CHAPTER 2

REVIEW OF LITERATURE

2.1 Application of pesticides

A pesticide is a compound which is utilized to repel, kill or to prevent any pest. On the basis of the target killed, pesticides are mainly classified as herbicides, fungicides and insecticides. The increased demand of food on account of population explosion has compelled man to use pesticides for better crop production (Tomer, 2013). Pesticides are used protect crops in the field as well as during post-harvest storage to minimize crop damage. *Brassica* species are widely attacked by insect pests which results in loss of yield. Crop plants including *Brassica juncea* are attacked by various pests like termites, soil insects, cut worms, leaf roller, aphids etc., and pesticides are used to control these pests (Goh *et al*., 2011). In the state Punjab (India) these yield loss account for 6.5 to 26.4 % in absence of any pesticide (Kular and Kumar, 2011). In the present era, there are other alternatives also to control these insect pests which include the use of bio-pesticides and developing pest resistant transgenic varieties. However, the use of chemical pesticides is still the best and widely applied strategy to protect crops from pests and results in high yield production of crops. It has been reported that approximately two million tonnes of pesticides are consumed annually throughout the world, and India shares 3.75% of the total pesticide consumption (De *et al*., 2014). Global pesticide consumption includes 47.55 of herbicides, 29.5% of insecticides, 17.5% of fungicides and 5.5% of other pesticides. In India, insecticides are used in majority (80%) followed by herbicides (15%), fungicides (2%) and other pesticides (3%) (De *et al*., 2014). India uses 260 pesticides of technical grade and 585 pesticides as formulations, and the total pesticide consumption during 2014-15 was 57353 metric tons (PIB, Ministry of Agriculture, Govt. of India). The rate of pesticide use in India is 0.5 Kg ha^{-1} which is very less as compared to 12.0 Kg ha^{-1} in Japan (De *et al*., 2014). In Punjab, total pesticide consumption during 2014-15 was 5699 metric tons and it has been estimated that for 2015-16, a total of 6370 metric tonnes of pesticides will be used (Directorate of Agriculture, Govt. of Punjab).

Imidacloprid (IMI)(1-((6-chloropyridin-3-yl)methyl)-4,5-dihydro-N-nitro-1H-imidazol- 2-amine), a neonicotinoid chemical and a systemic insecticide in nature, is one of the most effective and extensively used insecticides to control soil insects like termites and sucking insects like aphids, leaf hoppers and thrips (Ko *et al*., 2014). IMI has been reported to be more effective against sap sucking insects as compared to other pesticides (El-Naggar and Zidan, 2013). It is applied to the soil before seed sowing for protection of plants from soil borne pests. It is also effective against aerial insect pests due to its transport to the shoots (Bonmatin *et al*., 2005). Like other xenobiotic chemicals, IMI also translocates from soil to the leaves of the plants via xylem channel and then it is transported to flowers, fruits and other parts of plants through phloem (Laurent and Rathahao, 2003; Alsayeda *et al*., 2008). Recommended field dose of IMI is 20-70 g a.i. ha^{-1} (Sarkar *et al*., 2001) and its half-life period varies from 40 to124 days in soils without manure and with manure respectively (Gervais *et al*., 2010). Following IMI application @ 80 g a.i. ha^{-1}, the IMI residues (including its metabolites) detected after 30 and 60 days of treatment were 1.60 and 0.90 mg Kg^{-1} soil respectively (Sharma and Singh, 2014).

2.2 Uptake, transport and persistence of pesticides in plants

Uptake of pesticides means their absorption by plant system which results by controlling their leaching (Kerle *et al*., 2007). Transpiration pull helps in the absorption of water soluble pesticides and their entry into plant system. Volatile pesticides indirectly come into atmosphere via leaves through stomata during transpiration. Plants absorb pesticides via roots, leaf surface or through roots. A number of factors are involved in pesticide uptake and its metabolism in plant system which include external environmental factors (temperature, humidity and precipitation) and physiochemical properties of soil and pesticides (Finlayson and MacCarthy, 1973).Uptake of pesticides via root system and their metabolism in plant system is affected by factors like mode of application, amount of pesticide, physiochemical and biochemical properties of pesticides and their reaction with soil and stage of plant development (Führ, 1991). Absorption of pesticides by plants is also determined by the degree of their water solubility. Pesticide uptake takes place either by active absorption via root system, or by passive absorption. Absorbed pesticides are either metabolized by the plant system or get accumulate in plants and leading to bio-magnification in ecosystem (Mwevura, 2000).

IMI translocates from soil to the photosynthetic site of the plants via xylem channel and then transported to flowers and fruits through phloem (Laurent and Rathahao, 2003; Alsayeda *et al*., 2008). After translocation to aerial parts of the plant, IMI gets accumulated in plant parts, with higher concentrations of residues being in early leaves followed by young leaves, flowers and fruits, roots accumulating very less amount of IMI residues (Laurent and Rathahao, 2003; Alsayeda *et al*., 2008). Studies carried out by Laurent and Rathahao (2003) also reported the translocation of IMI from soil to leaves and inflorescence of *Helianthus annuus* plants. They also reported that IMI residues found in pollens were much less than the residues found in leaves. In another study carried out on peanut plants, fipronil was applied to seeds before sowing and it was observed that this pesticide was translocated to peanut fruits at harvesting stage (Li *et al*., 2015). In *H. annuus* seeds treated with fipronil prior to sowing, it was observed that fipronil was absorbed by plants via roots, translocated to all aerial parts and persisted in the form of residues (Aajoud *et al*., 2008). These researchers further suggested that the transfer of fipronil to inflorescence might have been via phloem from leaves and stem. Table 2.2.1 gives detailed information about the persistence of pesticide residues in plants after different modes of application.

Table 2.2.1 Persistence of pesticides in different parts of plants in the form of their residues after various modes of treatment.

Type of pesticide (www.alanwood.net/pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide applied	Plant part analyzed	Days after treatment	Residues detected (mg Kg^{-1})	Reference
Conazole	Penconazole	*Lycopersicon esculentum* L.	Spray	10 g ai fe^{-1}	Leaves	1	1.22	Romeh *et al*. (2009)
						7	0.50	
					Fruits	1	0.17	
						7	0.12	
	Tetraconazol	*Cucumis sativus* L.	Spray	50 g ai ha^{-1}	Fruits	1	0.10	Nasr *et al*. (2014)
						11	0.002	
Diamide	Flubendiamide	*Abelmoschus esculentus* L.	Spray	48 g ai ha^{-1}	Fruits	1	0.41	Das *et al*. (2012)
						5	0.21	
		Brassica oleracea L.	Spray	48 g ai ha^{-1}	Head	1	0.41	Mohapatra *et al*. (2010)
						7	0.19	
		Cicer aretinium L.	Spray	96 g ai ha^{-1}	Leaves	1	0.86	Singh *et al*. (2011)
						5	0.22	
					Pods	1	0.61	
						5	0.10	
		Cucumis anguria L.	Spray	120 g ai ha^{-1}	Fruits	1	1.03	Paramasivam *et al*. (2014)
						7	0.15	
		L. esculentum L.	Spray	100 g ai ha^{-1}	Fruits	1	0.31	Paramasivam and Banerjee (2012)
						5	0.10	
				96 g ai ha^{-1}	Fruits	1	0.08	Kooner *et al*. (2010)
						3	0.02	
Neonicotinoid	Acetamiprid	*Brassica juncea* L.	Spray	40 g ai ha^{-1}	Young plant	1	0.42	Pramanik *et al*. (2006)
						7	0.01	
		Capsicum annuum L.	Spray	40 g ai ha^{-1}	Fruits	1	0.03	Sanyal *et al*. (2008)
						7	0.009	
	Imidacloprid	*Beta vulgaris altissima* D.	Seed	900 µg^{-1} seed	Leaves	21	15.2	Westwood *et al*. (1998)
						97	0.5	
					Roots	49	1.3	
						97	0.08	
		Brassica campestris L.	Spray	40 g ai ha^{-1}	Herbage	1	1.86	Kumar and Dikshit (2001)
						15	0.17	
			Seed	10 g ai Kg^{-1} seed	Herbage	30	5.39	
						82	0.33	
		B. juncea L.	Spray	40 g ai ha^{-1}	Leaves	1	2.98	Mukherjee and Gopal (2000)
						10	0.90	
		B. oleracea L. var. capitata	Spray	40 g ai ha^{-1}	Leaves	1	6.14	
						10	0.97	
		B. oleracea L. var. Golden	Spray	40 g ai ha^{-1}	Leaves	2	0.18	Gajbhiye *et al*. (2004)
						5	0.03	

Type of pesticide (www.alanwood.net/pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide applied	Plant part analyzed	Days after treatment	Residues detected (mg Kg^{-1})	Reference
		acre						
		B. oleracea L. var. Ketki	Spray	40 g ai ha^{-1}	Leaves	2	0.32	
						5	0.03	
					Curd	2	0.57	
						5	0.12	
		C. aretinium L.	Spray	84 g ai ha^{-1}	Leaves	1	0.72	Chahil *et al.* (2014)
						5	0.34	
					Pods	1	0.30	
						5	0.07	
		Cucumis sativus L.	Spray	60 g ai ha^{-1}	Fruits	1	2.54	Hassanzadeh *et al.* (2012)
						7	1.01	
				125 g ai ha^{-1}	Fruits	1d	0.37	Nasr *et al.* (2014)
						15	0.03	
		L. esculentum L.	Spray	100 g ai fe^{-1}	Leaves	1	2.35	Romeh *et al.* (2009)
						7	0.76	
					Fruits	1	0.58	
						7	0.25	
		Oryza sativa L.	Spray	80 g ai ha^{-1}	Leaves	7	9.40	Akoijam and Singh (2014)
						45	0.59	
		Punica granatum L.	Spray	54 g ai ha^{-1}	Peel	1	0.33	Kadam *et al.* (2014)
						7	0.11	
					Whole fruit	1	0.25	
						7	0.05	
		Saccharum officinarum L.	Soil	80 g ai ha^{-1}	Leaves	7	12.99	Sharma and Singh (2014)
						45	2.37	
		Solanum melongena L.	Spray	84 g ai ha^{-1}	Fruits	1	0.25	Mandal *et al.* (2010)
						5	0.13	
				40 g ai ha^{-1}	Fruits	1	2.37	Mukherjee and Gopal (2000)
						10	0.37	
		Vitis vinifera L.	Spray	160 g ai ha^{-1}	Fruit	1	1.02	Mohapatra *et al.* (2011)
		Zea mays L.	Seed	1.0 mg^{-1} seed	Roots	45	0.29	Donnarumma *et al.* (2011)
						60	0.12	
					Leaves	45	0.013	
						60	0.005	
					Stem	45	0.008	
						60	0.006	
	Thiacloprid	*L. esculentum* M	Spray	96 g ai ha^{-1}	Fruits	1	0.14	Kooner *et al.* (2010)
						3	0.05	
Organophosphorus	Chlorpyrifos	*C. annuum* L.	Spray	1000 g ai ha^{-1}	Fruits	1	1.30	Jyot *et al.* (2013)
						7	0.47	

Type of pesticide (www.alanwood.net/pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide applied	Plant part analyzed	Days after treatment	Residues detected (mg Kg^{-1})	Reference
	Profenofos	*L. esculentum* L.	Spray	540 g ai fe^{-1}	Leaves	1	26.06	Romeh *et al.* (2009)
						7	0.33	
					Fruits	1	3.47	
						7	1.28	
Pyrazole	Fipronil	*C. annuum* L.	Spray	80 g ai ha^{-1}	Fruits	1	1.01	Xavier *et al.* (2014)
						7	0.50	
		S. officinarum L.	Sand	300 g ai ha^{-1}	Leaves	7	0.66	Mandal and Singh (2014)
						45	0.16	
Pyrethroid	β-Cyfluthrin	*Cajanus cajan* L.	Spray	25 g ai ha^{-1}	Green pods	1	13.73	Mukherjee *et al.* (2007)
						10	3.45	
		C. aretinium L.	Spray	25 g ai ha^{-1}	Green pods	1	5.98	
						10	1.22	
			Spray	36 g ai ha^{-1}	Leaves	1	0.57	Chahil *et al.* (2014)
						5	0.06	
					Pods	1	0.26	
						5	0.10	
		S. melongena L.	Spray	25 g ai ha^{-1}	Fruits	1	0.23	Sinha and Gopal (2002)
						7	0.11	
			Spray	36 g ai ha^{-1}	Fruits	1	0.08	Mandal *et al.* (2010)
						5	0.01	
	Cypermethrin	*B. oleracea* L. var. Snowball 16	Spray	100 g ai ha^{-1}	Heads	1	0.86	Singh *et al.* (1990)
						3	0.08	
					Leaves	1	0.35	
						3	0.08	
		C. annuum L.	Spray	100 g ai ha^{-1}	Fruits	1	0.28	Jyot *et al.* (2013)
						7	0.12	
	Deltamethrin	*B. oleracea* L. var. Snowball 16	Spray	24 g ai ha^{-1}	Heads	1	0.13	Singh *et al.* (1990)
						2	0.06	
					Leaves	1	0.09	
						2	0.04	
	Fenvalerate	*B. oleracea* L. var. Snowball 16	Spray	100 g ai ha^{-1}	Heads	1	1.07	
						3	0.25	
					Leaves	1	0.25	
						3	0.03	
Triazin	Atrazine	*O. sativa* L.	Hoagland medium	0.8 mg L^{-1}	Leaves	2	2.94	Zhang *et al.* (2014)
						6	4.26	

2.3 Phytotoxicity of pesticides to plants

In plants, phytotoxicity due to pesticides is observed in the form of necrosis, chlorosis, stunting, burns and twisting of leaves. The excessive use of pesticides is one of the major factors in reducing the diversity of structural vegetation (Donald, 2004). Sensitive or stressed plants may be extra vulnerable to phytotoxicity. The toxicity depends upon many factors such as use of pesticide, rate of application, spraying technique, conditions of climate, organization of flora, humidity and properties of soil such as moisture, temperature, pH, texture and microbial activity. It has been observed that pesticide application negatively affects plant growth and development (Sharma *et al*., 2015). Pesticide application causes oxidative stress to plants due to the generation of reactive oxygen species (ROS). This oxidative stress results in degradation of chlorophyll pigment, proteins and ultimately causes reduction in the photosynthetic efficiency of plants (Xia *et al*., 2006; Sharma *et al*., 2015). To cope up with oxidative stress, antioxidative defense system of plants gets activated which involves enzymatic and non-enzymatic antioxidants (Xia *et al*., 2009a; Sharma *et al*., 2015; Sharma *et al*., 2016a). Activation of antioxidative defense system helps in scavenging of ROS and reduces the oxidative stress in plants caused by pesticide toxicity (Sharma *et al*., 2015). Effects of application of pesticides in plants are summarized in table (2.3.1), growth parameters; table (2.3.2), pigments system; table (2.3.3), photosynthetic parameters; table (2.3.4), protein content; table (2.3.5), oxidative stress; table (2.3.6), enzymatic antioxidants and table (2.3.7), non-enzymatic antioxidants.

