CHAPTER II

REVIEW OF LITERATURE

The cruciferous vegetables are one of the most preferred winter vegetable produced throughout the country. The literature pertaining to the management of diamondback moth (DBM) with botanical insecticide, inter crops repellent plants, sex pheromone traps and their evaluation through push-pull strategies in cruciferous vegetable ecosystems are reviewed in this chapter.

2.1. Diamondback moth (DBM), *Plutella xylostella* (Linn.) (Lepidoptera: Plutellidae)

The diamondback moth is a major insect pest in more than 100 countries across the globe; it affects cruciferous plants, especially *Brassica* crops such as cabbage, cauliflower, broccoli, kale, kohlrabi, Brussels sprout and turnip (Alam, 1992; Talekar *et al.,* 1992). When the wings are folded on its body while at rest, a diamond shaped median dorsal patch is seen and hence the common name "diamondback moth" (Nayar, 1992). *Plutella xylostella* (L.) was first observed in North America in 1854, but quickly spread across the world and the life cycle of DBM is depend on the prevailing temperature and typically it completes its life cycle in about 25-30 days (Capinera, 2001; 2009). *P. xylostella* is believed to have originated in either the Mediterranean region (Talekar and Shelton, 1993) where *P. xylostella* is the most devastating pest on many cultivated cruciferous crops *viz.,* cabbage, cauliflower and broccoli in the areas of Punjab, Himachal Pradesh, Delhi, Uttar Pradesh, Bihar, Tamil Nadu and Karnataka (Mitchell *et al.,* 1999 and Uthamasamy *et al.,* 2011). Krishnakumar *et al.* (1986) reported that diamondback moth caused 52 per cent loss in nursery and 53 per cent loss in marketable yield in Tamil Nadu, while Calderson and Hare (1986) reported 100 percent loss in marketable yield of cabbage.

Today, this insect occurs wherever crucifers are grown and is believed to be the most ubiquitous of all lepidopteran (Talekar and Shelton, 1993). *P. xylostella* larvae feed on plants in the family crucifereae, which contain mustard oil and their glucosides like sinigrin, sinalbin, and glucocheirolin (Nayar and Thorsteinson, 1963). *P. xylostella* also feeds on many different cruciferous weeds, including *Barbarea vulgaris*; *Capsella bursapastoris*; *Lepidium* spp. and *Brassica* spp., which serve as important alternate hosts for the pest, especially in spring before crucifer vegetable crops are planted (Capinera, 2001).

Table 1. List of potential insecticidal plants against diamondback moth, *Plutella xylostella*

S.No.	Botanical Name	Plant parts used	Mode of action	References
1	*Annona reticulata*	bark, fruit	I, AF, R	Grainge *et al.,* (1984); Jacobson, (1975)
2	*Annona squamosa*	roots, fruit, oil	I, CP, SP, AF	Grainge *et al.,* (1984)
3	*Fittonia argyroneura*	leaves	AF	Jacobson (1958); Grainge *et al* (1984);
4	*Fittonia verschaffeltii*	leaves	AF	Gupta and Thorsteinson (1960)
5	*Nerium oleander*	roots, bark, stem, leaves and flowers	I, AF	Jacobson (1958); Grainge *et al.,* (1984); Gupta and Thorsteinson (1960)
6	*Hedera helix*	leaves	AF	Grainge *et al.,* 1984); Gupta and Thorsteinson (1960); Jacobson (1975)
7	*Philodendron* sp.	leaves	AF	Grainge *et al.,* (1984); Gupta *et al.,* (1960); Jacobson (1975)
8	*Chrysanthemum cinerariaefolium*	whole plant and flowers	I, AF	Grainge *et al.,* (1984)
9	*Matricaria matricarioides*	flowers	Insecticidal	Grainge *et al.,* (1984); Jacobson (1958),
10	*Senecio cineraria*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
11	*Tithonia diversifolia*	leaves	CP	Carino *et al.,* (1982); Grainge *et al.,* (1984)
12	*Impatiens sultani*	leaves	I, AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson (1975)
13	*Begonia pearcei*	leaves	Insecticidal	Grainge *et al.,* (1984); Jacobson, (1975),

S.No.	Botanical Name	Plant parts used	Mode of action	References
14	*Buxus sempervirens*	leaves	AF, R	Grainge *et al.,* (1984), Gupta and Thorsteinson (1960); Jacobson (1975)
15	*Dianthus* sp.	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
16	*Euonymus japonicus*	leaves	R	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson (1975)
17	*Tripterygium wilfordii*	roots, tubers, bark	I, SP, AF	Jacobson, (1958); Swingle, (1941)
18	*Mammea americana*	roots, tubers, bark	I, CP, SP	Grainge *et al.,* (1984), Gupta and Thorsteinson (1960); Jacobson, (1975)
19	*Tagetes erecta*	roots	CP	Morallo-Rejesus *et al.,* (1978);
20	*T. patula*	roots	CP	Grainge *et al.,* (1984)
21	*Tradescantia* sp	leaves	AF	
22	*Dahlia* sp	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
23	*Gynura* sp	leaves	AF	
24	*Ipomoea batatas*	leaves	AF	
25	*Citrullus colocynthis*	roots, tubers, leaves, fruit	Insecticidal	
26	*Cucumis sativus*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
27	*Azalea* spp.	leaves	AF	
28	*Acalypha indica*	leaves, bark	Insecticidal	Grainge *et al.,* (1984)

S.No.	Botanical Name	Plant parts used	Mode of action	References
29	*Euphorbia lathyris*	leaves	Insecticidal	
30	*Euphorbiasplendens*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975),
31	*Euphorbia poins- ettiana* Buist	leaves	AF	
32	*Phyllantus acuminatus*	roots, tubers	CP, SP	Grainge *et al.,* (1984); Jacobson, (1958),
33	*Derris malaccensis*	roots, tubers	I , SP, CP,R.AF	Grainge *et al.,* (1984)
34	*Pachyrhizus erosus*	whole plants, fruits, sap, seeds	I, CP, ST, AF	Grainge *et al.,* (1984); Jacobson, (1958)
35	*Piscidia acuminata*	roots, tubers, leaves	Insecticidal	Grainge *et al.,* (1984); Jacobson, (1958),
36	*Piscidia piseipula*	roots, tubers, bark, leaves	I, CP, SP, AF	Grainge *et al.,* (1984); Jacobson, (1958)
37	*Tephrosia vogelii*	leaves, seeds	I, AF, R	Grainge *et al.,* (1984)
38	*Exacum* sp.	leaves	AF	
39	*Geranium* sp	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
40	*Pelargonium* sp	leaf, stem, oil	AF, SP,AT,R	
41	*Negelia hyacin thi*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
42	*Coleus* sp	leaves	AF	
43	*Calopogonium coerruleum*	seeds, pods	Insecticidal	Grainge *et al.,* (1984); Jacobson, (1958)
44	*Lilium longiflorum*	leaves	I, AF	Grainge *et al.,* (1984); Gupta and Thorsteinson

