</b></p> <p>It is a synthetic auxin (plant hormone), and as such it is often used in laboratories for plant research and as a supplement in plant cell culture media such as MS medium<sup>[6]</sup>.</p>  <p>(2,4-dichlorophenoxy)acetic Acid</p>	<p><b>2,4-DB:</b></p> <p>selective systemic phenoxy herbicide used to control many annual and perennial broadleaf weeds in alfalfa, peanuts, soybeans, and other crops. Its active metabolite, 2,4-D, inhibits growth at the tips of stems and roots<sup>[7]</sup>.</p>  <p>4-(2,4-dichlorophenoxy)butanoic acid</p>	<p><b>2,4-DEP:</b></p> <p>Herbicides, plant growth regulator<sup>[8]</sup>.</p>  <p>tris[2-(2,4-dichlorophenoxy)ethyl]phosphite</p>
<p><b>Dichlorprop:</b></p> <p>chlorophenoxy herbicide similar in structure to 2,4-D that is used to kill annual and perennial broadleaf weeds. It is a component of many common weedkillers<sup>[9]</sup>.</p>  <p>R)-2-(2,4-dichlorophenoxy)propanoic acid</p>	<p><b>Fenoprop</b></p> <p>used as an herbicide for control of woody plants and broadleaf weeds<sup>[10]</sup>.</p>  <p>2-(2,4,5-Trichlorophenoxy)propionic acid</p>	<p><b>IAA:</b></p> <p>IAA is also produced from tryptophan through indole-3-acetaldoxime in <i>Arabidopsis</i>. treatment with IAA and analog 1(methyl)-IAA resulted in significantly decreased brain sizes<sup>[11]</sup>.</p>  <p>2-(1H-indol-3-yl)acetic acid</p>
<p>1-naphthalene acetamide: Synthetic auxin that acts as a rooting hormone.</p>	<p><math>\alpha</math>-naphthaleneacetic acids: The hormone NAA does not occur naturally. NAA can be</p>	<p>1-Naphthol: They are precursors to a variety of useful compounds. Naphthols</p>

<p>It can be found in commercial products such as Rootone.</p>  <p>2-Naphthalen-1-ylacetamide</p>	<p>detected by HPLC-tandem mass spectrometry (HPLC-MS/MS)<sup>[12]</sup>.</p>  <p>2-(1-Naphthyl)acetic acid</p>	<p>(both 1 and 2 isomers) are used as biomarkers for livestock and humans exposed to polycyclic aromatic hydrocarbons</p>  <p>1-Hydroxynaphthalene; 1-Naphthalenol; alpha-Naphthol</p>
<p>Naphthoxyacetic acids : “naphthoxyacetic acids” is given as an alternative<sup>[13]</sup>.</p>  <p>(1-naphthoxy)acetic acid and/or (2-naphthoxy)acetic acid</p>	<p>2,4,5-T: chlorophenoxy acetic acid herbicide used to defoliate broad-leaved plants<sup>[14]</sup>.</p>  <p>(2,4,5-Trichlorophenoxy)acetic acid</p>	

## CYTOKININS

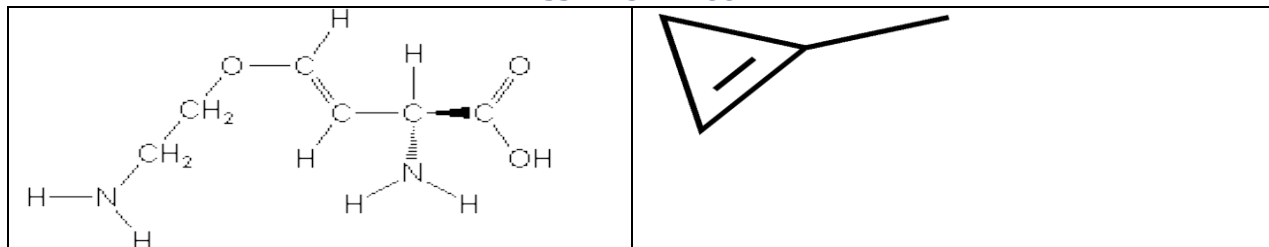
<p><b>2iP: plant growth regulators</b></p>  <p>N-(3-methylbut-2-enyl)-7H-purin-6-amine</p>	<p><b>6-Benzylaminopurine:</b> It is an inhibitor of respiratory kinase in plants<sup>[15]</sup>.</p>  <p>N-(Phenylmethyl)-7H-purin-6-amine</p>	<p><b>4-hydroxyphenethyl alcohol:</b> plant growth regulators.</p>  <p>4-(2-hydroxyethyl)phenol</p>
<p><b>Kinetin:</b> Ability to induce cell division, provided that auxin was present in the medium. Kinetin is often used in plant tissue culture for inducing formation of callus<sup>[16]</sup>.</p>  <p>N6-furfuryladenine</p>	<p><b>Zeatin:</b> It promotes growth of lateral buds and when sprayed on meristems stimulates cell division to produce bushier plants.</p>  <p>(E)-2-methyl-4-(7H-purin-6-ylamino)but-2-en-1-ol</p>	