Table 2.3.1 Phytotoxic effects of pesticides on various growth parameters of plants

Type of pesticide (www.alanwood.net/pesticides/)	Pesticide name	Plant name	Mode of application	Concentration applied	Time after treatment	Effect of pesticide on growth parameters: Parameter	Effect	Reference
Amide	Acetochlor	*Oryza sativa* L.	Culture solution	3.2 μM L^{-1}	10 d	Shoot fr. wt. Root fr. wt.	Decrease Decrease	Huang and Xiong (2009)
	Alachlor	*Zea mays* L. var. NAC-6002	Hoagland medium	10 ppm	7 d	Seedling fr. wt. Seedling dr. wt. Plumule length Radicle length	Decrease Decrease Decrease Decrease	Kumar and Jagannath (2015)
		Z. mays L. var. NAC-6004	Hoagland medium	10 ppm	7 d	Seedling fr. wt. Seedling dr. wt. Plumule length Radicle length	Decrease Decrease Decrease Decrease	
		Z. mays L. var. NAH-2049	Hoagland medium	10 ppm	7 d	Seedling fr. wt. Seedling dr. wt. Plumule length Radicle length	Decrease Decrease Decrease Decrease	
	Butachlor	*Ceratophyllum demersum* L.	Culture soln.	0.5 mg L^{-1}	21 d	Fresh weight	Decrease	Huiyun *et al*. (2009)
		Triticum aestivum L.	Hoagland medium	3 L ha^{-1}	16 d	Shoot fr. wt. Shoot dr. wt.	Decrease Decrease	Alla *et al*. (2008)
		Z. mays L.	Hoagland medium	3 L ha^{-1}	16 d	Shoot fr. wt. Shoot dr. wt.	Decrease Decrease	
	Napropamide	*Brassica napus* L.	Seedling	8 mg L^{-1}	5 d	Shoot dr. wt. Root dr. wt.	Decrease Decrease	Cui *et al*. (2010)
	Rac-metolachlor	*O. sativa* L.	Culture solution	10^{-6} M L^{-1}	5 d	Root length	Decrease	Liu *et al*. (2012)
		Z. mays L.	Culture solution	10^{-6} M L^{-1}	5 d	Root length	Decrease	
	S- metolachlor	*O. sativa* L.	Culture solution	10^{-6} M L^{-1}	5 d	Root length	Decrease	
		Z. mays L.	Culture solution	10^{-6} M L^{-1}	5 d	Root length	Decrease	
Aromatic acid	Clopyralid	*Z. mays* L.	Spray	4 Kg ha^{-1}	5 d	Biomass	Decrease	Vettakkorumakankav *et al*. (2002)
			Petri-plates	10^{-3} M	5 d	Shoot length Root length	Decrease Decrease	
	Dicamba		Spray	4 Kg ha^{-1}	5 d	Biomass	Decrease	
			Petri-plates	10^{-3} M	5 d	Shoot length Root length	Decrease Decrease	
	Picloram		Petri-plates	10^{-3} M	5 d	Shoot length Root length	Decrease Decrease	
	Quinclorac	*C. demersum* L.	Culture soln.	1 mg L^{-1}	21 d	Fresh weight	Decrease	Huiyun *et al*. (2009)
Carbamate	Methomyl	*Lycopersicon esculentum* L.	Spray	0.7 g L^{-1}	15 d	Biomass	Decrease	Hajjar *et al*. (2014)
Dinitroaniline	Pendimethalin	*Foeniculum vulgare* M.	Soil	8.5 mg L^{-1}	84 d	Shoot length Shoot fr. wt.	Decrease Decrease	El-Awadi and Hassan *et al*. 2011

Type of pesticide (www.alanwood.net/pesticides/)	Pesticide name	Plant name	Mode of application	Concentration applied	Time after treatment	Effect of pesticide on growth parameters		Reference
						Parameter	Effect	
						Shoot dr. wt. No. of leaves No. of branches	Decrease Decrease Decrease	
		Vigna mungo L. var. Shekhar	soil	10 ppm	15 d	Seedling height	Decrease	Singh *et al*. (2012)
Imidazolinone	*R*-imazethapyr	*Arabidopsis thaliana* L.	Culture solution	2.5 µg L^{-1}	28 d	Fresh weight	Decrease	Qian *et al*. (2011)
	S-imazethapyr	*A. thaliana* L.	Culture solution	2.5 µg L^{-1}	28 d	Fresh weight	Decrease	
		Z. mays L.	Culture soln.	800 mg L^{-1}	5 d	Biomass Seedling length	Decrease Decrease	Zhou *et al*. (2009)
Neonicotinoid	Imidacloprid	*Brassica juncea* L.	Soil	350 mg Kg^{-1}	60 d	Shoot length No. of leaves	Decrease Decrease	Sharma *et al*. (2016b)
		L. esculentum L.	Spray	1.5 g L^{-1}	15 d	Biomass	Decrease	Hajjar *et al*. (2014)
		O. sativa L	Sand	0.02%	12 d	Shoot length Root length Root number Fresh weight Dry weight	Decrease Decrease Decrease Decrease Decrease	Sharma *et al*. (2013)
				0.015%	12 d	Shoot length Root length Root number Fresh weight Dry weight	Decrease Decrease Decrease Decrease Decrease	Sharma *et al*. (2015)
Organochlorine	Endosulfan sulfate	*Cucumis sativa* L.	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Decrease Decrease Decrease	Somtrakoon and Pratumma (2012
		Ipomoea aquatic F.	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Decrease Decrease Decrease	
		Vigna sinensis L.	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Decrease Increase Decrease	
		Z. mays L. convar. Saccharata	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Decrease Decrease Decrease	
		Z. mays L. var. Ceratina Kuleshov	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Decrease Increase Increase	
	Heptachlor	*C. sativa* L.	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Increase Decrease Decrease	Somtrakoon and Pratumma (2012
		I. aquatic F.	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Decrease Decrease Decrease	

Type of pesticide (www.alanwood.net/pesticides/)	Pesticide name	Plant name	Mode of application	Concentration applied	Time after treatment	Effect of pesticide on growth parameters		Reference
						Parameter	Effect	
		V. sinensis L.	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Decrease Decrease Decrease	
		Z. mays L. convar. Saccharata	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Decrease Decrease Decrease	
		Z. mays L. var. Ceratina Kuleshov	soil	40 mg Kg^{-1}	10 d	Shoot length Root length Fresh weight	Decrease Decrease Decrease	
	Hexachlorocyclohexane	*Avena sativa* L.	Soil	10000 mg Kg^{-1}	35 d	Shoot length Root length	Decrease Decrease	Pereira *et al*. (2010)
		Hordeum vulgare L.	Soil	12500 mg Kg^{-1}	35 d	Biomass	Decrease	
				10000 mg Kg^{-1}	35 d	Shoot length Root length	Decrease Decrease	
		Pisum sativum L.	Soil	10000 mg Kg^{-1}	35 d	Shoot length Root length	Decrease Decrease	
				12500 mg Kg^{-1}	35 d	Biomass	Decrease	
		Phaseolus vulgaris L.	Soil	12500 mg Kg^{-1}	35 d	Biomass	Decrease	
				10000 mg Kg^{-1}	35 d	Shoot length Root length	Decrease Decrease	
		Solanum nigrum L.	Soil	10000 mg Kg^{-1}	35 d	Shoot length Root length	Decrease Decrease	
		T. aestivum L.	Soil	10000 mg Kg^{-1}	35 d	Shoot length Root length	Decrease Decrease	
				12500 mg Kg^{-1}	35 d	Biomass	Decrease	
		Trifolium pretense L.	Soil	10000 mg Kg^{-1}	35 d	Shoot length Root length	Decrease Decrease	
Organophosphorus	Chlorpyrifos	*O. sativa* L.	Sand	0.06%	12 d	Shoot length Root length Root number	Decrease Decrease Decrease	Sharma *et al*. (2012)
		V. radiata L.	Spray	15 mM	10 d	Shoot length Root length	Decrease Decrease	Parween *et al*. (2011)
	Diazinon	*O. sativa* L.	Seed	10 µg L^{-1}	4 d	Radicle length Coleoptile length	Increase Decrease	Moore and Kroger (2010)
	Dimethoate	*V. radiata* L.	Culture soln.	150 ppm	4 d	Biomass Leaf area	Decrease Decrease	Singh *et al*. (2014)
	Glyphosate	*Glycine max* L. var. RR1	Spray	2400 g a.e. ha^{-1}	28 d	Biomass	Decrease	Zobiole *et al*. (2011)
			Spray	2400 g a.e. ha^{-1}	32 d	Biomass	Decrease	
		V. radiate L. var. PDM54	Seed	10 mM	12 d	Root length Seedling fr. wt.	Decrease Decrease	Basantani *et al*. (2011)
		V. radiate L. var. PDM11	Seed	10 mM	12 d	Root length Seedling fr. wt.	Decrease Decrease	
		Z. mays L. var. Kneza-640	Spray	10 mM	10 d	Shoot fr. wt. Shoot length	Decrease Decrease	Sergiev *et al*. (2006)

Type of pesticide (www.alanwood.net/pesticides/)	Pesticide name	Plant name	Mode of application	Concentration applied	Time after treatment	Effect of pesticide on growth parameters		Reference
						Parameter	Effect	
Phenoxy	Fluazifop-p-butyl	*Z. mays* L. convar. Saccharata	Seedling immersing	6.5×10^{-5} M	7 d	Shoot length Root length	Decrease Decrease	Horbowicz *et al.* (2013)
	Quizalofop-*p*-ethyl	*G. max* L.	Seed	0.8 M	5 d	Shoot length Root length	Decrease Decrease	Aksoy *et al.* (2013)
Pyrazole	Chlorantraniliprole	*Z. mays* L.	Seed	0.5 ppm	7 d	Coleoptile length Radicula length Radicula number	Decrease Decrease Decrease	Kilic *et al.* (2015)
	Fipronil	*O. sativa* L.	Seed	10 µg L^{-1}	4 d	Radicle length Coleoptile length	Increase Decrease	Moore and Kroger (2010)
Pyrethroid	Lambda-cyhalothrin	*O. sativa* L.	Seed	10 µg L^{-1}	4 d	Radicle length Coleoptile length	Increase Decrease	Moore and Kroger (2010)
	Permethrin	*Typha latifolia* L.	Petri-plate	8 mg L^{-1}	7 d	Radicle length Coleoptile	Decrease Decrease	
Pyridine	Fluroxypyr	*O. sativa* L.	Culture soln.	0.8 mg L^{-1}	6 d	Shoot length Shoot dr. wt.	Decrease Decrease	Wu *et al.* (2010)
		Z. mays L.	Petri-plates	10^{-3} M	5 d	Shoot length Root length	Decrease Decrease	Vettakkorumakankav *et al.* (2002)
Triazine	Atrazine	*Acorus calamus* L.	Culture soln.	8 mg L^{-1}	15 d	Growth rate	Decrease	Wang *et al.* (2015)
		Ceratophyllum demersum L.	Culture soln.	0.5 mg L^{-1}	21 d	Fresh weight	Decrease	Huiyun *et al.* (2009)
		Lythrum salicaria L.	Culture soln.	8 mg L^{-1}	15 d	Growth rate	Decrease	Wang *et al.* (2015)
		O. sativa L.	Seed	10 µg L^{-1}	4 d	Radicle length Coleoptile length	Increase Decrease	Moore and Kroger (2010)
			Hoagland medium	0.4 mg L^{-1}	6 d	Root length Shoot length Biomass	Decrease Decrease Decrease	Zhang *et al.* (2014)
		Scirpus tabernaemontani P.	Culture soln.	8 mg L^{-1}	15 d	Growth rate	Decrease	Wang *et al.* (2015)
		T. latifolia L.	Petri-plate	30 mg L^{-1}	7 d	Radicle length Coleoptile	Decrease Increase	Moore and Locke (2012)
		Z. mays L. Giza 2	Soil	1.79 Kg ha^{-1}	8 d	Shoot fr. wt. Shoot dr. wt.	Decrease Decrease	Alla and Hassan (2006)
		Z. mays L. Hybrid 351	Soil	1.79 Kg ha^{-1}	8 d	Shoot fr. wt. Shoot dr. wt.	Decrease Decrease	
	Prometryne	*T. aestivum* L.	Soil	12 mg Kg^{-1}	10 d	Shoot length Root length Shoot dr. wt. Root dr. wt.	Decrease Decrease Decrease Decrease	Jiang and Yang (2009)
Triazinone	Metribuzin	*T. aestivum* L.	Hoagland medium	1 Kg ha^{-1}	16 d	Shoot fr. wt. Shoot dr. wt.	Decrease Decrease	Alla *et al.* (2008)
		Z. mays L.	Hoagland medium	1 Kg ha^{-1}	16 d	Shoot fr. wt. Shoot dr. wt.	Decrease Decrease	
Triazolopyrimidine	Metosulam	*Vicia faba* L.	Seedling's root	10^{-4} %	24 h	Seedling fr. wt. Seedling dr. wt.	Decrease Decrease	Badr *et al.* (2013)