S.No.	Botanical Name	Plant parts used	Mode of action	References
45	*Hemerocallis dumortieri*	leaves	I, AF	(1960); Jacobson, (1975),
46	*Tulipa* sp	leaves	AF	
47	*Abutilon pictum*	leaves	AF	
48	*Hibiscus syriacus*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
49	*Maranta bicolor*	leaves	AF	
50	*Azadirachta indica*	whole plant, bark, stem, seeds	I, CP, ST, GI, AF,	Grainge *et al.,* (1984); Shin-Foon and Yu-Tong, (1993)
51	*Melilotus officinalis*	leaves	R	
52	*Fuchsia* sp	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
53	*Blettia striata*	leaves	AF	
54	*Oxalis deppei*	leaves	AF	
55	*Passiflora alata*	leaves	AF	
56	*Peperomia* sp	leaves	AF	Gupta and Thorsteinson (1960); Jacobson, (1975)
57	*Piper nigrum*	seeds	CP	Grainge *et al.,* (1984); Javier, (1981)
58	*Punica granatum*	leaves	I, AF	Grainge *et al.,* (1984), Gupta and Thorsteinson (1960); Jacobson, (1997)
59	*Clematis* sp	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
60	*Dalphiniurn chinensis*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)

S.No.	Botanical Name	Plant parts used	Mode of action	References
61	*Eranthis hyemalis*	bulbs	Insecticidal	Grainge *et al.,* (1984); Jacobson, (1958)
62	*Rhamnus crenata*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
63	*Rosa* sp.	leaves	AF	
64	*Chinchona calisaya*	roots, tubers, bark, wood	Insecticidal	Grainge *et al.,* (1984); Jacobson, (1958)
65	*Randia nilotica*	roots, tubers	Insecticidal	
66	*Xeromphis spinosa*	roots, tubers, fruit	I, AF, R	Grainge *et al.,* (1984); Jacobson, (1975)
67	*Citrus aurantium*	leaves	I, AF, R	
68	*Medhuca latifolia*	bark, Stem, leaves	Insecticidal	Grainge *et al.,* (1984)
69	*Madhuca longifolia*	seeds	Insecticidal	Grainge *et al.,* (1984)
70	*Heuchera anguinea*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
71	*Hydrangea* sp.	leaves	AF	
72	*Balanites aegyptica*	roots, fruits, seeds	Insecticidal	Grainge *et al.,* (1984); Jacobson, (1958)
73	*Lycopercicum esculentum* Mill	whole plant, stem, fruits, leaves	I, AF, R, AT	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
74	*Petunia* sp	flowers, leaves	Insecticidal	
75	*Solanum tuberosum*	leaves	AF	Grainge *et al.,* 1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
76	*Solanum sp*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)

S.No.	Botanical Name	Plant parts used	Mode of action	References
77	*Jacquinia aristata*	roots, fruits, leaves	Insecticidal	Grainge *et al.,* (1984); Jacobson, (1958)
78	*Ficus carica*	leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
79	*Pellionia pulchra*	leaves	AF	Grainge *et al.,* 1984), Gupta and Thorsteinson (1960); (1960);Jacobson, (1975)
80	*Lantana camara*	flowers, leaves	AF	Grainge *et al.,* (1984); Gupta and Thorsteinson (1960); Jacobson, (1975)
81	*Vitex negundo*	leaves, stem, Seed oil	I, GI, R	Grainge *et al.,* (1984)
82	*Cissus rbombifolia*	stems, leaves	AF, SP	Gupta and Thorsteinson (1960); Jacobson, (1975),
83	*Tephrosia vogelii* Hook	leaves, pods, small branches, stem bark and wood	AF	Shin-Foon and Yu-Tong, (1993)
84	*Rhododendron molle*	dried flower	AF, I	Shin-Foon and Yu-Tong, (1993)
85	*Afromomummelegueta*	plant and seed	AF, IGR	Ntonifor *et al.,* (2010)
86	*A. citratum*	plant and seed	AF, IGR	
87	*Ajuga nipponensis*	stem	AF,IGR	Huang *et al*., (2008),
88	*Andrographis paniculata*	stem	AF,IGR	Hermawan *et al*., (1994)
89	*Artemisia annua*	stem	AF,IGR	Peng (2004)

S.No.	Botanical Name	Plant parts used	Mode of action	References
90	*Artemesia santonicum*	stem	AF,IGR	Erturk *et al*., (2004)
91	*Azadiracta indica* *Melia azedarach*	leaves	AF,IGR, O	Charleston *et al.* (2005)
92	*Curcuma longa*	rhizome	AF,IGR	Morallo-Rejesus and Sayaboc (1992)
93	*Euphorbiaantiquorum E. nivulia, E. tirucalli E. pulcherrima*	leaves	AF,IGR	Uma *et al.* (2009)
94	*Melia azedarach*	seed	AF,IGR	Sharma *et al*., (2006)
95	*Rhododendron molle*	flower	AF,IGR	Shin -Foon and Yu-Tong (1993)
96	*Severinia buxifolia*	root and bark	AF,IGR	Wu *et al*., (1997)
97	*Sabina vulgaris*	seed	Fumigant	Gao and Zhang, (1997)
98	*Annona squamosa*	seed	Larvicidal	Sinchaisri *et al*., (1991); Leatemia and Isman, (2004)
99	*Cyperus rotundus*	roots	Larvicidal	Visetson *et al.,* (2001); Dadang *et al*. (1996)
100	*Gymnema sylvestre, Solanum khasianum*	roots	Larvicidal	Seenivasan *et al*., (2003)
101	*Actinidia chinensis*	stems and leaves	Insecticidal	Junshan *et al*., (2008)
102	*Aglaia roxburghiana*	Stem bark	Insecticidal	Molleyres *et al*., (1999)
103	*Alpinia galanga*	rhizomes	Insecticidal	Dadang *et al*., (1998)
104	*Linum bienne*, *Laurus nobilis*, *Prunus laurocerasus*, *Redesaa alba, Scorzonera tomentosa*, *Scorzonera mollis, Tamarix smyrnensis*	stem	Insecticidal	Erturk *et al*., (2004)

S.No.	Botanical Name	Plant parts used	Mode of action	References
105	*Stellera chamaejasme*	roots	Insecticidal	Zhang (2000)
106	*Stemona collinsae*	roots	Insecticidal	Sinchaisri *et al*., (1991) and Phattharaphan *et al*., (2010)
107	*Zanthoxylum bungeanum*,	leaves	Insecticidal	Wei *et al*. (2005)
	Eucalyptus tereticornis			
108	*Nicotiana tabacum*, *Broussonetia papyrifera*, *Bauhinia variegata*, *Duranta repens*, *Euphorbia hirta* and *Camellia oleifera*	stem	Insecticidal	Wei *et al*. (2005)
109	*Melia azedarach*, *Laurus nobillis*, *Cissampelos glaberrima* and *Croton sp.*	leaves	Insecticidal	Torres *et al.* (2001)
110	*Tripterygium wilfordii*	roots (bark)	Insecticidal	Xu *et al*. (2006)
111	*Zingiber officinales* Rosh	rhizome	Insecticidal	Odewole and Adebayo (2014)
112	*Strychnus nux-vomica* Linn	seed, leaf, park, roots	I, AF,IGR, OD	Selvaraj (2015)

Note: AF- Antifeedant; R-Repellent; I-Insecticidal; OD- Oviposition deterency; O-Ovicidal; IGR- insect growth regulations; GI-Growth inhibition; SP- stomach poison;

Diamondback moth, *P. xylostella* has become the most destructive insect pest of crucifer vegetables worldwide, and annual costs for managing it are estimated to cost the world economy US$ 4-5 billion annually (Furlong *et al.,* 2013). In India the estimated annual crop losses due to this pest amount to US$ 16 million (Mohan and Gujar, 2003). The absence of very effective natural enemies and insecticide resistance are believed to be the major cause of the *P. xylostella* pest status in most parts of the world (Lim *et al.,* 1986; Talekar and Shelton, 1993). The diamondback moth, *P. xylostella* is the greatest threat to crucifer production in many parts of the world, sometimes causing more than 90 per cent crop loss (Verkerk and Wright, 1996).