### DEFOLIANTS

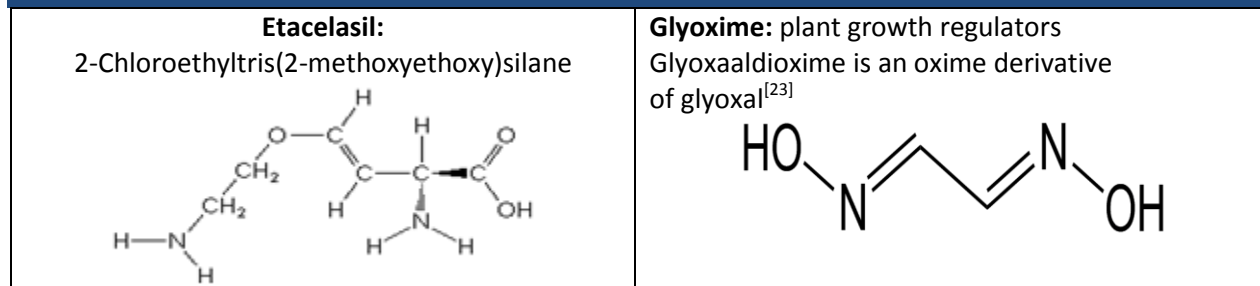
<p><b>Calcium cyanamide:</b> CaCN<sub>2</sub> is a calcium compound used as fertilizer<sup>[17]</sup></p> $\left[ \text{Ca}^{2+} \right] \left[ \text{N}=\text{C}=\text{N}^- \right]$ <p><b>Ethephon:</b> sprayed on mature-green pineapple fruits to degreen them to meet produce marketing requirements. There can be some detrimental effect on fruit quality<sup>[19]</sup>.</p>  <p>2-Chloroethylphosphonic acid</p>	<p><b>Dimethipin:</b> group of sulfones and dithiins. It is used as a defoliant for cotton, vines and gum trees, also as a growth regulator<sup>[18]</sup></p>  <p><b>Merphos:</b> plant growth regulators, tributyl phosphorotrithioite</p> 	<p>Endothal is a chemical compound from the group of dicarboxylic acids, as the herbicide can be used.</p>  <p><b>Metoxuron :</b> herbicides (phenylurea herbicides) plant growth regulators (defoliants)</p>  <p>3-(3-Chloro-4-methoxyphenyl)-1,1-dimethylurea</p>
<p><b>Pentachlorophenol:</b> organochlorine compound used as a pesticide and a disinfectant<sup>[20]</sup>.</p>  <p>2,3,4,5,6-Pentachlorophenol</p>	<p><b>Thidiazuron :</b> phenyl - urea derivative. It is a biologically active substance which is used as a plant growth regulator,<sup>[21]</sup> as a defoliant,</p>  <p>1-phenyl-3-(1,2,3-thiadiazol-5-yl) urea</p>	<p><b>Tribufos:</b> organofosfaatester as plant growth regulator used, especially as a defoliant for cotton.</p>  <p>S, S, S -tributyl-fosfortrithioaat</p>