Type of pesticide (www.alanwood.net/pesticides/)	Pesticide name	Plant name	Mode of application	Concentration applied	Time after treatment	Effect of pesticide on growth parameters		Reference
						Parameter	Effect	
			immersing					
Urea	Bensulfuron-methyl	*C. demersum* L.	Culture soln.	0.1 mg L^{-1}	21 d	Fresh weight	Decrease	Huiyun *et al*. (2009)
		Elodea nuttallii P.	Culture soln.	0.5 mg L^{-1}	21 d	Fresh weight	Decrease	
		O. sativa L.	Culture solution	0.96 µM L^{-1}	10 d	Shoot fr. wt. Root fr. wt.	Decrease Decrease	Huang and Xiong (2009)
	Chlorimuron-ethyl	*T. aestivum* L.	Hoagland medium	20 g ha^{-1}	16 d	Shoot fr. wt. Shoot dr. wt.	Decrease Decrease	Alla *et al*. (2008)
		Z. mays L.	Hoagland medium	20 g ha^{-1}	16 d	Shoot fr. wt. Shoot dr. wt.	Decrease Decrease	
	Chlorotoluron	*T. aestivum* L.	Soil	25 mg Kg^{-1}	10 d	Shoot length Root length Biomass	Decrease Decrease Decrease	Song *et al*. (2007)
	Isoproturon	*P. sativum* L.	Sand	10 mM	15 d	Root length Shoot length Fresh weight Dry weight	Decrease Decrease Decrease Decrease	Singh *et al*. (2016)
		T. aestivum L.	Soil	4 mg Kg^{-1}	10 d	Shoot length Root length Shoot dr. wt. Root dr. wt.	Decrease Decrease Decrease Decrease	Liang *et al*. (2012)
		T. aestivum	Soil	2.5 L ha^{-1}	15 d	Shoot length Shoot fr. wt. Shoot dr. wt.	Decrease Decrease Decrease	Alla and Hassan, (2014)
		T. aestivum L.	Soil	10 mg Kg^{-1}	10 d	Shoot length Shoot dr. wt.	Decrease Decrease	Yin *et al*. (2008)

Table 2.3.2 Effects of pesticide application on pigment system in plants.

Type of pesticide (www.alanwood.net/ pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on pigment content		Reference
							Pigment name	Effect	
Amide	Acetochlor	*Vitis vinifera* L. × *Vitis labrusca* L.	Soil	22460 g ai ha^{-1}	30 d	Leaves (upper node)	Chlorophyll Carotenoid	Decrease Decrease	Tan *et al.* (2012)
	Alachor	*Lactuca sativa* L.	Hoagland medium	2 µM	24 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Stajner *et al.* (2003)
		Phaseolus vulgaris L.	Hoagland medium	2 µM	24 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	
		Pisum sativum L.	Hoagland medium	2 µM	24 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	
	Butachlor	*Ceratophyllum demersum* L.	Culture soln.	0.5 mg L^{-1}	21 d	Leaves	Chlorophyll	Decrease	Huiyun *et al.* (2009)
		Vallisneria natans H.	Culture soln.	0.05 mg L^{-1}	21 d	Leaves	Chlorophyll	Decrease	
	Metolachor	*L. sativa* L.	Hoagland medium	2 µM	24 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Stajner *et al.* (2003)
		P. sativum L.	Hoagland medium	2 µM	24 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	
		P. vulgaris L.	Hoagland medium	2 µM	24 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	
Aromatic acid	Quinclorac	*C. demersum* L.	Culture soln.	1 mg L^{-1}	21 d	Leaves	Chlorophyll	Decrease	Huiyun *et al.* (2009)
Diamide	Chlorantraniliprole	*Zea mays* L.	Seed	0.5 ppm	7 d	Leaves	Chlorophyll Carotenoid Anthocyanin	Decrease Decrease Increase	Kilic *et al.* (2015)
Dicarboximide	Flumioxazin	*V. vinifera* L.	Soil	5 mM	25 d	Leaves	Chlorophyll	Decrease	Bigot *et al.* (2007)
Dinitroaniline	Pendimethalin	*Foeniculum vulgare* M.	Soil	8.5 mg L^{-1}	84 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	El-Awadi and Hassan *et al.* 2011
		Vigna mungo L. var. Shekhar	soil	10 ppm	15 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Singh *et al.* (2012)
Diphenyl	Fluoroglycofen	*V. vinifera* L. × *V. labrusca* L.	Soil	375 g ai ha^{-1}	30 d	Leaves (upper node)	Chlorophyll Carotenoid	Decrease Decrease	Tan *et al.*, (2012)
		V. vinifera L. × *V. labrusca* L.	Sand	187.5 g ai ha^{-1}	60 d	Leaves (upper node)	Chlorophyll Carotenoid	Decrease Increase	Tan *et al.*, (2014)
Imidazolinone	Imazapic	*Nicotiana tabacum* L.	Spray	0.12 mM	9 d	Leaves	Chlorophyll Carotenoid	No change Increase	Kaya and Doganlar (2016)

Type of pesticide (www.alanwood.net/ pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on pigment content		Reference
							Pigment name	Effect	
Neonicotinoid	Imidacloprid	*Brassica juncea* L.	Soil	350 mg Kg^{-1}	60 d	Leaves	Chlorophyll Carotenoid Anthocyanin Xanthophyll	Decrease Increase Increase Increase	Sharma *et al.* (2016b)
		Oryza sativa L.	Sand	0.02%	12 d	Seedlings	Chlorophyll	Decrease	Sharma *et al.* (2013)
Organophosphorus	Chlorpyrifos	*O. sativa* L.	Sand	0.06%	12 d	Seedlings	Chlorophyll	Decrease	Sharma *et al.* (2012)
	Dimethoate	*Vigna radiata* L.	Culture soln.	150 ppm	4 d	Leaves	Chlorophyll	Decrease	Singh *et al.* (2014)
	Glyphosate	*Bolboschoenus maritimus* L.	Hoagland medium	30 mg L^{-1}	20 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Mateos-Naranjo and Perez-Martin (2013)
		Glycine max L. var. RR1	Spray	2400 g ai ha^{-1}	32 d	Leaves	Chlorophyll	Decrease	Zobiole *et al.* (2011)
		Z. mays L. var. Kneza-640	Spray	10 mM	10 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Sergiev *et al.* (2006)
Phenoxy	Fluazifop-p-butyl	*Z. mays* L. convar. Saccharata	Seedling immersing	$6.5{\times}10^{-5}$ M	7 d	Leaves	Chlorophyll Carotenoid Anthocyanin	Decrease Decrease Increase	Horbowicz *et al.* (2013)
	Fusilade	*Arachis hypogaea* L.	Spray	60 ppm	14 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Fayez *et al.* (2014)
	Quizalofop-*p*-ethyl	*G. max* L.	Seed	0.8 M	5 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Aksoy *et al.* (2013)
		Helianthus annuus L.	Spray	0.8 mM	15 d	Leaves	Chlorophyll Carotenoid	Increase Decrease	Bayram *et al.* (2015)
Pyridine	Fluroxypyr	*O. sativa* L.	Culture soln.	0.8 mg L^{-1}	6	Leaves	Chlorophyll	Decrease	Wu *et al.* (2010)
Triazine	Atrazine	*Acorus calamus* L.	Culture soln.	8 mg L^{-1}	15 d	Leaves	Chlorophyll	Decrease	Wang *et al.* (2015)
		C. demersum L.	Culture soln.	0.5 mg L^{-1}	21 d	Leaves	Chlorophyll	Decrease	Huiyun *et al.* (2009)
		Iris pseudacorus L.	Culture soln.	32 mg L^{-1}	35 d	Leaves	Chlorophyll	Decrease	Wang *et al.* (2014)
		Lythrum salicaria L.	Culture soln.	8 mg L^{-1}	15 d	Leaves	Chlorophyll	Decrease	Wang *et al.* (2015)
		O. sativa L.	Hoagland medium	0.4 mg L^{-1}	6 d	Leaves	Chlorophyll	Decrease	Zhang *et al.* (2014)
		Scirpus	Culture	8 mg L^{-1}	15 d	Leaves	Chlorophyll	Decrease	Wang *et al.*

Type of pesticide (www.alanwood.net/ pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on pigment content		Reference
							Pigment name	Effect	
		tabernaemontani P.	soln.						(2015)
		V. natans H.	Culture soln.	0.05 mg L^{-1}	21 d	Leaves	Chlorophyll	Decrease	Huiyun *et al.* (2009)
		V. faba L.	Spray	1.79 Kg ai ha^{-1}	12 d	Leaves	Chlorophyll	Decrease	Hassan and Alla (2005)
		Z. mays L.	Spray	1.79 Kg ai ha^{-1}	12 d	Leaves	Chlorophyll	Decrease	Hassan and Alla (2005)
	Prometryn	*T. aestivum* L.	Soil	12 mg Kg^{-1}	10 d	Leaves	Chlorophyll	Decrease	Jiang and Yang (2009)
Triazolopyrimidine	Metosulam	*V. faba* L.	Seedling's root immersing	10^{-4} %	24 h	Leaves	Chlorophyll Carotenoid	Increase Decrease	Badr *et al.* (2013)
Urea	Bensulfuron-methyl	*C. demersum* L.	Culture soln.	0.1 mg L^{-1}	21 d	Leaves	Chlorophyll	Decrease	Huiyun *et al.* (2009)
		Elodea nuttallii P.	Culture soln.	0.5 mg L^{-1}	21 d	Leaves	Chlorophyll	Decrease	
		V. natans H.	Culture soln.	0.05 mg L^{-1}	21 d	Leaves	Chlorophyll	Decrease	
	Chlorimuron-ethyl	*T. aestivum* L.	Soil	300 µg Kg^{-1}	24 h	Leaves	Chlorophyll	Decrease	Wang and Zhou (2006)
	Chlorotoluron	*T. aestivum* L.	Soil	25 mg Kg^{-1}	10 d	Leaves	Chlorophyll	Decrease	Song *et al.* (2007)
	Diuron	*G. max* L. var. Clark	Soil	2 ppm	7 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Fayez (2000)
		G. max L. var. Crawford	Soil	2 ppm	7 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	
	Fluometuron	*V. faba* L.	Spray	2.98 Kg ai ha^{-1}	12 d	Leaves	Chlorophyll	Decrease	Hassan and Alla (2005)
		Z. mays L.	Spray	2.98 Kg ai ha^{-1}	12 d	Leaves	Chlorophyll	Decrease	
	Isoproturon	*P. sativum* L.	Sand	10 mM	15 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Singh *et al.* (2016)
		T. aestivum L.	Soil	2.5 L ha^{-1}	15 d	Shoot	Chlorophyll Carotenoid Anthocyanin	Decrease Decrease Decrease	Alla and Hassan, (2014)
				4 mg Kg^{-1}	10 d	Leaves	Chlorophyll	Decrease	Liang *et al.* (2012)
				10 mg Kg^{-1}	10 d	Leaves	Chlorophyll	Decrease	Yin *et al.* (2008)
	Rimsulfuron	*V. faba* L.	Spray	0.015 Kg ai ha^{-1}	12 d	Leaves	Chlorophyll	Decrease	Hassan and Alla (2005)

Type of pesticide (www.alanwood.net/ pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on pigment content		Reference
							Pigment name	Effect	
		Z. mays L.	Spray	0.015 Kg ai ha^{-1}	12 d	Leaves	Chlorophyll	Decrease	
Unclassified	Clomazone	*Hordeum vulgare* L.	Petri-plates	0.5 mM	12 d	Leaves	Chlorophyll Carotenoid	Decrease Decrease	Kaňa *et al*. (2004)
	Flurochloridone	*H. annuus* L.	Spray	11 mM	15 d	Leaves	Chlorophyll Carotenoid	Decrease No change	Kaya and Yigit (2014)

Table 2.3.3 Effects of pesticide on gaseous exchange parameters in plants.