2.1.1. Seasonal incidence

Seasonal incidence of the pest on cabbage and cauliflower varied among locations in Tamil Nadu (Coimbatore, Hosur, Ooty, Ottanchatram, Theni and Tenkasi). The larval population was the highest in Ottanchatram and the lowest in Tenkasi in a same season. Population of DBM is generally influenced by abiotic factors such as temperature, rainfall, wind and relative humidity. The population became abundant during September to October and March to April. Heavy rain can destroy the moth population. High build-up of larval populations has been reported during February-March (late winter) and April-August (summer and mid rainy season) (Abraham and Padmanabhan, 1968). All crop growth stages are subjected to *P. xylostella* infestation, which peaks in August to September.

Diamondback moth, *P. xylostella* is active throughout the year where cruciferous crops are grown year around (Talekar and Shelton 1993), but its rate of development is much influenced by temperature (Smith and Villet, 2004). Dhaliwal *et al.* (2010) reported that the DBM infestation increased gradually from first fortnight of August to September which leads to the total loss of crop. Climatic changes may lead to increase in severity of this pest in many regions of the country.

In the rainy season, larval population of *P. xylostella* decreased down and significantly unfavourable for the immature stages (Ahamad and Ansari, 2010). It was confirmed by Talekar and Shelton (1993) that rain can dislodge the larvae of *P. xylostella* from the plants and can drown the larvae in to the soil. Iga (1985) reported that almost

100 per cent mortality of I - II instars of *P. xylostella* and a range of 14.30 to 71.40 per cent mortality of III - IV instar larvae might be due to rain. While, Sivapiragasam *et al*. (1988) found that rainfall generally washed off 38 percent eggs of *P. xylostella* and also first instars were found to be susceptible to drowning when they are trapped in water at the leaf axel. It was thoroughly studied and stated by Kobori and Amano (2003) that one hour of simulated rain resulted 95.30 per cent drop off of first instar, 72.00 per cent second instar, 60.70 per cent third instar and 42.70 per cent fourth instar. Falling rate of eggs of *P. xylostella* are significantly higher on the upper surface than the lower surface of cabbage leaves, direct impact by rain drops, washing off by water flowing across the leaf surfaces and secondary impacts from drops hitting the soil and water particles back at the leaves (Ahamad and Ansari, 2010). Ayalew and Ogol (2006) reported that rainfall and maximum temperature significantly influenced DBM numbers and parasitoid activity.

Ahamad and Ansari (2010) reviewed that in second fortnight of September and first week of October, parasitization was insignificantly low and did not provide any control on the infestation level by *P. xylostella*. He also observed the parasitism rate reached to 41.52 per cent at temperature fluctuating between 9.29 to 19.50°C with relative humidity of 67.10 to 73.40 per cent in 2004, while 46.64 per cent parasitism at a temperature of 5.41 to 20.35°C and relative humidity ranging between 48.10 to 94.00 per cent was observed during fourth week of December 2005. Nagarkatti and Jayanth (1982) found significantly high build up of larval populations during the rainy season (July-September) as compared to other seasons. The *P. xylostella* population became abundant during September to October and March to April. Heavy rain can destroy the moth population. *P. xylostella* is active throughout the year where cruciferous crops are grown year around (Talekar and Shelton, 1993), but its rate of development is much influenced by temperature (Smith and Villet, 2002). Between December and March less than one generation was completed making this period the most favourable for cabbage cultivation (Grillo Ravelo and Hernandez-Rodriguez, 1994).

Yamada and Umeya (1972) reported that female moths collected from cabbage fields in August were short lived and laid fewer eggs, while the female moths collected from December to March were long lived and laid more eggs. Chin (1974) found that the occurrence of *P. xylostella* was the highest in March and least in June. Annamalai *et al.* (1988)

recorded 33.00 to 62.00 per cent mortality of first instar larvae in cabbage fields due to rainfall and some unknown factors and 38.00 per cent mortality of the diamondback moth from the direct impact of rain which washed off the eggs. Kahono *et al*. (2004) reported that the higher temperature of summer months is congenial for increase in pest population at Maharashtra. Ayalew *et al.* (2006) reported that rainfall and maximum temperature significantly influenced DBM and its parasitoid activity in cruciferous vegetables.

2.1.2. Natural enemies

Krishnamurthy and Mani (2000) reported that diamondback moth (DBM), *P. xylostella* is a major pest of cabbage and cauliflower in India. Only very few parasitoids have been exploited for the control of DBM either as a sole method of biological control or incorporated as one of the components in Integrated Pest Management strategies. *Trichogrammatoidea bactrae* Nagaraja and *Cotesia plutellae* (Kurdjumov) were studied extensively and used against DBM management. No effort has been made either to conserve the predators or to exploit for the control of DBM. Use of parasitoids is one of the most effective and suitable control methods for DBM. Among these parasitoids, *C. plutellae* (*Apanteles plutellae* Kurdjumov) is a primary solitary endo larval parasitoid of DBM larvae (Haseeb *et al.,* 2001) and has been reported as an impressive suppressing agent of DBM population (Mitchell *et al.,* 1999). Parasitism by *C. plutellae* and *Oomyzus sokolowskii* Kurdjumov reached to 18-52.5 per cent and an average of 75 per cent DBM larvae were parasitized (Alam, 1992). Navatha and Murthy (2006) observed a higher rate of parasitism (60.00 percent) during August on *P. xylostella* in South India. Among the parasitoid of diamondback moth, only *Brachymeria excarinata* Gahan, was reported as a potential pupal parasitoid (Lingappa *et al*. 2000).

Krishnamoorthy (2002) and Krishnamoorthy *et al.* (2002) found that eggs and larval parasitoids have the great potential in regulating the population of DBM in cabbage and cauliflower crops. Among them, *C. plutellae* and *Diadegma semiclasum* Hellen are important. These parasitoids regulate the larval stage of the pest complex. Conservation of the local *C. plutellae* on the other hand helps in checking DBM population (Chauhan *et al.,* 1997).

Coccinellids locate their prey by initially searching their habitat extensively but switch to intensive searching following an encounter with prey (Omkar and Srivastava, 2003). Adult of C*occinella septempunctata* Linn. consumed more aphids in both generations of aphid as compared to larvae (Omkar and Srivastava, 2003). Insect parasitoids species have been recorded on the DBM of forty-eight species were catalogued by Thompson (1946), while Goodwin (1979) stated that there are more than 90 spp. Among these, 6 species are attack diamondback moth eggs, 38 attack larvae and 13 attack pupae (Lim, 1982). However, not all parasitoids are effective natural enemies. Keinmeesuke *et al.* (1990) reported that 68 per cent of DBM larval mortality was due to various predators including birds.

Lim (1992) reported that the potential to function as biological control agents varied between species, often depending not only on their direct relationships with their host(s) but also on interrelationships between each other (interspecific interactions) and the environment. *Diadegma insulare* (Cresson) is one of most important parasitoids of the DBM (Mitchell *et al.,* 1997) and *D. insulare* has been reared successfully in greenhouse conditions with a parasitism rate of 95 per cent and a population comprising 45-63 per cent females are obtained (Xu *et al.,* 2001). Sharma and Bhalla (1991) have reported that syrphid larvae are effective predators of cabbage aphid *Brevicoryne brassicae* (L).