### ETHYLENE INHIBITORS

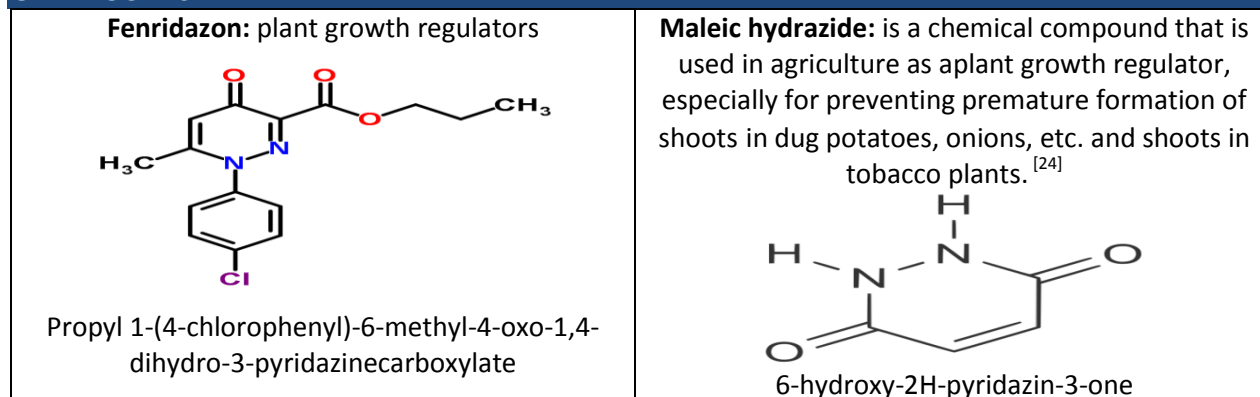
<p><b>Aviglycine:</b> plant growth regulators (2S,3E)-2-amino-4-(2-aminoethoxy)but-3enoic acid</p>	<p><b>1-methylcyclopropene:</b> is a cyclopropene derivative used as a synthetic plant growth regulator. It is structurally related to the natural plant hormone ethylene and it is used commercially to slow down the ripening of fruit and to help maintain the freshness of cut flowers<sup>[22]</sup>.</p>
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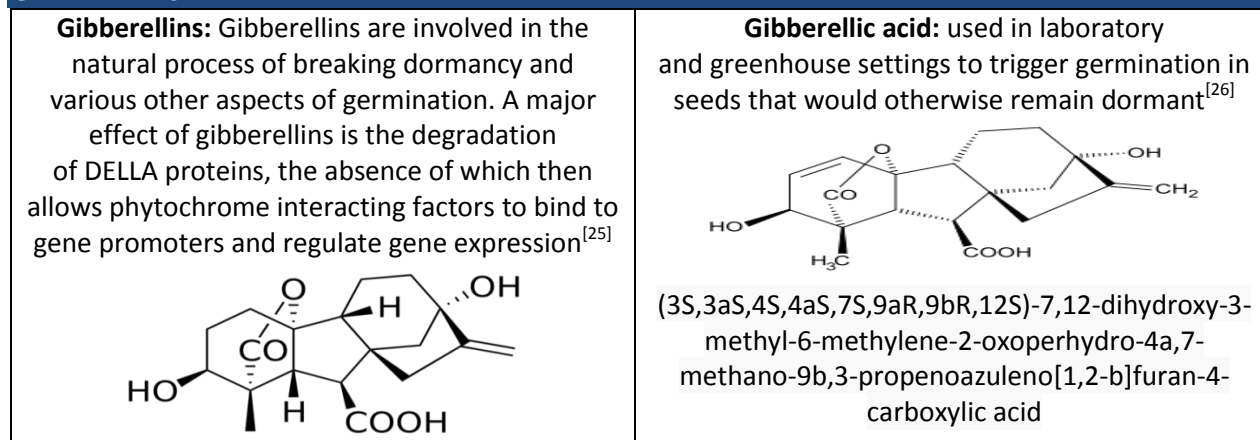
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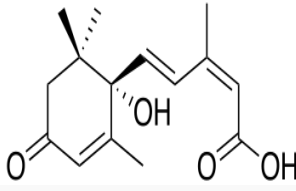
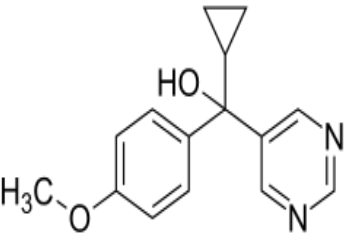
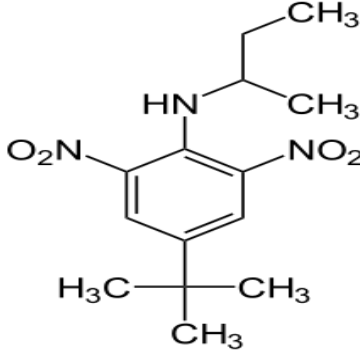
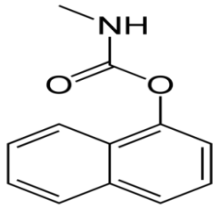
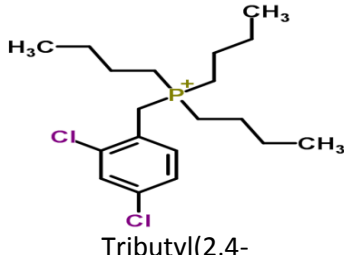
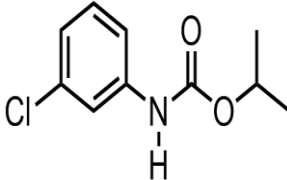
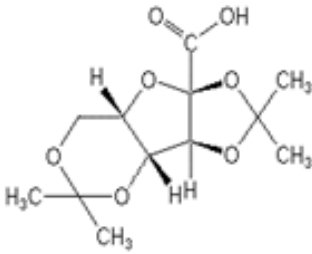
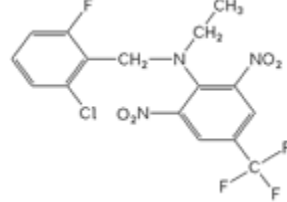
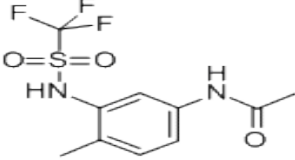
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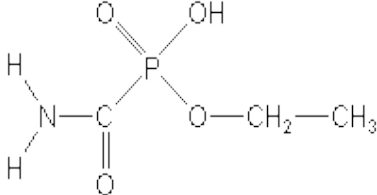
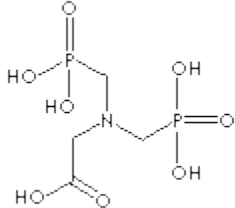
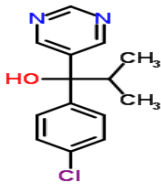
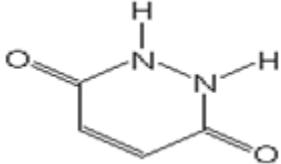
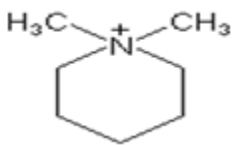
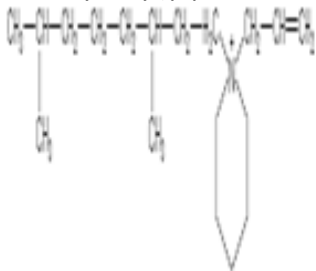
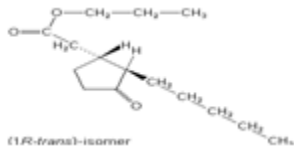
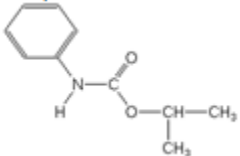
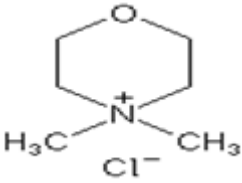