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on gaseous exchange parameters		Reference
							Parameter	Effect	
Amide	Acetochlor	*Vitis vinifera* L. × *Vitis labrusca* L.	Soil	22460 g ai ha^{-1}	30 d	Leaves (upper node)	Pn Gs ΦPSII	Decrease Decrease Decrease	Tan *et al*. (2012)
Conazole	Flusilazole	*Cucumis sativus* L.	Spray	0.04 g L^{-1}	24 h	Leaves	Pn Gs Ci ΦPSII qP NPQ	Increase Decrease Decrease Decrease Increase Increase	Xia *et al*. (2006)
Copper	Cuproxat	*C. sativus* L.	Spray	0.54 g L^{-1}	24 h	Leaves	Pn Gs Ci ΦPSII qP NPQ	Decrease Decrease Decrease Increase Increase Increase	Xia *et al*. (2006)
Dicarboximide	Flumioxazin	*Vitis vinifera* L.	Soil	5 mM	10 d	Leaves	Pn Gs Et ΦPSII Fv/Fm NPQ qP qNP	Decrease Decrease Decrease Decrease Decrease Decrease Decrease Decrease	Bigot *et al*. (2007)
Diphenyl	Fluoroglycofen	*V. vinifera* L. × *V. labrusca* L.	Soil	375 g ai ha^{-1}	30 d	Leaves (upper node)	Pn Gs ΦPSII	Decrease Decrease Decrease	Tan *et al*. (2012)
			Sand	187.5 g ai ha^{-1}	60 d	Leaves (upper node)	Pn Gs	Decrease Decrease	Tan *et al*. (2014)
Imidazole	Cyazofamid	*C. sativus* L.	Spray	0.22 g L^{-1}	24 h	Leaves	Pn Gs Ci ΦPSII qP NPQ	Decrease Decrease Increase Decrease Decrease Increase	Xia *et al*. (2006)
Macrocyclic lactone	Abamectin	*C. sativus* L.	Spray	0.005 g L^{-1}	24 h	Leaves	Pn Gs Ci ΦPSII qP NPQ	Decrease Decrease Decrease Decrease Increase Increase	Xia *et al*. (2006)
Neonicotinoid	Imidacloprid	*Brassica juncea* L.	Soil	350 mg Kg^{-1}	60 d	Leaves	Pn Gs Ci	Decrease Decrease Decrease	Sharma *et al*. (2016b)

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on gaseous exchange parameters		Reference
							Parameter	Effect	
							Et	Decrease	
		C. sativus L.	Spray	0.02 g L^{-1}	24 h	Leaves	Pn Gs Ci ΦPSII qP NPQ	Decrease Decrease Increase Decrease Increase Increase	Xia *et al.* (2006)
Organophosphorus	Chlorpyrifos	*Acorus calamus* L.	Hoagland medium	16 mg L^{-1}	10 d	Leaves	ΦPSII Fv/Fm Fo qP	Decrease Decrease Increase Decrease	Wang *et al.* (2016)
		C. sativus L.	Spray	0.48 g L^{-1}	24 h	Leaves	Pn Gs Ci ΦPSII qP NPQ	Decrease Decrease Increase Decrease Decrease Increase	Xia *et al.* (2006)
	Dimethoate	*Vigna radiata* L.	Culture soln.	150 ppm	4 d	Leaves	Fv/Fm qP NPQ	Decrease Decrease Increase	Singh *et al.* (2014)
	Glyphosate	*Bolboschoenus maritimus* L.	Hoagland medium	30 mg L^{-1}	20 d	Leaves	Pn Gs Ci ΦPSII Fv/Fm NPQ	Decrease Decrease Increase Decrease Decrease Increase	Mateos-Naranjo and Perez-Martin (2013)
Phenoxy	Fluazifop-*p*-butyl	*C. sativus* L.	Spray	0.20 g L^{-1}	24 h	Leaves	Pn Gs Ci ΦPSII qP NPQ	Decrease Decrease Increase Decrease Decrease Increase	Xia *et al.* (2006)
	Haloxyfop	*C. sativus* L.	Spray	0.14 g L^{-1}	24 h	Leaves	Pn Gs Ci ΦPSII qP NPQ	Decrease Decrease Decrease Decrease Decrease Decrease	
Quaternary ammonium	Paraquat	*C. sativus* L.	Spray	2.76 g L^{-1}	24 h	Leaves	Pn Gs Ci ΦPSII qP NPQ	Decrease Decrease Increase Decrease Decrease Decrease	Xia *et al.* (2006)
Triazine	Atrazine	*Iris pseudacorus* L.	Culture soln.	32 mg L^{-1}	35 d	Leaves	Fo Fm	Increase Decrease	Wang *et al.* (2014)

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on gaseous exchange parameters		Reference
							Parameter	Effect	
							Fv/Fm	Decrease	
	Terbuthylazine	*Olea europaea* L.	Soil	3 Kg ha^{-1}	60 d	Leaves	Pn Gs Ci Fv/Fm NPQ	Decrease Increase Increase Decrease Decrease Decrease	Canero *et al*. (2011)
Unclassified	Clomazone	*Hordeum vulgare* L.	Petri-plates	0.5 mM	12 d	Leaves	Fv/Fm	Decrease	Kaňa *et al*. (2004)

Net photosynthetic rate (Pn), stomatal conductance (Gs), inter-cellular CO_2 (Ci), transpiration rate (Et), efficiency of Photosystem II (ΦPSII), maximum quantum efficiency of photosystem II (Fv/Fm), *Non-photochemical quenching* (NPQ).

Table 2.3.4 Effect of pesticides on protein content in plants.

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on protein content	Reference
Amide	Acetochlor	*Oryza sativa* L.	Culture solution	3.2 µM L^{-1}	10 d	Shoot	Decrease	Huang and Xiong (2009)
	Butachlor	*Triticum aestivum* L.	Hoagland medium	3 L ha^{-1}	16 d	Shoot	Decrease	Alla *et al*. (2008)
		Zea mays L.	Hoagland medium	3 L ha^{-1}	16 d	Shoot	Decrease	
	Metosulam	*Vicia faba* L.	Seedling's root immersing	10^{-4} %	24 h	Leaves Stems Roots	Decrease Decrease Decrease	Badr *et al*. (2013)
Cyclohexene oxime	Clethodim	*Z. mays* L.	Soil	200 ppm	21 d	Leaves	Increase	Radwan (2012)
Dinitroaniline	Pendimethalin	*Foeniculum vulgare* L.	Soil	8.5 mg L^{-1}	84 d	Leaves	Decrease	El-Awadi and Hassan (2011)
		Vigna mungo L. var. Shekhar	Soil	10 ppm	15 d	Leaves	Decrease	Singh *et al*. (2012)
		Z. mays L.	Hoagland medium	10 ppm	15 d	Shoot-root axis	Decrease	Rajashekar *et al*. (2012)
Neonicotinoid	Imidacloprid	*O. Sativa* L.	Sand	0.015%	12 d	Seedling	Decrease	Sharma *et al*. (2015)
				0.020%	12 d	seedling	Decrease	Sharma *et al*. (2013)
Organochlorine	DDT	*Glycine max* L.	Soil	63.5 ng g^{-1}	60 d	Root Leaf	Decrease Decrease	Mitton *et al*. (2016)
		Medicago sativa L.	Soil	63.5 ng g^{-1}	60 d	Root Leaf	Decrease Increase	
Organophosphorus	Chlorpyrifos	*Vigna radiata* L.	Spray	15 mM	10 d	Leaves	Decrease	Parween *et al*. (2011)
		O. Sativa L.	Sand	0.04%	12 d	Seedling	Decrease	Sharma *et al*. (2015)

				0.06%	12 d	Seedling	Decrease	Sharma *et al*. (2012)
Triazinone	Metribuzin	*T. aestivum* L.	Hoagland medium	1 Kg ha^{-1}	16 d	Shoot	Decrease	Alla *et al*. (2008)
		Z. mays L.	Hoagland medium	1 Kg ha^{-1}	16 d	Shoot	Decrease	
Urea	Bensulfuron-methyl	*O. sativa* L.	Culture solution	0.96 µM L^{-1}	10 d	Shoot	Decrease	Huang and Xiong (2009)
	Chlorimuron-ethyl	*T. aestivum* L.	Hoagland medium	20 g ha^{-1}	16 d	Shoot	Decrease	Alla *et al*. (2008)
			Soil	300 µg Kg^{-1}	24 h	Leaves	Decrease	Wang and Zhou (2006)
			Soil	300 µg Kg^{-1}	24 h	Roots	Decrease	Wang and Zhou (2006)
		Z. mays L.	Hoagland medium	20 g ha^{-1}	16 d	Shoot	Decrease	Alla *et al*. (2008)
	Diuron	*G. max* L. var. Clark	Soil	2 ppm	7 d	Leaves	Increase	Fayez (2000)
		G. max L. var. Crawford	Soil	2 ppm	7 d	Leaves	Increase	
	Isoproturon	*Pisum sativum* L.	Sand	10 mM	15 d	Leaves	Decrease	Singh *et al*. (2016)
		T. aestivum L.	Spray	1 Kg ha^{-1}	15 d	Leaves	Decrease	Sing *et al*. (2013)

Table 2.3.5 Effects of pesticides on oxidative stress markers in plants as a consequence of toxicity.

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part	Effect of pesticide on oxidative stress markers		Reference
							Parameter	Effect	
Amide	Acetochlor	*Vitis vinifera* L. × *Vitis labrusca* L.	Soil	22460 g ai ha^{-1}	30 d	Leaves (upper node)	$O\cdot\square_2$ MDA	Increase Increase	Tan *et al*. (2012)
	Napropamide	*Brassica napus* L.	Seedling	8 mg L^{-1}	5 d	Leaves	TBARS	Increase	Cui *et al*. (2010)
						Roots	TBARS	Increase	
	Rac-metolachlor	*Oryza sativa* L.	Culture solution	6.2 µM L^{-1}	5 d	Roots	MDA	Increase	Liu *et al*. (2012)
		Zea mays L.	Culture solution	74.4 µM L^{-1}	5 d	Roots	MDA	Increase	
	S- metolachlor	*O. sativa* L.	Culture solution	6.2 µM L^{-1}	5 d	Roots	MDA	Increase	
		Z. mays L.	Culture solution	74.4 µM L^{-1}	5 d	Roots	MDA	Increase	
Cyclohexene oxime	Clethodim	*Z. mays* L.	Soil	200 ppm	21 d	Leaves	H_2O_2 MDA	Increase Increase	Radwan (2012)
Dinitroaniline	Pendimethalin	*Vigna mungo* L. var. Shekhar	Soil	10 ppm	15 d	Leaves	MDA	Decrease	Singh *et al*. (2012)
Diphenyl ether	Fluoroglycofen	*V. vinifera* L. × *V. labrusca* L.	Soil	375 g ai ha^{-1}	30 d	Leaves (upper node)	$O\cdot\square_2$ MDA	Increase Increase	Tan *et al*. (2012)
Imidazolinone	Imazapic	*Nicotiana tabacum* L.	Spray	0.12 mM	9 d	Leaves	MDA	Increase	Kaya and Doganlar (2016)
	R (-)-imazethapyr	*Arabidopsis thaliana* L.	Culture solution	2.5 µg L^{-1}	28 d	Plantlets	$O\cdot\square_2$ H_2O_2 MDA	Increase Increase Increase	Qian *et al*. (2011)
	S (+)-imazethapyr	*A. thaliana* L.	Culture solution	2.5 µg L^{-1}	28 d	Plantlets	$O\cdot\square_2$ H_2O_2 MDA	Increase Increase No change	
Neonicotinoid	Imidacloprid	*Oryza sativa* L.	Sand	0.015%	12 d	Seedlings	$O\cdot\square_2$ H_2O_2 MDA	Increase Increase Increase	Sharma *et al*. (2015)
				0.02%	12 d	Seedlings	MDA	Increase	Sharma *et al*. (2013)
Organophosphorus	Chlorpyrifos	*O. sativa* L.	Sand	0.04%	12 d	Seedlings	$O\cdot\square_2$ H_2O_2 MDA	Increase Increase Increase	Sharma *et al*. (2015)
				0.06%	12 d	Seedlings	MDA	Increase	Sharma *et al*. (2012)
		Vigna radiata L.	Spray	15 mM	10 d	Leaves	TBARS	Increase	Parween *et al*. (2012)
	Dimethoate	*V. radiata* L.	Culture soln.	150 ppm	4 d	Leaves	$O\cdot\square_2$ H_2O_2 MDA OH^-	Increase Increase Increase Increase	Singh *et al*. (2014)