Mortality caused by invertebrate predators and parasitoids is an important factor in the regulation and dynamics of pest populations but the role of predators has often been underestimated (Symondson *et al.,* 2002). Spiders and many generalist insect predators consume large numbers of prey, and cause no or only minor damage to plants. Such predators can reach high enough densities to be important agents in pest control, although at very high densities their numbers may be reduced by territorial behavior and cannibalism (Lee and Kim, 2001). Sometimes the interactions between predator species are synergistic and the impact of several species together will then be greater than the sum of the impacts of individual species (Simberloff and VonHolle, 1999). The effect of predators needs to be considered when analyzing their effective use in the control of diamondback moth (Polis *et al.,* 1989). To date, the majority of studies of natural enemies, in general, and of those attacking DBM, in particular, mainly relate to parasitoids.

Predation and other sources of mortality have historically been very much ignored and are poorly understood (Lim, 1992; Talekar and Shelton, 1993; Furlong *et al.,* 2004; Ma *et al.,* 2005). For example, Alam (1992) reported that the most common groups of insect predators found in cabbage field were coccinellids, chrysopids, syrphids and staphylinids etc. If predators are discussed at all, they are often merely listed in terms of the species found in traps in crucifer fields (Lim, 1992) and only a few papers report experiments where predators have actually been shown to predate diamondback moth. Several workers have noted that the abundance and diversity of predators and parasities within a field are closely related to the nature of the vegetation in the field. Many agro ecosystems are unfavorable environments for natural enemies due to high levels of disturbance (Landis *et al.,* 2001).

Visual sampling of plants and pitfall trapping during the experiments showed that the major arthropod predators present in the crops were aranae, staphylinidae and formicidae. The commercial crops within which the studies were conducted were regularly treated with insecticides in a range of (synthetic pyrethroids, spinosad, emamectin benzoate and *Bacillus thuringiensis*) and while predator populations were significantly depressed following the application of pyrethroids, other insecticides had only a minor impact on predator abundance. The results are considered within the context of the small-scale mixed farming agro ecosystem and the factors which might have contributed to the highly effective nature of the arthropod natural enemy complex in the insecticide intensive cropping system are considered in in the highlands of West Java, Indonesia (Murtiningsih *et al.,* 2011).

2.2. Evaluation of botanical insecticide against diamondback moth, *Plutella xylostella* (L.) and its natural enemies

2.2.1. Insecticidal Plants

Plant product is also eco-friendly, easily available in local area and economically viable. Biopesticides are considered to be safe natural products and free from any residue problem on the crop and in the environment (Mukherjee and Singh, 2006). Totally 1,800 plant species reported by Grainge *et al.* (1984) to possess pest control properties, only 82 species have been reported to be active against DBM. This information was obtained from literature searches and from responses to a survey received from national and international organizations based in Bangladesh, China, Costa Rica, England, France, Fiji, India, Malaysia, Mauritius, Mexico, New Zealand, Pakistan, the Philippines, Sri Lanka, Switzerland, Thailand, USA, Vietnam, and West Germany. The plant families, asteraceae, fabaceae and euphorbiaceae contain most of the insecticidal and other plant species list are reported in following Table 1.

The plant parts used for extraction or assay were the leaves, roots, tubers, fruits, seeds, flowers, the whole plant, bark, sap, pods, bulbs, and wood. The most commonly utilized part was the leaf (62 species) followed by the root (16 species) and tuber (12 species). A few reports did not specify the plant parts used. Most of these plants were reported to be insecticidal without specifying the type of action. In these cases it is assumed that the reports meant that these plants were toxic as contact and/or stomach poisons. Many plants were reported to be antifeedant. The minimum effective dilution ratio ranged from 1:2 to 1:100,000 for bio efficacy and only very few plants were assayed using semi-purified or purified extracts.

Rahman (1944) reported that in India the potato tuber moth (PTM) damage can be drastically reduced by covering tubers with a 2.5 cm thick layer of dried and chopped *Lantana* leaves. Lal (1988) reported that in India covering tubers with 2.5 cm thick layer of dried and crushed leaves of *Lantana* had about only 4 per cent tuber infestation by the potato tuber moth (PTM) after 6 months of storage as compared with about 75 per cent tuber infestation in the untreated tubers. La1(1988) reported in India the stored tubers covered with dried and chopped leaves of *Lantana* reduced PTM damage from 99 to 5 per cent due to *Lantana* leaves contain the repellent property.

Dried and shredded plants of *Lantana* reduced the PTM damage in storage in Peru (Raman and Booth, 1984). Pandey *et al.* (1979) have shown that antifeedant activity of *L. camara* var. *aculeata* against mustard sawfly, *Athalia proxima* Kiug has been reported. Further, using dried leaves of *Lantana* as 2.5 cm thick layer protected potato in storage from 42 per cent mortality to third instar larvae of PTM pest upto 6 months (Lal, 1987). In Sri Lanka, covering tubers with a 2 cm thick layer of air dried and crushed leaves of *Lantana* significantly reduced PTM damage in storage (Wahundeniya, 1989). Islam *et al.*

(1990) observed that covering tubers with crushed dried leaves of *Lantana* at 2.5 cm depth significantly reduced the PTM damage in storage in Bangladesh. Gingerols and shogaols are the active insecticidal materials in *Z. officinale* rhizome against *P. xylostella* larvae (Goto *et al.,* 1990).

Chouvalitwongporn and Vattanatangum (1985) reported from Thailand that the dried and crushed leaves of *Lantana* reduced the PTM damage in storage. Oil extracted from *Lantana* is known to exhibit ovicidal, insecticidal, antifeedant, attractant, repellent, antiviral and antijuvenile hormone activities (Morallo-Rejesus, 1986). The sprout damage was 24.02 per cent in *Lantana* treated tubers while 73.85 per cent sprout infestation in the control tubers. According to Pradhan (1987) in Nepal, covering tubers with chopped and dried leaves of *L. camara* reduced the PTM damage in rustic stores. *Lantana* flower extract in coconut oil provided 94.50 per cent protection from *Aedes albopictus* (Skuse) and *A. aegypti*. The mean protection time was 1.9h. One application of *Lantana* flower extract can provide more than 50 per cent protection up to 4h against the possible bites of *Aedes* mosquitoes. No adverse effects to the human volunteers were observed through 3 months after the application (Dua *et al.,* 2003).

Reddy and Urs (1991) reported that cabbage leaves treated with 4 per cent acetone extract of the xerophytic perennial plant (*Agave cantala* Roxb.) prolonged the larval and pupal periods of DBM. Srinivasan and Krishnamoorthy (1991) reported that NSKE 5% consistently provided significant reduction of *P. xylostella* larvae on cabbage as compared to other treatments grown under IPM involving mustard as trap crop. Schmutterer (1990) and Verkerk and Wright (1996) reported that neem seed kernel powder alone, neem seed kernel extract and enriched formulated extract of *Azadirachtin* and Neemazal effective against DBM. Losses caused by hairy caterpillar, *Spilosoma oblique* (Walker) could be minimized by spraying of aqueous leaf extracts of *Lantana* (Sharma *et al.,* 1992). Systemic transport of neem in plants and controlling effects are also documented for the cabbage pests *Pieris brassica* (Linnaeus) (Osman and Port, 1990) and *P. xylostella* (Wendorf and Shuler, 1992). Patel *et al.* (1993) showed that NSKE 5 per cent suspension was effective against *P. xylostella* while neem leaf extract 5 per cent suspension was least effective.