### GIBBERELLINS

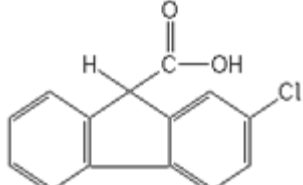
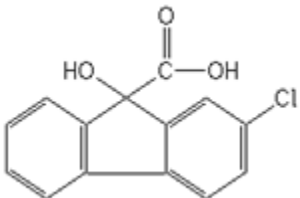
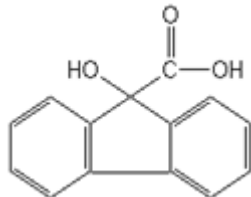


**GROWTH INHIBITORS**

<p><b>Abscisic acid:</b> also known as abscisin II and dormin, is a plant hormone. ABA functions in many plant developmental processes, including bud dormancy. It is degraded by the enzyme (+)-abscisic acid 8'-hydroxylase into phaseic acid<sup>[27]</sup>.</p>  <p>(2Z,4E)-5-[(1S)-1-hydroxy-2,6,6-trimethyl-4-oxocyclohex-2-en-1-yl]-3-methylpenta-2,4-dienoic acid</p>	<p><b>Ancymidol:</b> It is used as a growth regulator used<sup>[28]</sup>. it is a 1:1 mixture of two enantiomers of the chemical compounds from the group of pyrimidines.</p>  <p><math>\alpha</math>-cyclopropyl-<math>\alpha</math>-(4-methoxyphenyl)-5-pyrimidylmethanol.</p>	<p><b>Butralin:</b> is a racemic mixture from the group of dinitroaniline derivatives. Butralin is used as a pre-emergence herbicide<sup>[29]</sup>.</p>  <p>(RS)-N-sec-Butyl-4-tert-butyl-2,6-dinitroanilin</p>
<p><b>Carbaryl:</b> is a chemical in the carbamate family used chiefly as an insecticide<sup>[30]</sup>.</p>  <p>1-naphthyl methylcarbamate</p>	<p><b>Chlorphonium</b></p>  <p>Tributyl(2,4-dichlorobenzyl)phosphonium</p>	<p><b>Chlorpropham:</b> used as a sprout suppressant. used to inhibit potato sprouting and for sucker control in tobacco<sup>[31]</sup>.</p> 
<p><b>Dikegulac:</b> dikegulac-sodium</p> 	<p><b>Flumetralin:</b> N-[(2-chloro-6-fluorophenyl)methyl]-N-ethyl-2,6-dinitro-4-(trifluoromethyl)aniline</p> 	<p><b>Fluoridamid:</b> 3-Trifluoromethylsulfonamido-p-acetotoluidide; N-[4-methyl-3-[[trifluoromethyl)sulfonyl]amino]phenyl]acetamide; n(sup4)-acetyl-n(sup2)-trifluoromethylsulfonyl-toluene-4-diamine</p> 
<p><b>Fosamine:</b> ethyl hydrogen carbamoylphosphonate</p>	<p><b>Glyphosine:</b> N,N-bis(phosphonomethyl)</p>	<p><b>Isopyrimol:</b> 1-(4-Chlorophenyl)-2-methyl-1-(5-pyrimidinyl)-1-propanol</p>