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part	Effect of pesticide on oxidative stress markers		Reference
							Parameter	Effect	
	Glyphosate	*Glycine max* L. var. DM48	Spray	0.94 %	24 h	Leaves	MDA	Increase	Moldes *et al*. (2008)
						Roots	MDA	Increase	
		G. max L. var. DM4800RG	Spray	0.94 %	24 h	Leaves	MDA	Increase	
						Roots	MDA	Decrease	
		G. max L. var. MSOY7501	Spray	0.94 %	24 h	Leaves	MDA	Increase	
						Roots	MDA	Increase	
		G. max L. var. MSOY7575RR	Spray	0.94 %	24 h	Leaves	MDA	Increase	
						Roots	MDA	Increase	
		Z. mays L. var. Kneza-640	Spray	10 mM	10 d	Leaves	H_2O_2 MDA Electrolyte leakage	Increase Increase Increase	Sergiev *et al*. (2006)
Phenoxy	Clodinafop-propargyl	*Secale cereale* L.	Spray	800 µg L^{-1}	7 d	Leaf	O·□$_2$	Increase	Lukatkin *et al*. 2013
		Triticum aestivum L.	Spray	800 µg L^{-1}	7 d	Leaf	O·□$_2$	Increase	
		Z. mays L.	Spray	800 µg L^{-1}	7 d	Leaf	O·□$_2$	Increase	
	Fluazifop-*P*-butyl	*Acanthospermum hispidum* DC.	Shoot immersing	10 µM	24 h	Leaves	MDA	Increase	Luo et *al*. (2004)
		Avena sativa L.	Shoot immersing	10 µM	24 h	Leaves	MDA	Increase	
	Fusilade	*Arachis hypogaea* L.	Spray	60 ppm	14 d	Leaves	H_2O_2 MDA	Increase Increase	Fayez *et al*. (2014)
	Quizalofop-*p*-ethyl	*Helianthus. annuus* L.	Spray	0.8 mM	15 d	Leaves	MDA	Increase	Bayram *et al*. (2015)
	R-diclofop-methyl	*A. thaliana* L.	Culture medium	1 mg L^{-1}	28 d	Plantlets	MDA	Increase	Zhang *et al*. (2012)
	S-diclofop-methyl	*A. thaliana* L.	Culture medium	1 mg L^{-1}	28 d	Plantlets	MDA	Increase	
Pyrethroid	Deltamethrin	*G. max* L. Merr.	Spray	0.20 %	10 d	Leaves	MDA	Increase	Bashir *et al*. (2007)
Pyridine	Fluroxypyr	*O. sativa* L.	Culture soln.	0.8 mg L^{-1}	6 d	Leaves	O·□$_2$ H_2O_2 MDA	Increase Increase Increase	Wu *et al*. (2010)
Quaternary ammonium	Paraquat	*Papaver somniferum* L.	Spray	0.48 %	24 h	Leaves	MDA Electrolyte leakage	Increase Increase	Zhao *et al*. (2010)
Triazine	Atrazine	*Acorus calamus* L.	Culture soln.	8 mg L^{-1}	15 d	Leaves	MDA	Increase	Wang *et al*. (2015)
		Lythrum salicaria L.	Culture soln.	8 mg L^{-1}	15 d	Leaves	MDA	Increase	
		O. sativa L.	Hoagland medium	0.4 mg L^{-1}	6 d	Leaves	O·□$_2$ H_2O_2 TBARS	Increase Increase Increase	Zhang *et al*. (2014)
		Pennisetum americanum L.	Soil	10 mg Kg^{-1}	38 d	Shoot	MDA	Increase	Jiang *et al*. (2016)
						Root	MDA	Increase	
		Scirpus tabernaemontani	Culture soln.	8 mg L^{-1}	15 d	Leaves	MDA	Increase	Wang *et al*. (2015)

Type of pesticide (www.alanwood.net /pesticides/)	**Pesticide name**	**Plant name**	**Mode of application**	**Concentration of pesticide**	**Time after treatment**	**Plant part**	**Effect of pesticide on oxidative stress markers**		**Reference**
							Parameter	**Effect**	
		P.							
		Vicia faba L.	Spray	1.79 Kg ai ha^{-1}	12 d	Shoot	H_2O_2 MDA C=O	Increase Increase Increase	Hassan and Alla (2005)
		Z. mays L.	Spray	1.79 Kg ai ha^{-1}	12 d	Shoot	H_2O_2 MDA C=O	Increase Increase Increase	
				78 mM	5 d	Leaves	MDA	Increase	Akbulut and Yigit (2010)
			Hoagland medium	10 mg L^{-1}	3 d	Shoot	MDA	No change	Li *et al*. (2012)
						Root	MDA	Increase	
		Z. mays L. Hybrid 351	Soil	1.79 Kg ha^{-1}	8 d	Shoot	H_2O_2 MDA C=O	Increase Increase Increase	Alla and Hassan (2006)
		Z. mays L. Giza 2	Soil	1.79 Kg ha^{-1}	8 d	Shoot	H_2O_2 MDA C=O	Increase Increase Increase	
	Prometryne	*T. aestivum* L.	Soil	12 mg Kg^{-1}	10 d	Leaves	TBARS	Increase	Jiang and Yang (2009)
						Roots	TBARS	Increase	
Urea	Chlorotoluron	*T. aestivum* L.	Soil	25 mg Kg^{-1}	10 d	Leaves	O·□$_2$ H_2O_2 TBARS	Increase Increase Increase	Song *et al*. (2007)
	Chlorimuron-ethyl	*T. aestivum* L.	Soil	300 µg Kg^{-1}	24 h	Leaves	MDA	Increase	Wang and Zhou (2006)
						Roots	MDA	Increase	
	Fluometuron	*V. faba* L.	Spray	2.98 Kg ai ha^{-1}	12 d	Shoot	H_2O_2 MDA C=O	Increase Increase Increase	Hassan and Alla (2005)
		Z. mays L.	Spray	2.98 Kg ai ha^{-1}	12 d	Shoot	H_2O_2 MDA C=O	Increase Increase Increase	
	Granstar	*Avena fatua* L.	Spray	300 µg L^{-1}	3 d	Leaves	O·□$_2$ MDA	Increase Increase	Gar'kova *et al*. (2011)
		Secale cereale L.	Spray	300 µg L^{-1}	3 d	Leaves	O·□$_2$ MDA	Increase Increase	
			Leaf disk immersing	300 µg L^{-1}	3 h	Leaves	O·□$_2$	Increase	
		T. aestivum L.	Leaf disk immersing	300 µg L^{-1}	3 h	Leaves	O·□$_2$	Increase	
			Spray	300 µg L^{-1}	3 d	Leaves	O·□$_2$ MDA	Increase Increase	
		Z. mays L.	Leaf disk immersing	300 µg L^{-1}	3 h	Leaves	O·□$_2$	Increase	
			Spray	300 µg L^{-1}	3 d	Leaves	O·□$_2$ MDA	Increase Increase	
	Isoproturon	*P. sativum* L.	Sand	10 mM	15 d	Leaves	H_2O_2	Increase	Singh *et al*. (2016)

Type of pesticide (www.alanwood.net /pesticides/)	**Pesticide name**	**Plant name**	**Mode of application**	**Concentration of pesticide**	**Time after treatment**	**Plant part**	**Effect of pesticide on oxidative stress markers**		**Reference**
							Parameter	**Effect**	
							MDA Electrolyte leakage	Increase Increase	
		T. aestivum L.	Soil	2.5 L ha^{-1}	15 d	Shoot	H_2O_2 MDA	Increase Increase	Alla and Hassan (2014)
				4 mg Kg^{-1}	10 d	Shoot	$O^{\cdot -}_2$ H_2O_2 TBARS	Increase Increase Increase	Liang *et al.* (2012)
						Roots	TBARS	Increase	
						Leaves	H_2O_2	Increase	
				10 mg Kg^{-1}	10 d	Leaves	TBARS	Increase	Yin *et al.* (2008)
						Roots	TBARS	No change	
	Rimsulfuron	*V. faba* L.	Spray	0.015 Kg ai ha^{-1}	12 d	Shoot	H_2O_2 MDA C=O	Increase Increase Increase	Hassan and Alla (2005)
		Z. mays L.	Spray	0.015 Kg ai ha^{-1}	12 d	Shoot	H_2O_2 MDA C=O	Increase Increase No change	
Unclassified	Dichlorobenzene	*Z. mays* L.	Hoagland medium	80 mg L^{-1}	7 d	Roots	H_2O_2	Increase	San Miguel *et al.* (2012)
						Leaves	H_2O_2	Decrease	
	Flurochloridone	*H. annuus* L.	Spray	11 mM	15 d	Leaves	MDA	Increase	Kaya and Yigit (2014)
	Monochlorobenzene	*Z. mays* L.	Hoagland medium	80 mg L^{-1}	7 d	Roots	H_2O_2	Increase	San Miguel *et al.* (2012)
						Leaves	H_2O_2	No change	
	Trichlorobenzene	*Z. mays* L.	Hoagland medium	40 mg L^{-1}	7 d	Roots	H_2O_2	Increase	
						Leaves	H_2O_2	Increase	

Table 2.3.6 Effect of pesticides on enzymatic antioxidants in plants.

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on enzymatic antioxidants: Parameter	Effect of pesticide on enzymatic antioxidants: Effect	Reference
Amide	Acetochlor	*Vitis vinifera* L. × *Vitis labrusca* L.	Soil	22460 g ai ha^{-1}	30 d	Leaves (upper node)	APOX CAT POD SOD	Decrease Decrease Decrease Decrease	Tan *et al*. (2012)
	Alachlor	*Lactuca sativa* L.	Hoagland medium	2 µM	24 d	Leaves	CAT POD SOD	Increase Increase Increase	Stajner *et al*. (2003)
		Phaseolus vulgaris L.	Hoagland medium	2 µM	24 d	Leaves	CAT POD SOD	Increase Increase Increase	
		Pisum sativum L.	Hoagland medium	2 µM	24 d	Leaves	CAT POD SOD	Increase Increase Increase	
	Fomesafen	*Glycine max* L. Merr.	Spray	1000 g ha^{-1}	2 d	Leaves	GST	Increase	Andrews *et al*. (2005)
	Metolachlor	*L. sativa* L.	Hoagland medium	2 µM	24 d	Leaves	CAT POD SOD	No change Decrease Increase	Stajner *et al*. (2003)
		P. vulgaris L.	Hoagland medium	2 µM	24 d	Leaves	CAT POD SOD	Increase Increase Increase	
		P. sativum L.	Hoagland medium	2 µM	24 d	Leaves	CAT POD SOD	Decrease Increase Increase	
	Metosulam	*Vicia faba* L.	Seedling's root immersing	10^{-4} %	24 h	Leaves	APOX CAT POD	Increase Increase Decrease	Badr *et al*. (2013)
	Napropamide	*Brassica napus* L.	Seedling	8 mg L^{-1}	5 d	Leaves	APOX CAT GST POD SOD	Increase Increase Increase Increase Increase	Cui *et al*. (2010)
	Rac-metolachlor	*Oryza. sativa* L.	Culture solution	6.2 µM L^{-1}	5 d	Roots	CAT POD	Decrease Decrease	Liu *et al*. (2012)
		Zea mays L.	Culture solution	74.4 µM L^{-1}	5 d	Roots	CAT POD SOD	Decrease Decrease Decrease	
	S- metolachlor	*O. sativa* L.	Culture solution	6.2 µM L^{-1}	5 d	Roots	CAT POD	Decrease Decrease	
		Z. mays L.	Culture solution	74.4 µM L^{-1}	5 d	Roots	CAT POD SOD	Decrease Decrease Decrease	

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on enzymatic antioxidants		Reference
							Parameter	Effect	
Cyclohexene oxime	Clethodim	*Z. mays* L.	Soil	200 ppm	21 d	Leaves	APOX CAT POD SOD	Increase Decrease Increase Decrease	Radwan (2012)
Diphenyl ether	Fluoroglycofen	*V. vinifera* L. × *V. labrusca* L.	Soil	375 g ai ha^{-1}	30 d	Leaves (upper node)	APOX CAT POD SOD	Decrease Decrease Decrease Decrease	Tan *et al*. (2012)
	Oxyfluorfen	*G. max* L. Merr.	Spray	2500 g ha^{-1}	2 d	Leaves	GST	Increase	Andrews *et al*. (2005)
Imidazolinone	Imazapic	*Nicotiana tabacum* L.	Spray	0.12 mM	9 d	Leaves	APOX CAT GR GST	Increase Increase Increase Increase	Kaya and Doganlar (2016)
	R (-)-imazethapyr	*Arabidopsis thaliana* L.	Culture solution	2.5 µg L^{-1}	28 d	Plantlets	APOX CAT GPOX SOD	Decrease Decrease Increase Decrease	Qian *et al*. (2011)
	S (+)-imazethapyr	*A. thaliana* L.	Culture solution	2.5 µg L^{-1}	28 d	Plantlets	APOX CAT GPOX SOD	Increase Decrease Increase Decrease	
Neonicotinoid	Imidacloprid	*Brassica juncea* L.	Soil	300 mg Kg^{-1}	65 d	Leaves	GR GST POD	Increase Increase Increase	Sharma *et al*. (2016c)
					80 d	Green pods	APOX GPOX GR GST POD	Increase Increase Increase Increase Increase	Sharma *et al*. (2016d)
		O. sativa L.	Sand	0.01%	12 d	Seedlings	APOX CAT DHAR GR MDHAR POD SOD	Increase Decrease Increase Increase Increase Decrease Increase	Sharma *et al*. (2013)
				0.015%	12 d	Seedlings	APOX CAT DHAR GR MDHAR POD SOD	Increase Increase Decrease Increase Increase Decrease Increase	Sharma *et al*. (2015)
Organochlorine	DDT	*G. max* L.	Soil	63.5 ng g^{-1}	60 d	Leaves Root	GST GST	Decrease Increase	Mitton *et al*. (2016)