Joshi *et al.* (1993) reported that S. *litura* is currently being managed with neem extract in South India. Verkerk and Wright (1996) reported that 2 neem extracts *viz.,* AZT (30 mg azadirachtin/ml) and Neem-Azal (3 mg azadirachtin/ml) recorded 50 and 90 per cent mortality of *P. xylostella* in 13 days after application. Evaluation of neem extracts and formulations showed that fresh water extracts of neem seed kernels were effective, mainly as an antifeedant, against DBM larvae (Loke *et al.* 1997). In field experiment with botanical pesticides on cauliflower, neem oil 2 per cent was far superior to other plant products in overall effectiveness against *P. xylostella* as well as in increasing the yield (Kalyanasundaram, 1995).

Mohapatra *et al.* (1995) reported that the methanol extracts of neem seed kernel at 1 per cent concentration provided greatest protection (100%) of the cauliflower leaves against *S. litura.* Perez *et al*. (1998) found that among various neem products tested Cubanimt achieved 80 per cent efficacy against cabbage diamondback moth, *P. xylostella* after 4 applications, statistically equal to the commercial insecticide (Karate-Lambda-chalothrin) and decreased pest intensity from 0.95 to 0.02 larvae per plant by the 4^{th} application.

Torres *et al.* (2001) reported 100 per cent mortality against *P. xylostella* larvae with 10 per cent aqueous solution of the wood bark of *A. pyrifolium* in Brazil. Bruce *et al.* (2004) reported that application of neem oil at 0.075 ml per maize plant leads to a reduction in the number of eggs laid by *Sesamia calamistis* Hampson and *Eldana saccharina* Walker of 88 and 49 per cent respectively, compared with the control. Field studies showed that the volatiles emitted from neem cake were effective in controlling diamond back moth. DBM, *P. xylostella* of cabbage, a notorious insect pest is known to develop resistance against most of the commercially available pesticides and other insects affecting vegetable crops (Krishnamoorthy *et al.,* 2004). Oviposition deterrence was also observed in *Mussidia nigrivenella* Ragonot by Agboka *et al.* (2009) and who reported significantly higher oviposition deterrence index with neem oil at 2.5 and 5 per cent. Among the host plants where DBM oviposit, *Barbarea vulgaris* represents a paradox because larvae cannot survive on some varieties and types of this plant despite strong stimulation of oviposition (Badenes-Perez *et al.,* 2006).

Seljasen and Meadow (2006) reported that the concentration of the active ingredient azadirachtin-A needed to protect plants from damage by 2nd instar larvae was 8 mg/ml. The lethal doses for 2nd instar larvae were determined by probit analysis to be 6.2 and 17.2 mg/ml for LC50 and LC95, respectively. Neem, *Azadirachta indica* A. Juss. has insecticidal properties, acaricide, nematocide, pest repellency, antifeedant, and impaired growth regulation, antifungal, antibacterial, *etc.* reported by Schmutterer (1990); Charleston (2004). Extracts of *Lantana* leaves were studied for their phytochemical constituents and termiticidal effects against adult termite workers. The 5% chloroform extract was found to be significantly effective against termite workers reported by Rajesh and Suman (2006).

Charleston *et al.* (2006) indicated that *Pungamia pinnata* Zomera oil may attract more natural enemies of *P. xylostella* larvae and thus increase natural parasitizing levels of DBM larvae. Chloroform extract of *L. camara var. aculeata* at a concentration of 5 per cent was found to be significantly effective against termite workers (Verma and Verma, 2006). Pongam oil is shown to possess insecticidal, repellent and anti oviposition properties (Pavela and Herda, 2007). Prakash *et al.* (2008) and Pavela (2009) reported that plants are the rich source of bio-active organic chemicals and many botanicals have been successfully exploited as insecticides all the tested botanical insecticides showed good efficiency on the mortality of *P. xylostella* larvae. Botanicals affect the colonization and feeding of DBM. Weekly dusting of one part of finely ground derris root with nine parts of talc gave good control of *P. xylostella*. Synergists sesamex and piprotol improved three fold the effectiveness of neem kernel extract against *P. xylostella*. Piperonylbutoxide enhanced the effectiveness of enriched neem seed extracts, escalating the mortality of diamondback moth larvae.

Neem oil (2%) and Neem seed kernel extracts (NSKE) 5 per cent are effective in checking the DBM larval population in Tamil Nadu reported by Kalyanasundaram, (1995). Sharma *et al.* (1992) reported that the *Lantana* leaf aqueous extract repellency effect decreased with the increase in the treatment time in both the cases i.e. from 32.9 per cent larvae repelled after 2 hours to 8.8 per cent larvae repelled after 6 hours against *P. brassicae* larvae @10% concentration. Kodjo *et al.* (2011) stated that the effect of different treatments of *Ricinus communis* plant extract (20%) and oil emulsion (5 and 10%)

and their persistence (0, 3 and 5 days after application) on mortality and oviposition behaviour of *P. xylostella* were tested in laboratory and field cage experiments.

In general, *R. communis* products have strong larvicidal effect on *P. xylostella,* with 100% mortality recorded on third instars larvae treated with oil emulsion (10%) in both ingestion and contact toxicity tests. Aqueous extracts were significantly less toxic with the highest mortality rates (67.49 ± 1.98% and 70.86 ± 0.85%) recorded with seed kernel extract and the lowest with the root extract (53.98 ± 1.21% and 54.87 ± 1.88%), in topical toxicity and ingestion toxicity experiments, respectively. The adult emergence was significantly affected with the lowest emergence rate recorded in oil emulsion (5%), 57.72 ± 72 and 49.98 ± 0.98 per cent in topical toxicity and ingestion toxicity tests, respectively. Among emerged adults from larvae treated with oil and aqueous extracts caused to 44 -79 per cent abnormal development as wings and legs deformation were observed.

Cleistanthus collinus Benth popularly known as Oduvan (Tamil) result of chloroform fraction (7.5 %) of both leaf and bark extracts was found to have 40 per cent insecticidal activity against *P. xylostella* (Bagde *et al*., 2013). Razmjoo *et al.* (2013) reported that *P. xylostella* larvae mortality rates between the concentration extracts (3, 5 and 10 g) showed a significant difference (F2, 72 =7.063 P< 0.001). Average mortality of ten grams extracts are (55/13) percent, five grams (44/14) and three grams (19/97) percent, respectively. Significant difference found with ten grams of extract, the extract of three and five grams extract did not show any significant difference. At a concentration of 0.5 per cent (w/v), an aqueous emulsion of ethanol seed extract was 2.5 fold more effective than 1.0 per cent rotenone, a commercial botanical insecticide. Crude aqueous seed extracts showed good efficacy comparable to pyrethrum, the most widely used botanical insecticide. Seed extract of *Annona squamosa* Linn. 0.5 per cent is a promising candidate for development as a simple botanical insecticide against diamondback moth for local use in rural Indonesia (Leatemia and Isman, 2004).

Pathak *et al.* (2014) revealed that methanol extract of *Lantana camara* (L.) leaves extract of methanol found more effective than ethanol as methanol has been inhibited by 2.8 per cent infected leaf compare to 1.1 per cent increase by ethanol extract against teak skeletonizer, *Eutectona macheralis* Walk.in forest nursery. Odewole and Adebayo (2014) evaluated the efficacy of three plant extracts, *Tephrosia vogelli* Hooks, *Zingiber officinales* Rosh and *Lantana* spanish flag, applied at 5, 10 and 25 per cent (w/v) concentrations *Z. officinales* extract effectively control *P. xylostella* larvae at all concentrations with 25 per cent gave the best yield while *T. vogelii* and *L. camara* extracts were as effective as deltamethrin at different concentrations in cabbage crop.