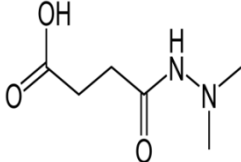
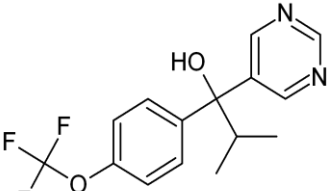
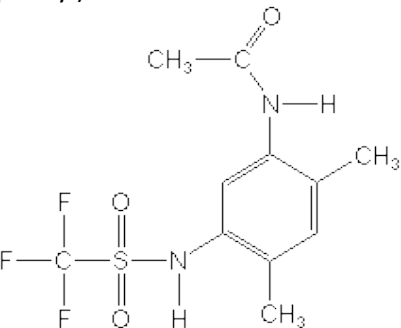
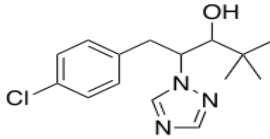
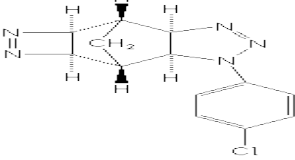
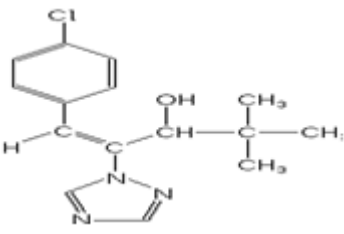
		
<p><b>Maleic hydrazide Maleic:</b> hydrazide is a synthetic compound which has a plant growth regulating action. It is used as a foliar treatment of potatoes to prevent volunteer formation and sprouting during storage.</p> 	<p><b>Mepiquat:</b> 1,1-dimethylpiperidinium</p> 	<p><b>Piproctanyl:</b> (RS)-1-allyl-(3,7-dimethyloctyl)piperidinium.</p> 
<p><b>Prohydrojasmon:</b> propyl(1R,2RS)-(3-oxo-2-pentylcyclopentyl)-acetate containing 10±2% propyl (1RS,2SR)-(3-oxo-2-pentylcyclopentyl)acetate</p>  <p>(1R-trans)-isomer</p>	<p><b>Propham:</b> isopropyl phenylcarbamate</p> 	<p><b>Tiaojean :</b>4,4-dimethylmorpholin-4-iumchloride</p> 

### MORPHACTINS

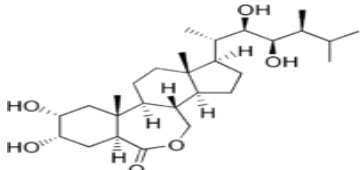
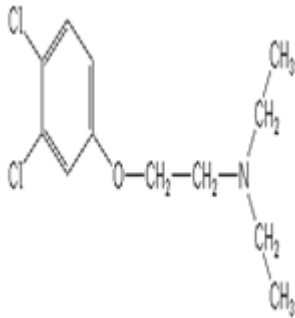
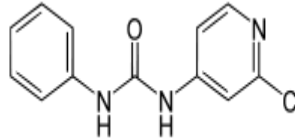
<p><b>Chlorfluren:</b> ( 2RS, 3RS)-1-(4-chlorophenyl)-4, 4-dimethyl- 2-(1H-1, 2, 4-triazol-1-yl) pentan-3-ol</p> 	<p><b>Chlorflurenol:</b> 2-chloro-9-hydroxyfluorene-9-carboxylic acid</p> 	<p><b>Flurenol:</b> 9-hydroxyfluorene-9-carboxylic acid.</p> 
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### GROWTH RETARDANTS