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on enzymatic antioxidants		Reference
							Parameter	Effect	
		Medicago sativa L.	Soil	63.5 ng g^{-1}	60 d	Leaves Root	GST GST	Increase Increase	
Organophosphorus	Chlorpyrifos	*Vigna radiata* L.	Spray	15 mM	10 d	Leaves	APOX CAT GR SOD	Increase Decrease Increase Increase	Parween *et al*. (2012)
	Dimethoate	*V. radiata* L.	Culture soln.	30 ppm	4 d	Leaves	CAT DHAR GR SOD	Increase Increase Increase Increase	Singh *et al*. (2014)
				150 ppm	4 d	Leaves	CAT DHAR GR SOD	Decrease Decrease Decrease Increase	
	Glyphosate	*G. max* L. var. DM48	Spray	0.94 %	24 h	Leaves	APOX CAT POD	Increase Increase Increase	Moldes *et al*. (2008)
						Roots	APOX CAT POD	Increase Increase Decrease	
		G. max L. var. DM4800RG	Spray	0.94 %	24 h	Leaves	APOX CAT POD	Increase Decrease Increase	
						Roots	APOX CAT POD	Increase Decrease Increase	
		G. max L. var. MSOY7501	Spray	0.94 %	24 h	Leaves	APOX CAT POD	Increase Decrease Increase	
						Roots	APOX CAT POD	Increase Decrease Increase	
		G. max L. var. MSOY7575RR	Spray	0.94 %	24 h	Leaves	APOX CAT POD	Increase Increase Increase	
						Roots	APOX CAT POD	Increase Increase Increase	
		V. radiate L. var. PDM11	Seed	10 mM	12 d	Root	CAT GST POD	Increase Increase Increase	Basantani *et al*. (2011)
		V. radiate L. var. PDM54	Seed	10 mM	12 d	Root	CAT POD GST	Increase Increase Increase	
		Z. mays L. var. Kneza-640	Spray	10 mM	10 d	Leaves	CAT GST	Increase Increase	Sergiev *et al*. (2006)

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on enzymatic antioxidants		Reference
							Parameter	Effect	
							POD	Increase	
Phenoxy	Clodinafop-propargyl	*Secale cereale* L.	Spray	800 µg L^{-1}	7 d	Leaves	CAT APOX	Increase Increase	Lukatkin *et al.* 2013
		Triticum aestivum L.	Spray	800 µg L^{-1}	7 d	Leaves	CAT APOX	Increase Increase	
		Z. mays L.	Spray	800 µg L^{-1}	7 d	Leaves	CAT APOX	Increase Increase	
	Fenoxaprop-*p*-ethyl	*T. aestivum* L.	Spray	250 g ha^{-1}	15 d	Leaves	CAT POD	Increase Increase	Sing *et al.* (2013)
	Fusilade	*Arachis hypogaea* L.	Spray	60 ppm	14 d	Leaves	APOX CAT POD SOD	Increase Decrease Increase Decrease	Fayez *et al.* (2014)
	Haloxyfop-ethoxyethyl	*Triticum vulgare* L.	Drop on leaf	50 µM	12 h	Leaf	APOX CAT POD SOD	Increase Increase Increase Decrease	Janicka *et al.* (2008)
	Quizalofop-*p*-ethyl	*Helianthus annuus* L.	Spray	0.8 mM	15 d	Leaves	APOX POD	Increase Increase	Bayram *et al.* (2015)
	R-diclofop-methyl	*A. thaliana* L.	Culture medium	1 mg L^{-1}	28 d	Plantlets	CAT POD SOD	Decrease Increase Increase	Zhang *et al.* (2012)
	S-diclofop-methyl	*A. thaliana* L.	Culture medium	1 mg L^{-1}	28 d	Plantlets	CAT POD SOD	Increase Increase Decrease	
Pyrethroid	Deltamethrin	*G. max* L. Merr.	Spray	0.20 %	10 d	Leaves	APOX CAT GR SOD	Increase Decrease Increase Increase	Bashir *et al.* (2007)
Pyridine	Fluroxypyr	*O. sativa* L.	Culture soln.	0.8 mg L^{-1}	6 d	Leaves	APOX CAT POD SOD	No change Decrease Increase Increase	Wu *et al.* (2010)
Quaternary ammonium	Paraquat	*Papaver somniferum* L.	Spray	0.48 %	24 h	Leaves	CAT POD SOD	Increase Decrease Increase	Zhao *et al.* (2010)
Triazine	Atrazine	*Acorus calamus* L.	Culture soln.	8 mg L^{-1}	15 d	Leaves	POD	Increase	Wang *et al.* (2015)
		Lythrum salicaria L.	Culture soln.	8 mg L^{-1}	15 d	Leaves	POD	Decrease	
		O. sativa L.	Hoagland medium	0.4 mg L^{-1}	6 d	Leaves	APOX CAT GR GST POD SOD	Increase Increase Increase Increase Increase Increase	Zhang *et al.* (2014)
						Roots	APOX	Increase	

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on enzymatic antioxidants: Parameter	Effect of pesticide on enzymatic antioxidants: Effect	Reference
							CAT GR GST POD SOD	Increase Increase Decrease Increase Increase	
		Pennisetum americanum L.	Soil	10 mg Kg^{-1}	38 d	Shoot	APOX CAT POD SOD	Increase Increase Increase Increase	Jiang *et al*. (2016)
						Root	APOX CAT POD SOD	Increase Increase Increase Increase	
		Scirpus tabernaemontani P.	Culture soln.	8 mg L^{-1}	15 d	Leaves	POD	Decrease	Wang *et al*. (2015)
		V. faba L.	Spray	1.79 Kg ai ha^{-1}	12 d	Shoot	APOX CAT POD SOD	Decrease Decrease Decrease Decrease	Hassan and Alla (2005)
		Z. mays L.	Spray	1.79 Kg ai ha^{-1}	12 d	Shoot	APOX CAT POD SOD	Decrease Decrease Decrease Increase	
				78 mM	5 d	Leaves	APOX POD	Increase Increase	Akbulut and Yigit (2010)
			Hoagland medium	10 mg L^{-1}	3 d	Shoot	CAT POD SOD	Increase Increase Increase	Li *et al*. (2012)
						Root	CAT POD SOD	Increase Increase Increase	
		Z. mays L. Hybrid 351	Soil	1.79 Kg ha^{-1}	8 d	Shoot	APOX CAT POD GST SOD	Increase Decrease Decrease Increase Increase	Alla and Hassan (2006)
		Z. mays L. Giza 2	Soil	1.79 Kg ha^{-1}	8 d	Shoot	APOX CAT POD GST SOD	Decrease Decrease Decrease Decrease Decrease	
	Prometryn	*T. aestivum* L.	Soil	12 mg Kg^{-1}	10 d	Leaves	APOX CAT GST POD	Increase Increase Increase Increase	Jiang and Yang (2009)

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on enzymatic antioxidants		Reference
							Parameter	Effect	
							SOD	Increase	
						Root	APOX CAT GST POD SOD	Increase Increase Increase Increase Increase	
Urea	Chlorotoluron	*T. aestivum* L.	Soil	25 mg Kg^{-1}	10 d	Root	APOX CAT POD SOD	Increase Decrease Increase Increase	Song *et al*. (2007)
	Chlorimuron-ethyl	*T. aestivum* L.	Soil	300 µg Kg^{-1}	24 h	Leaves	POD	Increase	Wang and Zhou (2006)
						Roots	POD	Increase	
	Fluometuron	*Z. mays* L.	Spray	2.98 Kg ai ha^{-1}	12 d	Shoot	APOX CAT POD SOD	Decrease Decrease Decrease Decrease	Hassan and Alla (2005)
		V. faba L.	Spray	2.98 Kg ai ha^{-1}	12 d	Shoot	APOX CAT POD SOD	Decrease Decrease Decrease Decrease	
	Granstar	*S. cereale* L.	Leaf disk immersing	300 µg L^{-1}	3 h	Leaves	APOX CAT SOD	Increase Increase Increase	Gar'kova *et al*. (2011)
		T. aestivum L.	Leaf disk immersing	300 µg L^{-1}	3 h	Leaves	APOX CAT SOD	Increase Increase Increase	
		Z. mays L.	Leaf disk immersing	300 µg L^{-1}	3 h	Leaves	APOX CAT SOD	Increase Increase Increase	
	Isoproturon	*P. sativum* L.	Sand	10 mM	15 d	Leaves	APOX CAT GPOX SOD	Increase Increase Decrease Increase	Singh *et al*. (2016)
		T. aestivum L. .	Soil	2.5 L ha^{-1}	15 d	Shoot	APOX CAT SOD	Decrease Decrease Decrease	Alla and Hassan, (2014)
				4 mg Kg^{-1}	10 d	Shoot	APOX CAT GR GST POD SOD	Increase Decrease Increase Increase Increase Increase	Liang *et al*. (2012)
				4 mg Kg^{-1}	10 d	Roots	APOX CAT GR GST	Increase Decrease Increase Increase	

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on enzymatic antioxidants		Reference
							Parameter	Effect	
							POD SOD	Increase Increase	
				10 mg Kg^{-1}	10 d	Leaves	APOX CAT GST POD SOD	Increase Decrease Increase Increase Increase	Yin *et al*. (2008)
				10 mg Kg^{-1}	10 d	Root	APOX CAT GST POD SOD	Increase Increase Increase Increase Increase	
			Spray	1 Kg ha^{-1}	15 d	Leaves	CAT POD	Increase Increase	Sing *et al*. (2013)
	Rimsulfuron	*V. faba* L.	Spray	0.015 Kg ai ha^{-1}	12 d	Shoot	APOX CAT POD SOD	Increase Increase Increase Increase	Hassan and Alla (2005)
		Z. mays L.	Spray	0.015 Kg ai ha^{-1}	12 d	Shoot	APOX CAT POD SOD	Increase Increase Increase Increase	
	Sulfosulfuron	*T. aestivum* L.	Spray	800 g ha^{-1}	15 d	Leaves	CAT POD	Increase Increase	Sing *et al*. (2013)
Unclassified	Dichlorobenzene	*Z. mays* L.	Hoagland medium	80 mg L^{-1}	7 d	Roots	GR POD	Increase Decrease	San Miguel *et al.* (2012)
						Leaves	GR POD	Decrease Decrease	
	Flurochloridone	*H. annuus* L.	Spray	11 mM	15 d	Leaves	APOX CAT GR GST SOD	Decrease Decrease Increase Increase Increase	Kaya and Yigit (2014)
		V. sativa L.	Spray	32 mM	15 d	Leaves	GR GST	Increase Increase	Kaya and Yigit (2012)
	Monochlorobenzene	*Z. mays* L.	Hoagland medium	80 mg L^{-1}	7 d	Roots	GR POD	Increase Increase	San Miguel *et al.* (2012)
						Leaves	GR POD	Decrease Increase	
	Trichlorobenzene	*Z. mays* L.	Hoagland medium	40 mg L^{-1}	7 d	Roots	GR POD	Increase No change	
						Leaves	GR POD	Decrease No change	

Table 2.3.7 Effect of pesticides on non-enzymatic antioxidants in plants.

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on non-enzymatic antioxidants		Reference
							Parameter	Effect	
Amide	Fomesafen	*Glycine max* L. Merr.	Spray	1000 g ha^{-1}	2 d	Leaves	HGSH	Increase	Andrews *et al.* (2005)
	Metosulam	*Vicia faba* L.	Seedling's root immersing	10^{-4} %	24 h	Leaves	Proline	Increase	Badr *et al.* (2013)
						Stems	Proline	Increase	
						Roots	Proline	Increase	
Cyclohexene oxime	Clethodim	*Zea mays* L.	Soil	200 ppm	21 d	Leaves	Total phenolics	Increase	Radwan (2012)
Diamide	Chlorantraniliprole	*Z. mays* L.	Seed	0.5 ppm	7 d	Leaves	Proline	Increase	Kilic *et al.* (2015)
Dinitroaniline	Pendimethalin	*Foeniculum vulgare* L.	Soil	8.5 mg L^{-1}	84 d	Leaves	Total phenolics	Increase	El-Awadi and Hassan *et al.* 2011
Diphenyl ether	Oxyfluorfen	*G. max* L. Merr.	Spray	2500 g ha^{-1}	2 d	Leaves	HGSH	Increase	Andrews *et al.* (2005)
Imidazolinone	Imazapic	*Nicotiana tabacum* L.	Spray	0.12 mM	9 d	Leaves	GSH	Increase	Kaya and Doganlar (2016)
Neonicotinoid	Imidacloprid	*Brassica juncea* L.	Soil	300 mg Kg^{-1}	60 d	Leaves	Ascorbate GSH Tocopherol Polyphenols Total phenolics	Increase Increase Increase Increase Increase	Sharma *et al.* (2016a)
					65 d	Leaves	GSH	Increase	Sharma *et al.* (2016c)
					80 d	Green pods	GSH	Increase	Sharma *et al.* (2016d)
		Oryza sativa L.	Sand	0.02%	12 d	Seedling	Proline	Increase	Sharma *et al.* (2013)
				0.015%	12 d	Seedling	Proline	Increase	Sharma *et al.* (2015)
Organophosphorus	Chlorpyrifos	*O. sativa* L.	Sand	0.06%	12 d	Seedling	Proline	Increase	Sharma *et al.* (2012)
				0.04%	12 d	Seedling	Proline	Increase	Sharma *et al.* (2015)
		Vigna radiata L.	Spray	15 mM	10 d	Leaves	Proline Ascorbate GSH	Increase Decrease Increase	Parween *et al.* (2012)
	Dimethoate	*V. radiata* L.	Culture soln.	30 ppm	4 d	Leaves	GSH Ascorbate	Increase Increase	Singh *et al.* (2014)
				150 ppm	4 d	Leaves	GSH Ascorbate	Decrease Decrease	
	Glyphosate	*Z. mays* L. var. Kneza-640	Spray	10 mM	10 d	Leaves	Proline GSH	Increase Increase	Sergiev *et al.* (2006)