Te efficacy of 3 plant extracts, *Tephrosia vogelli* Hooks, *Zingiber officinales* Rosh and *Lantana* applied at 5, 10 and 25 per cent (w/v) concentrations delthamethrin and an unsprayed plot were included as positive and negative controls respectively. *Z. officinales* extract effectively control *P. xylostella* larvae at all concentrations with 25 per cent gave the best yield of 0.50 kg/plant while *T. vogelii* and *Lantana* extracts were as effective as deltamethrin at different concentrations of effective botanicals against diamondback moth adult and larvae of cabbage can be formulated from extract of *T. vogelii*, *L. camara* and *Z. officinales* at 25 per cent concentration respectively (Odewole and Adebayo, 2014).

Alao and Adebayo (2015) reported that plant extracts did not show any significant difference in treated plants with respect to three concentrations of *Tephrosia vogelii* and *Moringa oleifera* Lam. extracts (5, 10 and 20%) at 1st and 2nd WAT. At 2nd WAT, plant extracts were significantly effective in the control of *Dacus cucurbitae* Coquuillet compared with untreated. Plants treated with plant extracts at highest concentration had a significant ($P < 0.05$) reduction in the infestation level *D. cucurbitae* as observed in the synthetic insecticide (Lambda cyhalothrin) treated plants. Although there was no significant difference between plots treated with *M. oleifera* at 10% and 20% at 3rd and 4th WAT but the population densities of *D. cucurbitae* was slightly higher in the plots treated with 10 per cent.

2.2.2. Botanical insecticide and natural enemies

The neem extract solution did not affect the *C. plutellae* populations the only endo parasite natural enemy present. The absence of any disturbing effects due to azadirachtin on the parasitoid populations has been already reported (Schmuttterer, 1990; Leskovar and

Boales, 1996). Goudegnon *et al.* (2000) supported that *Cotesia* populations could have developed an acquired tolerance to neem over years of contact allowing the adults to continue to search for DBM larvae to be parasitized.

Charleston *et al.* (2006) reported that results from the analysis of variance indicated that there were no significant differences between the survival of the parasitoids exposed to the different *M. azedarach* extracts ($F6, 383=1.14$, $P=0.341$ - *C. plutellae* and $F6, 290=0.44$, $P=0.852$ *D. collaris*), and in fact they lived for a slightly longer period on the treated strips of filter paper. Mortality was high at the beginning of the period, with a few individuals surviving for longer periods. Among *C. plutellae,* mortality had reached approximately 50 per cent by the 5^{th} day, with a maximum survival of 34 days for one individual. *Diadromus collaris* is a much longer-lived and again the plant extracts did not appear to have any significantly negative impact on the parasitoid, with mortality reaching approximately 50 per cent by the 18^{th} day, with a maximum survival of 184 days for an individual.

Effect of botanicals on the foraging behavior of the mealybug predator *Cryptolaemus montrouzieri* Mulsant, predator larvae and adults were exposed to leaves and the mealybug *Planococcus citri* (Risso) treated with one of the following: a crude neem seed extract; a formulation of azadirachtin a pyrethrum extract; and one of two naphthoquinones isolated from *Calceolaria andina* Benth. Simmonds *et al.* (2000), he also reported naphthoquinones decreased the number of times *C. montrouzieri* moved from leaf to leaf and the time they spent on treated leaves. The beetles also consumed fewer naphthoquinone-treated than untreated mealybugs. The results suggest that the naphthoquinones would reduce the foraging efficiency of the predator on naphthoquinone-treated leaves. However, if this resulted in the beetles seeking out untreated mealybugs on untreated foliage, perhaps their efficiency in controlling mealybugs would be increased.

2.2.3. Botanical insecticides to non-target organism

The use of botanical insecticides has recently been promoted as an alternative pest control method, especially in crop systems where the conventional synthetic insecticides have limited use, such as in agro ecological farming and organic agricultural systems

(Isman, 2006; Duke *et al.* 2010). However, botanical insecticides might cause adverse effects to non-target organisms such as bees (Koskor *et al.* 2009 and Xavier *et al.* 2010). The repellent effects of garlic and citronella extracts on *A. mellifera* were also observed by Nicodemo and Nogueira Couto (2004). However, Naumann *et al.* (1994) found that although foragers were deterred from feeding on sugar solutions with extremely low concentrations of azadirachtin, no significant reduction was noted in the foraging bees in canola fields sprayed with neem insecticide. Although Melathopoulos *et al.* (2000) did not observe negative effects of neem on adult honey bees; they observed that this insecticide reduced the amount of larvae in colonies and, at sub lethal doses, different malformations occurred when the bees emerged from the cocoons. Rembold *et al.* (1980) found that neem oil extracts were acutely toxic to immature honey bees and adult workers of *A. mellifera* with an increased exposure time of the bees to different concentrations of neem oil.

Xavier *et al.* (2010) showed that *A. mellifera* is the main pollinator of crop plants. With the increased emphasis on organic agriculture, the use of botanical insecticides has also increased. Assessing the acute toxicity and sub lethal behavioural effects of botanical insecticides such as andiroba oil, citronella oil, eucalyptus oil, garlic extract, neem oil, and rotenone on honey bees, *A. mellifera*. Adult workers that ingested citronella oil, eucalyptus oil, garlic extract, neem oil, or rotenone suffered from 42 to 60 per cent higher mortality rates than workers fed with uncontaminated control diets. Only the andiroba oil did not increase the adult worker mortality. Worker larvae exposed to dietary andiroba oil, garlic extract, and neem oil experienced an increased mortality compared with workers fed on control diets.

The garlic extract and neem oil induced toxicity to both larvae and adult worker bees. The citronella oil, eucalyptus oil, and rotenone demonstrated toxicity only to adult worker bees, but the andiroba oil was toxic to larvae only. All these botanical insecticides were repellent to *A. mellifera* adult workers. In addition, the eucalyptus oil, garlic extract, neem oil, and rotenone decreased the rate of walking activity in adult bees. The results demonstrate the potential acute toxicity and sub lethal effects of botanical insecticides on honey bees and provide evidence of the importance of assessing the risks of the side effects of biopesticide, often touted as environmentally friendly, to non-target organisms such as pollinators (Xavier *et al.,* 2015).

2.3. Isolation, identification and characterizations of volatile chemical compounds of *Lantana camara* var. *aculeata* by using GC-MS

2.3.1. *Lantana* extracts with Organic solvents

The genus *Lantana* (Verbenaceae), as described by Linnaeus in 1753, contained seven species, six from South America and one from Ethiopia. They are rich source of secondary metabolites with interesting biological activities. In general, these secondary metabolites are an important source with a variety of structural arrangements and properties.