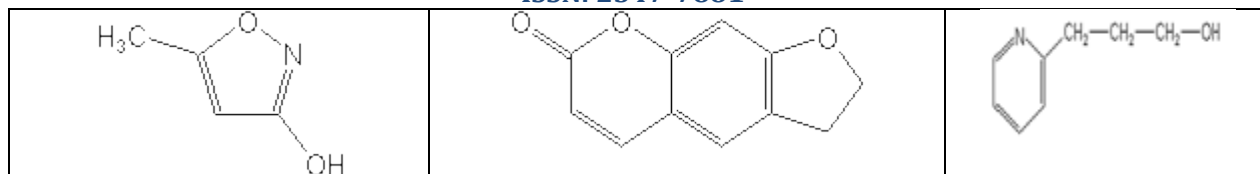
<p><b>Daminozide :</b> is a plant growth regulator,</p>	<p><b>Flurprimidol :</b>It is the active substance in the product Topflor of</p>	<p><b>Mefluidide:</b> N-(2,4-Dimethyl-5-{{(trifluoromethyl)sulfonyl}amino}</p>
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<p>a chemical sprayed on fruit to regulate their growth, make their harvest easier, and keep apples from falling off the trees before they are ripe<sup>[32]</sup>.</p> 	<p>Sepro. Flurprimidol is used to slow down. Undesirable rapid growth<sup>[33]</sup></p>  <p>(RS)-2-methyl-1-pyrimidin-5-yl-1-(4-trifluoromethoxy-phenyl) propan-1-ol</p>	<p>phenyl)acetamide</p> 
<p><b>Paclobutrazol</b> : It acts by inhibiting gibberellins biosynthesis, reducing internodial</p>  <p>(2S,3S)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)pentan-3-ol</p>	<p><b>Tetcyclacis</b>: (1R,2R,6S,7R,8R,11S)-5-(4-chlorophenyl)-3,4,5,9,10-pentaazatetracyclo[5.4.1.0.2,6.0.8,11]d-oct-3,9-diene.</p> 	<p><b>Uniconazole</b>: (E)-(RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1H-1,2,4-triazol-1-yl)pent-1-en-3-ol</p> 

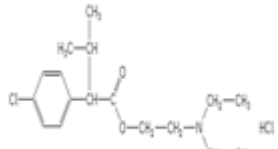
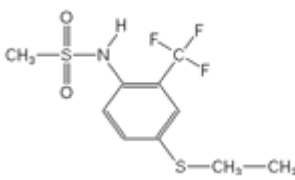
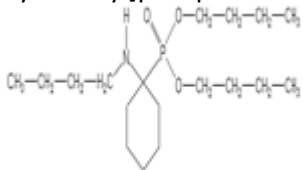
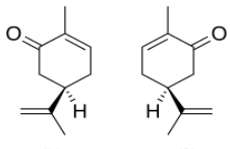
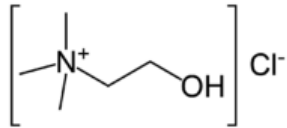
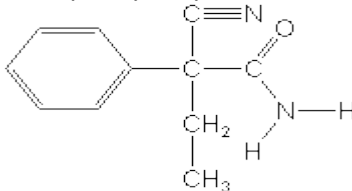
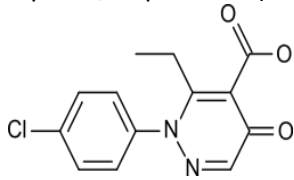
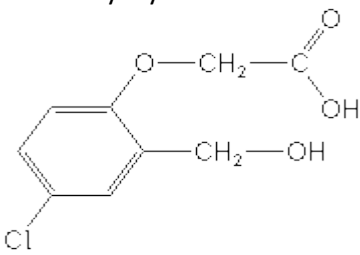
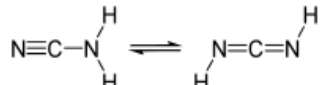
### GROWTH STIMULATORS