Type of pesticide (www.alanwood.net /pesticides/)	Pesticide name	Plant name	Mode of application	Concentration of pesticide	Time after treatment	Plant part analyzed	Effect of pesticide on non-enzymatic antioxidants		Reference
							Parameter	Effect	
Phenoxy	Fluzifop-*p*-butyl	*Arachis hypogaea* L. var. Giza 5	Spray	0.156 g L^{-1}	14 d	Leaves	Proline	Increase	Fayez *et al.* (2011)
	Quizalofop-*p*-ethyl	*Helianthus annuus* L.	Spray	0.8 mM	15 d	Leaves	Total phenolics	Increase	Bayram *et al.* (2015)
Pyrethroid	Deltamethrin	*G. max* L. Merr.	Spray	0.20 %	10 d	Leaves	Proline Ascorbate GSH	Increase Increase Increase	Bashir *et al.* (2007)
Pyridine	Fluroxypyr	*O. sativa* L.	Culture soln.	0.8 mg L^{-1}	6 d	Leaves	Proline	Increase	Wu *et al.* (2010)
Triazine	Atrazine	*Z. mays* L. Hybrid 351	Soil	1.79 Kg ha^{-1}	8 d	Shoot	GSH Ascorbate	Increase Increase	Alla and Hassan (2006)
		Z. mays L. Giza 2	Soil	1.79 Kg ha^{-1}	8 d	Shoot	GSH Ascorbate	Decrease Decrease	
Urea	Chlorotoluron	*Triticum aestivum* L.	Soil	25 mg Kg^{-1}	10 d	Leaves	Proline	Increase	Song *et al.* (2007)
	Diuron	*G. max* L. var. Clark	Soil	2 ppm	7 d	Leaves	Proline	Increase	Fayez (2000)
		G. max L. var. Crawford	Soil	2 ppm	7 d	Leaves	Proline	Increase	
	Isoproturon	*T. aestivum*	Soil	2.5 L ha^{-1}	15 d	Shoot	GSH	Decrease	Alla and Hassan (2014)
Unclassified	Bentazon	*A. hypogaea* L. var. Giza 6	Spray	1.6 g L^{-1}	14 d	Leaves	Proline	Increase	Fayez *et al.* (2011)
	Flurochloridone	*Vicia sativa* L.	Spray	32 mM	15 d	Leaves	GSH	Increase	Kaya and Yigit (2012)

2.4 Detoxification of pesticides in plants

Plants can detoxify chemical pesticides via three phase detoxification system as mentioned in Fig. 2.4.1 (Coleman *et al*., 1997; Cherian and Oliveira, 2005; Xia *et al*., 2009a). In the first phase the absorbed pesticides are metabolically activated with the help of enzymes like P450 monooxygenases, peroxidases and carboxylesterases. In the second phase enzymes glutathione-S-transferase (GST) and UDP-glycosyltransferase (UGT) help in conjugation of pesticides to glutathione and glucose respectively. In the third phase, sequestration and storage of less toxic metabolites takes place in the vacuoles/apoplast. Recent studies also confirmed the reduction of pesticide residues in cucumber, Indian mustard and tomato accompanied by the enhanced activities of pesticide detoxifying enzymes (Xia *et al*., 2009a; Zhou *et al*., 2015; Sharma *et al*., 2016c, d).

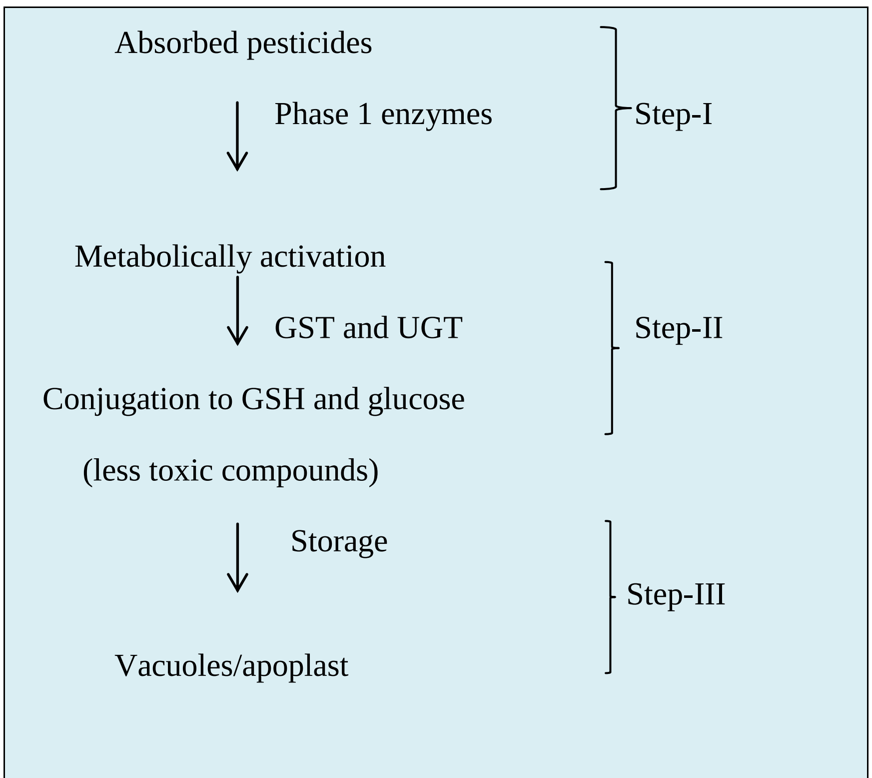

Fig. 2.4.1. Flow chart of three step pesticide detoxification system (Cherian and Oliveira, 2005; Coleman *et al*., 1997). Phase 1 enzymes = P450 monooxygenase, peroxidase and carboxylesterase, GST = glutathione-s-transferase, UGT = UDP-glycosyltransferase and GSH = glutathione.

Metabolic activation of pesticides takes place with the catalyst action of P450-monooxygenases or peroxidases. These important enzymes are supposed to exist in cellular membrane, cytosol and/or in apoplast (Morant *et al*., 2003; Passardi *et al*., 2005). Glutathione conjugation has also been suggested as key step in the degradation of chemical pesticides (Hatzios, 2001). Theodolou (2000) has suggested that third phase of pesticide detoxification involves two steps. First step involves transfer of less toxic pesticide metabolites into the vacuoles, followed by the second step which expels these metabolites out of the plant cells. Some studies has also reported the presence of pesticide residues in the gutation drops of plants grown from pesticide dressed seeds or in pesticide containing soils (Krischik *et al*., 2007; Girolami *et al*., 2009; Hoffmann and Castle, 2012). It has also been demonstrated that plant hydrolytic enzymes can help in pesticide degradation via hydrolytic reactions (Hoagland and Zablotowicz, 2001).

Pesticide metabolites are also supposed to be conjugated with water insoluble compounds like lignins, resulting in the formation of compounds which are non-extractable and are known as bounded residues (Sandermann *et al*., 2001). This prevents further reactivity and toxicity of pesticides due to the decreased water solubility of the pesticides. Metal chelators are also involved in reduction of pesticide toxicity. It has been reported that free movement of pesticides can be prevented by phytochelatins and metallothioneins due to the efficiency of cysteine to bind-up with pesticide molecules (Blum *et al*., 2010). It has been demonstrated that hexacyclochlorobenzene, an organochlorine pesticide, can be degraded by soil bacteria through enzymatic system involving the participation of *lin* genes (Boltner *et al*., 2005; Ceremonic *et al*., 2006). Genes encoding Esc enzyme in *Arthobacter* spp. are also reported to enhance the degradation of endosulfan pesticide (Weir *et al*., 2006). Moreover, use of rDNA technology has also been demonstrated by various researchers to enhance the pesticide degradation in plants. Introduction of laccase enzyme encoding genes of fungus *Coriolus versicolor* and organophosphorus hydrolase (OPH) encoding genes of bacteria into tobacco plant has been observed to enhance the degradation of pentachlorophenol and methyl parathion respectively (Sonoki *et al*., 2005; Wang *et al*., 2008). The ability of glyphosate oxidase (GOX) to detoxify glyphosate has been enhanced by genetic transfer of GOX encoding genes in plants (Scott *et al*., 2008).

Monooxygenases belong to two-component flavin-diffusible monooxygenase (TC-FDM) family, and are involved in pesticide degradation (Galan *et al*., 2000). Two important enzymes of Esc and Esd are involved in the degradation of pesticide endosulfan (Goebel *et al*., 1982; Sutherland *et al*., 2004). Scott *et al*. (2008) has also reported the pesticide degradation potential of cytochrome P450-oxidoreductase. Pesticides like atrazine, chlortoluron and norflurazon have also been observed to be degraded by the enzyme cytochrome P450-1A1 (CYP1A1) belonging to cytochrome P450 family (Yamada *et al*., 2002; Kawahigashi *et al*., 2005, 2007). Moreover, incorporation of genes encoding CYP1A1 enzyme into rice and potato has also been reported to degrade the pesticides like atrazine, chlortoluron and norflurazon (Kawahigashi *et al*., 2006).

2.5 Brassinosteroids and their role in pesticide detoxification

2.5.1 Brassinosteroids

Brassinosteroids (BRs) are novel class of plant polyhydroxysteroids which were discovered by Grove *et al*. (1979). These are distributed throughout the plant kingdom and are present in pollens, seeds, and young vegetative tissues at low levels (Clouse and Sasse, 1998; Bhardwaj *et al*., 2008; Kanwar *et al*., 2015). An active BR in crystalline form was isolated from the pollens of *Brassica napus* by Grove *et al*. (1979) and was called as brassinolide (BL). At present, more than 70 analogues of BRs have been reported from 66 different plant species (Bajguz and Tretyn, 2003). Four different types of BRs have been reported in radish seeds which include brassinolide, castasterone, 28-homoteasterone and teasterone (Schmidt *et al*., 1991, 1993). According to Khripach *et al*. (2000), endogenous concentration of BRs varies with age and plant part. The concentration of BRs was highest in pollens and immature seeds. However, they found that pollens of *Brassica napus* and *Vicia faba* contain highest concentration of BRs (10^{-1} nmol g^{-1} fr. wt.) but lowest concentration of BRs was found in immature seeds and sheaths of Chinese cabbage (10^{-7} nmol g^{-1} fr. wt.).

2.5.2 Physiological roles of BRs

BRs have the potential to raise plant resistance against various types of environmental stresses. BRs provide resistance to plants under abiotic stresses like temperature, salt, drought, ozone and pesticides (Krishna, 2003). BRs share similar structure with insect and animal steroid hormones and were also reported to be present in plant roots (Bajguz and Tretyn, 2003). 5α-cholestan is the basic structure of BRs and their structural variability is accredited to type and orientation of functional group on basic structure (Fujioka and Sakurai, 1997). BRs are generally classified into C29, C28 and C27, based upon their alkyl substitution on the side chain (Yokota, 1997). Brassinolides, particularly 24-epibrassinolide (EBR) and 28-homobrassinolide (HBR) are the most active forms of BRs, and are extensively used in physiological studies (Vardhini and Anjum, 2015).

Important roles played by BRs in physiology of plants include process of cell elongation and differentiation, development of pollen tube, differentiation of vascular bundles, reassembling of nucleic acids resulting in protein formation, activation antioxidative defense system of plants and regulation of photosynthesis (Sasse, 2003; Yu *et al.,* 2004; Xia *et al*., 2006; Sharma *et al*., 2015). In dicots, BRs are reported to enhance the elongation of epicotyles, hypocotyls and peduncles, whereas in monocots, they increase the elongation of coleoptiles and mesocotyls (Clouse, 1996; Mandava, 1988). When HBR and 28-homocastasterone were applied in suspension cells of *Arabidopsis thaliana*, promotion of cell expansion through plasma membrane hyperpolarization was observed. This hyperpolarization was regulated by both anion channels and proton pump (Zhang *et al*., 2005).

BRs like EBR and HBR have been observed to play an important role in promotion of seed germination (Sasse *et.al*., 1995; Sharma and Bhardwaj, 2007). The percentage of germination was observed to increase in *Cicer arietinum* and *Triticum aestivum* after seed application of HBR (Hayat and Ahmed, 2003; Ali *et al*., 2005). Regulation of plant vegetative growth is also one of the important roles of BRs. Increase in yield, carbonic anhydrase activity and net photosynthetic rate was observed when HBR was applied to *B. juncea* plants (Hayat *et al*., 2000). Moreover, HBL application in rice resulted in increased growth parameters like leaf number, fresh and dry weight accompanied by enhanced activities enzymes like nitrate reductase and carbonic anhydrase (Hayat *et al*., 2001). EBR seed treatment has been observed to enhance the growth and photosynthesis of *B. juncea* plants (Sharma *et al*., 2016b). Enhancement in shoot and root length was observed in radish after the application of EBR and HBR (Sharma *et al*., 2010, 2011). The net photosynthetic rate was reported to be enhanced by the application of BRs in various plant species including *B. juncea, C. sativus, G. max, O. sativa* and *V. radiata* (Fariduddin *et al*., 2003; Hayat *et al*.,2007; Xia *et al*., 2006; Zhang *et al*.,2008; Farooq *et al*., 2009; Sharma *et al*., 2015).