Khan *et al.* (2000) stated that the chemical composition of leaves and flowers essential oils of *L. camara* from India were analyzed by GC–MS, which resulted in the identification of 71 and 64 constituents, representing 99.0 and 97.0 per cent of the oils, respectively. The major constituents in the leaf oil were germacrene-D (20.5%), γ -elemene (10.3%), β-caryophyllene (9.4%), β-elemene (7.3%), α-copaene (5.0%) and α -cadinene (3.3%), while the major constituents in the flower oil were β-elemene (14.5%), germacrene-D (10.6%), α-copaene (10.7%), α - cadinene (7.2%), β-caryophyllene (7.0%) and γ-elemene (6.8%). A comparison with the chemical composition of *L. camara* oils of different origin showed that our oils were significantly different from others with respect to their major constituents. Steam distilled essential oil obtained from the leaves of *Lantana indica* Roxb was analyzed by capillary Gas Chromatography (GC) and Gas Chromatography Mass Spectrometry. These phyto chemicals identified from the *Lantana* oil were trans-caryophyllene, α-selinene, globulol, trans-caryophyllene oxide, α-guaiene, valencene, humulene, and β-eudesmene (Akhtar *et al.,* 2006).

The oilextracted through supercritical state mainly consisted of (E)-caryo-phyllene (7.8%), α-humulene (9.6%), (E)-β-farnesene (2.5%), allo-aromadendrene (4.8%), γ-curcumene (7.6%), arcurcumene (38.7%), α-zingiberene (7.8%), curcumene (3.2%), 7-epi-α-selinene (2.4%) and β-sesquiphellandrene (2.4%). The main difference between SFE and HD oils was the content of arcurcumene, β-curcumene and β- farnesene, which are higher in SFE product and the content of (E)-caryophyllene and α-humulene which are higher in the HD product (Marongiu *et al.*, 2007).

Barbosa *et al.* (2012) stated that a comparative study of the chemical composition of essential oils of two very similar species (*Lantana camara* and *L. radula*) revealed that the main components of essential oil of *L. camara* were germacrene-D (19.8%) and E-caryophyllene (19.7%), while those of *L. radula* were E-caryophyllene (25.3%), phytol (29.2%) and E-nerolidol (19.0%).

Oil extracted from the leaves of *Lantana* by hydro-distillation was processed for bioactive molecules of insecticidal action against the teak defoliator, *Hyblaea puera* Cramer. Oil fraction analysed by GC/MS/MS has revealed about 36 compounds were characterized from essential oil of *Lantana*, some of them like α- copaene, germacrene D and B, α – cubebene, β – elemene, α – guaiene, α – humulene, aromadendrene, β – selinene, α – selinene, caryophyllene oxide, nerolidol, spathulenol and delta – cadinene, bicyclo [5.2.0] nonan, 2-methyl have expressed tritrophic interactions as reported by earlier findings as well as insecticidal activity in terms of larval mortality against teak defoliator Murugesan *et al*. (2012). Hence, he reported that biological control is intimately linked with the allelochemical web involving plant, pest, parasitoid, and predator, resulting in a tritrophic or sometimes a tetratrophic level of interaction. For effective manipulation of the communication systems involved in this complex allelochemical relationship, an understanding of the direct or indirect, beneficial or detrimental effects of plant secretions on phytophagous insects and their natural enemies is important.

The determination of the chemical profile of essential oil from the leaves of *Lantana* was done by hydro distillation method. Gas Chromatograph coupled with Mass Spectrometer (GC-MS) was used for chemical analysis and eighteen constituents were identified, representing 100 per cent composition of the oil. The constituents were mainly monoterpenes and sesquiterpenes. The major constituents were found to be caryophllene oxide (21.75%), (-) -spathulenol (14.95%), D-nerolidol (10.39%) and (-) -β-caryophyllene (9.90%). The yield of essential oil obtained was 0.19%. The essential oil of *L. camara* leaves is worth exploiting for use by relevant industries suggested by Jawonisi and Adoga (2013).

2.3.2. Head space volatiles

Van Langenhove *et al.* (1991) reported that active compounds *viz.,* thiols, polysulphides, sulphides, isothiocyanates, nitriles, carbonyl compounds, furans, esters and terpenes were identified in the head space of both vegetables. Isothiocyanates and nitriles were predominant in brussels sprouts whereas aldehydes were the most abundant cauliflower volatiles. 2-Methylbutyl isothiocyanate and 3-methylpentanenitrile, breakdown products of 2-methylbutyl glucosinolate, were identified in the head space of brussels sprouts. In cauliflower, aldehydes are 70.80 per cent of head space volatiles in laboratory experiments and 75.10 per cent of volatiles in industrial samples. Glucosinolate breakdown products and organic sulphur compounds represent 15 per cent in cauliflower.

The methanol extract of leaf samples of *Tagetes erecta* L. were injected for screening of total bioactive compounds in GC- MS analyses. About 19 numbers of bio compounds were identified from leaf extract samples. The retention time taken by the bioactive compounds of leaf sample varied from 16.015 to 27.349 second and the area percentage varied from 0.72 to 16.45. The list of bioactive compounds from the leaf sample *viz.,* tetra decanoic acid, 2,6,10- trimethyl 14 – ethylene – 14 – pemtadecme, butanoic acid, 3,7 – dimethyl 6 – octenyl ester, citronellyl isobutyrate, heptadecanoic acid, methyl ester, 9-mexadecenoic acid, N – hexadecanmic acid, phosphorothoic acid, 0,0-diethyl 0-(3,5,6 – trichloro-2 pridinyl) ester, tetradecanoic acid, ethyl ester, 15-hydroxy penta decanoic acid, hexcadecadienoic acid, methyl ester, 2,15 – octadecatrienoic acid, ethyl ester (2,2,2), Cis – 9 –hexa decenal, 15- hydroxy penta decanoicacid, 15-hydroxy-3-(9E)-9-octadecenoyloxy, Propyl(9E)-9-Octadecenoate, celidoniol, deoxy, alpha – tacopherol – buta – D – mannoside and stigmasterol are reported by Devika and Justin (2014) and they also suggested the phytochemicals are used as antibacterial, antimicrobial, insecticides, nematicides and are highly effective in wound healing activities.

Potter and Fagerson (1990) reported important volatiles recovered from the fresh green leaves of coriander by steam distillation with pentane and analysed by capillary Gas Chromatography-Mass Spectrometry. A total of 41 compounds were detected among these (E)-2-decenal more dominant (46.1%) followed by (E)-2-dodecenal (10.3%). Constituents identified included alkenals in the C_9-C_{16} range, C_7-C_{17}, alkanals, C_{10}-C_{12}

primary alkenols, alkanols, and nonane. The estimated mass of volatiles recovered was 4 mg/g (wet weight of leaves) with aldehydes accounting for 82.6 per cent and alcohols 16.6 per cent of the compounds detected.

Lanzotti (2006) revealed that activities are related to the thiosulfinates, volatile sulfur compounds, which are also responsible for the pungent of the vegetables. Besides, these low-molecular weight compounds, onion and garlic were characterized by more polar compounds of phenolic and steroidal origin, often glycosilated, showing interesting pharmacological properties. These compounds, compared to the more studied thiosulfinates, present the advantages to be not pungent and more stable to cooking. The stability of thiosulfinates in freshly prepared extracts from garlic powder stored 4 days at room temperature (293 K), and in extracts from powder stored for 18 months at 278 K was analyzed by HPLC. Allicin, allyl-methyl-/methyl-allyl-thiosulfinate and dimethyl-thiosulfinate were the most representative components in freshly extracts from garlic bulbs.

Msaada *et al.* (2007) reported that the essential oils composition of coriander, *Coriandrum sativum* L. fruits obtained by GC-MS. Essential oil yields showed marked increase during maturation process and forty one compoundswere identified. Geranyl acetate (46.27%), linalool (10.96%), nerol (1.53%) and neral (1.42%) were the main compounds at the first stage of maturity (immature fruits). At the middle stage, linalool (76.33%), cis-dihydrocarvone (3.21%) and geranyl acetate (2.85%) were reported as the main constituents. Essential oils at the final stage of maturity (mature fruits) consist mainly on linalool (87.54%) and cis-dihydrocarvone (2.36%).