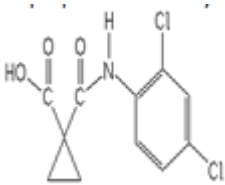
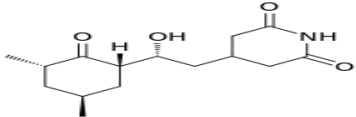
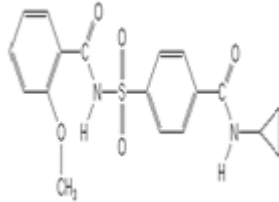
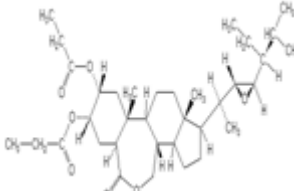
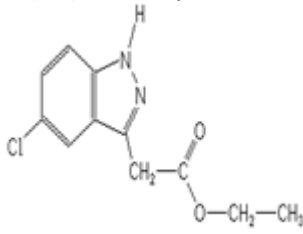
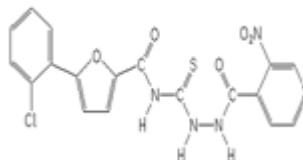

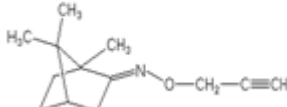
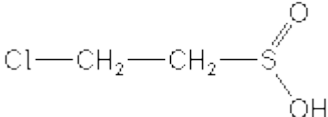
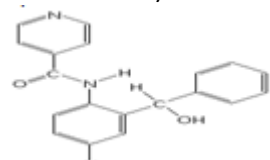
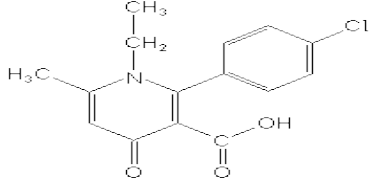
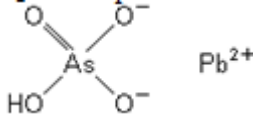
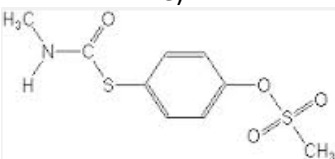
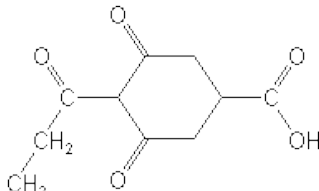
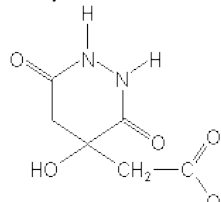
<p><b>Brassinolide</b> The first isolated brassinosteroid, it was discovered when it was shown that pollen from rapeseed (<i>Brassica napus</i>) could promote stem elongation and cell division<sup>[34]</sup></p>  <p>(3aS,5S,6R,7aR,7bS,9aS,10R,12aS,12bS)-10-[(2S,3R,4R,5S)-3,4-dihydroxy-5,6-dimethyl-2-heptanyl]-5,6-dihydroxy-7a,9a-dimethylhexadecahydro-3H-benzo[c]indeno[5,4-e]oxepin-3-one</p>	<p><b>DCPTA</b>: 2-(3,4-dichlorophenoxy)-N,N-diethylethanamine.</p> 	<p><b>Forchlorfenuron</b>: is a plant growth regulator. It has been approved for use on kiwi fruit and grapes in the USA,</p>  <p>1-(2-chloropyridin-4-yl)-3-phenylurea</p>
<p><b>Hymexazol</b>: 5-methyloxazol-3-ol</p>	<p><b>Prosuler</b>: 7H-furo[3,2-g]chromen-7-one</p>	<p><b>Pyripropanol</b>: 3-(2-pyridyl) propan-1-ol.</p>

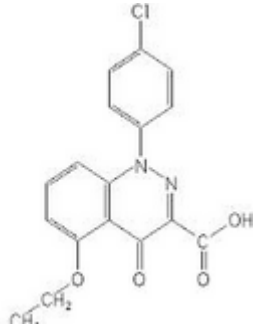
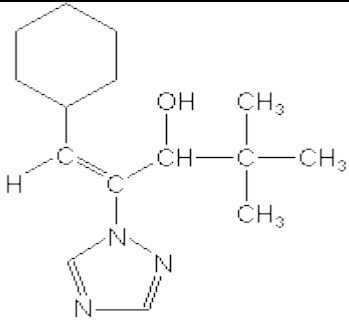
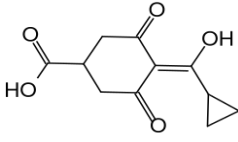