BRs also play a role in stimulation of flowering in *Arabidopsis thaliana* (Domagalska *et al*., 2010). Deluc *et al*. (2007) found significant role of brassinosteroids in fruit ripening. Pilati *et al*. (2007) concluded that accumulation of BRs during the process of fruit development can lead to the ripening of fleshy fruits. Many researchers have also reported the enhanced ripening of cucumber, grapes, rice, tomato and yellow passion fruit after the application of BRs (Fujii *et al*., 2001; Vardhini and Rao, 2002; Gomes *et al*., 2006; Symon *et al*.,2006; Fu *et al*., 2008). BRs are also reported to affect the expression of other genes that plays important role in plant defense as well as biosynthesis of other plant growth regulators (Bari and Jones, 2009). Several studies have documented their important role in protecting plants from adverse environmental stress conditions like drought, heavy metals, pesticides, salinity and viruses (Krishna, 2003; Ozdemir *et al*., 2004; Wachman *et al*., 2004; Sharma and Bhardwaj, 2007; Sharma *et al*., 2012).

2.5.3 Role of Brassinosteroids in pesticide detoxification

Pesticide toxicity causes generation of reactive oxygen species resulting in reduction of plant growth and development. However, plants respond to this stress by activation of their internal defense system known as antioxidative defense system. Application of BRs has been further reported to increase this antioxidative defense system and provide resistance to plants against pesticide toxicity as shown in Fig. 2.5.1.

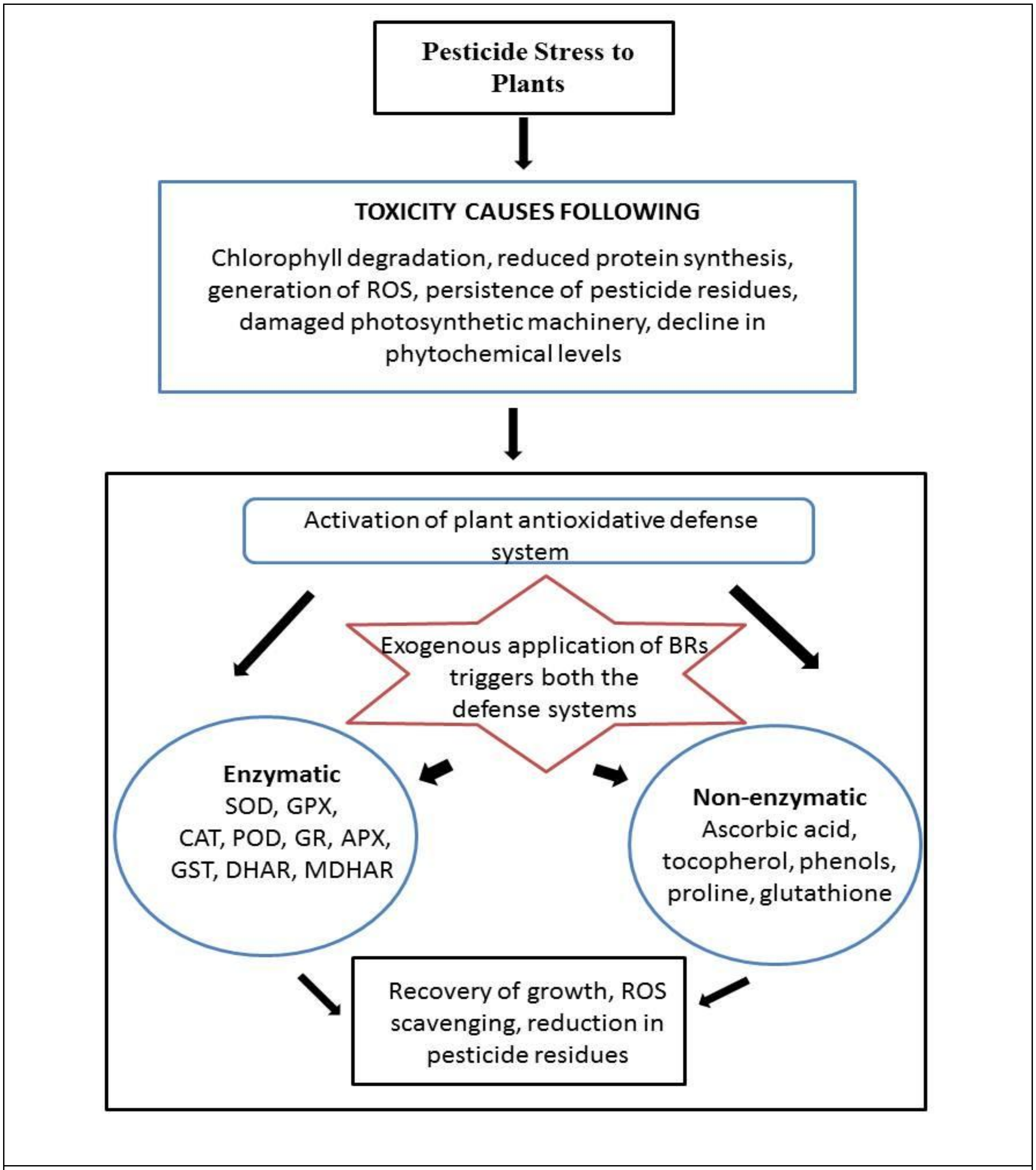

Fig. 2.5.1 Overview of plant response to pesticide stress and exogenous BRs application. ROS=reactive oxygen species, BRs=brassinosteroids, SOD=superoxide dismutase, GPX=glutathione peroxidase, CAT=catalase, POD=guaiacol peroxidase, GR=glutathione reductase, APX=ascorbate peroxidase, GST=glutathione-S-transferase, DHAR=dehydroascorbate reductase, MDHAR=monodehydroascorbate reductase.

Some studies have demonstrated the pesticide stress protective roles of BRs in plants (Xia *et al*., 2006, 2009a; Sharma *et al*., 2012; Zhou *et al*., 2015). In cucumber plants, exogenous applications of EBR have resulted in reduction of phytotoxic effects of various pesticides including herbicides, fungicides and insecticides (Xia *et al*., 2006). Studies carried out by Xia *et al*. (2006) have demonstrated that exogenous application of EBR improves the net photosynthetic rate along with increase in quantum yield of photosystem II under pesticide toxicity. They also demonstrated that imidacloprid and abamectin application to cucumber plants caused reduction in photosynthetic efficiency of plants, but exogenous application of EBR resulted in overcoming the side effects of pesticides. In rice plants, recovery of impaired growth due to pesticide toxicity was observed after the seed application of EBR and HBR (Sharma *et al*., 2012; 2013; 2015). Application of EBR to cucumber has been observed to increase the degradation of pesticides accompanied by up-regulation of pesticide detoxification genes and ultimately reduction of toxic effect of pesticides (Xia *et al*., 2009a; Zhou *et al*., 2015). Application of chlorpyrifos resulted in persistence of pesticides in the form of residues but treatment of EBR to plants resulted in decrease in pesticide residue levels in cucumber plant. Sharma *et al*. (2016b) also demonstrated that EBR seed soaking before sowing in IMI amended soils resulted in recovery of reduced growth, chlorophyll contents and photosynthetic efficiency of *B. juncea* plants. They also observed that the pigments which act as antioxidants including carotenoids, anthocyanins and xanthophylls were increased in plants raised from EBR treated seeds and grown in IMI amended soils.

EBR and HBR have been reported to increase the activities of antioxidative enzymes like SOD, CAT, APX, GPOX, GR, DHAR and MDHAR in rice seedlings grown in sand supplemented with chlorpyrifos (CPF) and IMI pesticides (Sharma *et al*., 2012, 2013, 2015). These researchers also reported that EBR and HBR applications resulted in declined oxidative stress due to the reduction of reactive oxygen species like superoxide anion and hydrogen peroxide, which were generated due to pesticide toxicity. It was also observed that the contents of protein and proline were increased after the application of BRs followed by the reduction in malondialdehyde content. In *B. juncea*, activities of antioxidative enzymes like GR, GPOX, GST and POD were observed to increase as a result of EBR seed soaking and growing in IMI containing soils (Sharma *et al*., 2016c,d). Non-enzymatic antioxidants including ascorbate, tocopherol, glutathione, polyphenols and total phenolics are also important part of plant antioxidative defense system, which gets activated under environmental stress conditions (Vardhini and Anjum, 2015). Application of BRs has been reported to enhance the contents of these non-enzymatic antioxidants in plants under normal as well as abiotic stress conditions including and pesticide toxicity (El-Mashad and Mohamed, 2012; Serna *et al*., 2012; Champa *et al*., 2015; Zhou *et al*., 2015; Sharma *et al*., 2016a).

Exogenous application BRs have also reported to regulate the expression of genes involved in pesticide detoxification in plants (Table 2.5.1).

Table 2.5.1 BRs application enhances the expression of below mentioned genes under pesticide stress.

<table>
<tr><th>Gene</th><th>Brassinosteroid used</th><th>Pesticide used</th><th>Plant</th><th>Reference</th></tr>
<tr><td>Cu/Zn SOD</td><td rowspan="6">EBR, HBR</td><td rowspan="5">CPF, IMI</td><td rowspan="5">Rice</td><td rowspan="5">Sharma et al. (2012, 2013, 2015)</td></tr>
<tr><td>Fe-SOD</td></tr>
<tr><td>Mn-SOD</td></tr>
<tr><td>CAT</td></tr>
<tr><td>APX</td></tr>
<tr><td>GR</td><td>CPF, IMI, CHT</td><td>Rice, tomato</td><td>Sharma et al. (2012, 2013, 2015), Zhou et al. (2015)</td></tr>
<tr><td>GST</td><td rowspan="6">EBR</td><td rowspan="3">CMT, CHT, CBZ</td><td rowspan="2">Tomato, cucumber</td><td rowspan="2">Xia et al. (2009a), Zhou et al. (2015)</td></tr>
<tr><td>P450</td></tr>
<tr><td>MRP</td><td>Cucumber</td><td>Xia et al. (2009a)</td></tr>
<tr><td>GSH</td><td rowspan="3">CHT</td><td rowspan="3">Tomato</td><td rowspan="3">Zhou et al. (2015)</td></tr>
<tr><td>ABC</td></tr>
<tr><td>RBOH1</td></tr>
<tr><td colspan="5">Fe-iron, Cu-copper, Zn-zinc, Mn-manganese, SOD-superoxide dismutase, CAT-catalase, GR-glutathione reductase, GST-glutathione-s-transferase, P450-cytochrome P450, MRP-Mitochondrial RNA processing enzyme, GSH-glutathione-S-transferase, ABC-ATP binding cassette transporter, RBOH-respiratory burst oxidase 1, CPF-chlorpyrifos, CHT-chlorothalonil, CMT-cypermethrin, CBZ-carbendazim</td></tr>
</table>

The expression and activities of the enzymes involved in pesticide detoxification have been reported to increase after the application of BRs (Xia *et al*., 2009a; Zhou *et al*., 2015). Since BRs have also been observed to be involved directly in the degradation of the pesticides, these hold strong future prospects in pest management. Xia *et al*. (2009a) reported that application of EBR to cucumber plants reduced the residues of pesticides including chlorpyrifos, carbendazim, cypermethrin and chlorothalonil. They further noticed that EBR induced reduction in pesticide residues was accompanied by the increased activity of various enzymes like POD, GST and GR. The investigators also observed that EBR application significantly up-regulated the expression of *P450* (P450 monooxygenase), *GST* and *MRP* (Multidrug resistance associated protein) genes involved in pesticide detoxification. Zhou *et al*. (2015) reported that EBR enhances the degradation of pesticides in crop plants by 34 to 71%, e.g., chlorpyrifos in cucumber, tea, rice, broccoli and chinese cabbage; phoxim in tea and chinese chives; chlorothalonil in tomato, celery, strawberry and asparagus; omethoate in cucumber; cypermethrin in cucumber, tea, chinese cabbage and broccoli; carbofuran in garlic and chinese chives; and 3-hydroxycarbofuran in chinese chives. They also noticed that EBR application up-regulated the genes in tomato plants subjected to chlorothalonil pesticide stress. Further it was noticed that 1725 genes were expressed when EBR was applied along with chlorothalonil pesticide. However, during EBR application only, 1584 genes and in alone chlorothalonil pesticide treated plants, 1545 genes were expressed. It was further reported that out of all the genes expressed, only 301 were mutually up-regulated by all the three treatments. Recently, studies carried out on *Solanum lycopersicum* have revealed that mitogen activated protein kinase (MAPK) and nitric oxide (NO) play key role in BR mediated pesticide detoxification (Yin *et al*., 2016).

Pesticide toxicity to plants and the persistence of pesticide residues in plants is a world-wide problem. BRs have the potential to reduce phytotoxicity as well as pesticide residues in plants. A review of literature reveals that IMI has not been extensively studied in this regard. The present study has been designed to fill this lacuna. Therefore, keeping in mind the role of BRs in pesticide stress management, the present study attempts to reveal the physiological response of *B. juncea* plants raised from EBR soaked seeds and grown under IMI pesticide stress.