## UNCLASSIFIED PLANT GROWTH REGULATORS

<p><b>Bachmedesh:</b> 2-(diethylamino)-ethyl(2<i>rs</i>)-2-(4-chlorophenyl)-3-methylbutyrate hydrochloride</p> 	<p><b>Benzofluor:</b> 4'-ethylthio-2'-(trifluoromethyl)methylsulfonanilide.</p> 	<p><b>Buminafos:</b> dibutyl[1-(butylamino)-cyclohexyl]phosphonate.</p> 
<p><b>Carvone:</b> are used in the food and flavor industry.<sup>[35]</sup> R-(-)-Carvone is also used for air freshening products and, like many essential oils, oils containing carvones are used in aromatherapy and alternative medicine.</p>  <p>(<i>R</i>)                      (<i>S</i>) 2-Methyl-5-(1-methylethenyl)-2-cyclohexenone</p>	<p><b>Choline chloride</b> : is an organic compound and a quaternary ammonium salt. It has a choline cation with chloride anion. Alternative names are heptacholine, biocolina and lipotril.<sup>[36]</sup></p>  <p>2-hydroxy-N,N,N-trimethylethanaminium chloride OR (2-hydroxyethyl)trimethylammonium chloride</p>	<p><b>Ciobutide</b> : (RS)-2-cyano-2-phenylbutyramide</p> 
<p><b>Clofencet:</b><sup>[37]</sup> active substance in the plant protection product (or plant , or pesticide )</p> 	<p><b>Cloxyfonac</b> : 4-chloro-<math>\alpha</math>-hydroxy-o-tolyoxyacetic acid</p> 	<p><b>Cyanamide:</b> is an organic compound with the formula <math>CN_2H_2</math>. used in agriculture and the production of pharmaceuticals and other organic compounds. It is also used as an alcohol deterrent</p> 
<p><b>Cyclanilide:</b> 10[(2,4-dichlorophenyl)carbamoyl]</p>	<p><b>Cycloheximide:</b> is an inhibitor of protein</p>	<p><b>Cyprosulfamide:</b> N-[4-(cyclopropylcarbamoyl)-</p>

<p>cyclopropane-1-carboxylic acid.</p> 	<p>biosynthesis in eukaryotic organism s, produced by the bacterium <i>Streptomyces griseus</i>. Cycloheximide exerts its effect by interfering with the translocation step in protein synthesis<sup>[38]</sup></p> 	<p>phenylsufonyl]-o-anisamide</p> 
<p><b>Epocholeone:</b> 22,23-epoxy-6-oxo-7-oxa-6(7a)-homo-5α-stigmastane-2α,3α-diyldipropionate</p> 	<p><b>Ethychlozate:</b> ethyl 5-chloro-3-(1H)-indazolylacetate</p> 	<p><b>Fuphenthio urea:</b> 5-(20chlorophenyl)-N-{[N;-(2-nitrophenylcarbonyl)-hydrazino]thiocarbonyl)furan-2-carboxamide</p> 
<p><b>Furalane:</b> 2-(2-furyl)1,3-dioxolane</p> 	<p><b>Heptopargil:</b> (1RS,4RS)-barnan-2-one(E)-o-prop-2-ynyloxime</p> 	<p><b>Holosulf:</b> 2-chloroethanesulfinic acid</p> 
<p><b>Inabenfide:</b> (RS)-4'-chloro-2'-(α-hydroxybenzyl)isonicotinamide</p> 	<p><b>Karetazan:</b> 2-(4-chlorophenyl)-1-ethyl-1,4-dihydro-6-methyl-4-oxonicotinic acid</p> 	<p><b>Lead arsenate:</b> acid lead arsenate or LA, chemical formula <math>PbHAsO_4</math>, used primarily against the potato beetle.<sup>[39]</sup></p> 
<p><b>Methasulfocarb:</b> S-4-(mesyloxy)-phenylmethyl(thiocarbamate)</p> 	<p><b>Prohexadione:</b> 3,5-dioxo-4-propionylcyclohexanecarboxylic acid.</p> 	<p><b>Pydanon:</b> (RS)-haxahydro-4-hydroxy-3,6-dioxopyridazin-4-ylacetic acid</p> 
<p><b>Sintofen:</b> 1-(4-chlorophenyl)1,4-dihydro-5-(2-methoxyethoxy)4-</p>	<p><b>Triapenthenol:</b> (E)-(RS)-1-cyclohexyl-4,4-dimethyl-2-(1H-1,2,4-triazol-1-yl)pent-1-en-3-ol</p>	<p><b>Trinexapac:</b> is a growth regulator from the family of carboxylic acids. Trinexapac</p>

<p>oxocinnoline-3-carboxylic acid</p> 		<p>inhibits the biosynthesis of gibberellins. It acts as Internodienverkürzer and is used for cereals, rice and sunflower as Halmstabilisator.<sup>[40]</sup></p>  <p>(RS)-4-cyclopropyl (hydroxy) methylene-3,5-dioxycyclohexancarbonsäure</p>
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