2.4. Effect of intercropping on the incidence of diamondback moth and natural enemies

Intercropping is regular cultural practices are well known in many parts of the world for a variety of reasons. Intercropping of field vegetable crops with other crops shows insect pest suppression which may reduce chemical control and fits into environmentally acceptable and sustainable production practices. Physical factors like protection from wind, shading, sheltering, prevention of dispersal, alteration of colour etc. and biological factors like presence of natural enemies, production of adverse chemical stimuli etc. in intercropping system may influence the pest population build-up (Andow, 1986 and Theunissen, 1994).

2.4.1. Cabbage

Burandy and Raros (1973) reported that eggs and adults of *P. xylostella* were more in cabbage sole crop than in the intercropped with tomato. They concluded that *P. xylostella* adults were repelled by volatile compounds emitted by tomatoes. The olfactory stimulus to insect pests offered by the main crop could be camouflaged by various intercrops. In intercropping systems many photophilic pests avoid short crops, when they are shaded by taller crops. The taller crops also check the dispersal of the flying pests of shorter crop (Gerard, 1976). Jayarathnam (1977) suggested that cabbage could be intercropped with tomato so as to reduce pest incidence. The repellent action of tomato was essentially due to emission of volatile compounds and presence of inhibitors like coumarin.

Srinivasan (1991) reported that tomato and Indian mustard grown as intercrop, influence in reducing pest damage to cauliflower due to characteristic repellent odour that each of them possess. Intercropping cabbage with tomatoes, garlic, dill, safflower, clover, oat and barley has been shown to reduce the density of *P. xylostella* on cabbage plants (Talekar *et al.,* 1992). However, large-scale experiments to test the repellences of these plants in the field have yielded inconsistent results (Latheef and Irwin, 1983).

Crops like sunflower grow tall, act as a barrier against pests, which are carried by winds over distances and also provide lot of pollen, so it act as a better niche to natural enemies. Populations of *P. cruciferae* and *B. brassicae* were lower on cabbage grown with any living mulch than on cabbage sole crop (Andow *et al.,* 1986). Kowalska (1986) reported that cabbage having lucerne as a cover crop had less infestation of cabbage aphid *B. brassicae* because of more syrphids on lucerne. Talekar *et al.* (1986) tested 54 intercrops with cabbage, dill, garlic, oat and tomato had relatively less *P. xylostella*.

Srinivasan (1984) later successfully demonstrated the usefulness of mustard as trap crop. Alternate rows of mustard and cabbage had lower numbers of *P. xylostella* larvae and pupae on the cabbages as compared to those on the pure stand cabbage.

Similarly, garlic as intercrop of cabbage also has been reported to decrease larvae of *P. xylostella* numbers (Talekar *et al.,* 1986). Srinivasan and Krishnamoorthy (1991) reported that 15 rows of cabbage followed by 2 rows of mustard was most promising for successful management of *P. xylostella* and *C. binotalis* as these pests preferred mustard compared to cabbage. One row of mustard was sown 15 days before and other one 25 days after cabbage transplanting. The confusing olfactory and visual cues received from host and non-host plants, leading to disruption of mating, are believed to be partly responsible for the reduction in larval numbers, while tomato is known to release certain volatile chemicals, which have a repellent action on the adults. Srinivasan and Krishnamoorthy (1991) indicated that intercropped cabbage could be raised successfully during the rainy season without insecticidal application, while 2nd sprays with 0.5% cartaphydrochloride or 500 g/ha; its dose reduced *P. xylostella* population by 71.3 to 80.5 per cent.

Ferguson and Baratt (1993) found that African marigold, *Tagetes erecta* as companion crop in cabbage gave higher yield than endosulfan, methyl-demeton, lambda cyhalothrin treatment under high incidence of *P. brassicae*. Trap cropping with Indian mustard in cabbage was not effective against *P. xylostella* and *S. litura* (Krott *et al.,* 1995). Theunissen *et al.,* (1995) observed less infestation of cabbage moth and cabbage aphid, *B. brassica* on cabbage when, it was intercropped with clover *Trifolium repens* L. and *T. sutterraneum*.

Srinivasan (1984) found that tomato intercropped with cabbage has been reported to inhibit that the oviposition on cabbages. In Hawaii, reported that Indian mustard was not preferentially attractive to DBM, but showed potential use as trap crops for *Helulla undalis* (Fabricius), *Trichoplusia ni* (Hübner) and *Chrysodeixis eriosoma* (Doubleday). The effect of intercropping with tomato, coriander and garlic, combined with the application of neem seed kernel extract was found to be even more efficient in protecting cabbage plants in the field. In fact, the cabbage-tomato-neem combination treatment was observed to be comparable to that of the recommended insecticide, (Cartap hydrochloride), with respect to the number of diamondback moth larvae and pupae, number of infested cabbage plants per plot and the quality of harvested heads (Facknath, 1996). Subrahmanyam (1998) found mustard as a trap crop in cabbage was not economically feasible for the control of *P. xylostella* because it occupied more space and the value of main crop, cabbage lost.

Nentwig (1998) found that planting of sweet alyssum (*Lobularia maritime* Linnaeus) around cabbage fields is to increase longevity of parasitic wasps that are beneficial in reducing pest populations in the field. Bender *et al.* (1999) revealed that cabbage inter-cropping with Indian mustard had no significant effect on the number of lepidopterous larvae on cabbage. Indian mustard did not preferentially attract lepidopterous insects but was highly attractive to hemipteran insect, *Murgantia histrionica* (Hahn) in Texas. Intercropping of cabbage with tomato, *Lycopersicon esculentum* Mill and fava bean, *Vicia fava* L. did not reduce the number of DBM eggs laid on cabbage (Badenes-perez *et al.,* 2005).

Mitchell *et al.* (1999) showed that densities of *P. xylostella* never exceeded the action threshold of 0.3 larvae per plant in cabbage fields that were surrounded by collards, but did exceed threshold in three out of nine fields of conventional monoculture cabbage. Moreover, the numbers of insecticide applications were greatly reduced in cabbage surrounded by collards compared with conventional cabbage, but with no reduction in marketable yield. Singh and Singh (1999) reported that marigold, fenugreek, coriander and mustard were effective in reducing pests and increasing yield of cabbage.

Hooks and Johnson (2002) compared the preference of broccoli intercropped with tomato or yellow sweet clover and monoculture. It showed that incidence of cabbage worm, *Artogeia rapae* L. was greater in monoculture compared with intercropped plantings. The mean percentage of broccoli heads infested with insects and associated frass were higher in monocultures than in intercropped crops. Hooks and Johnson, (2002) reported that yellow sweet clover intercropped with broccoli reduced imported cabbage worm and cabbage looper numbers on broccoli heads, but did not increase insect pest predation. Yellow sweet clover and white clover intercropped with broccoli resulted in late season increase in the abundance of spiders and overall reduction of lepidopteran pests on broccoli foliage. Asare-Bediako *et al.* (2010), however, stated that intercropping cabbage with non-host crops such as onion and tomato significantly reduced *P. xylostella* numbers on cabbage.

2.4.2. Cauliflower

Hokkanen (1991) found that cauliflower with marigold and sunflower as a trap crop to reduce the incidence of rape blossom beetle, *Meligethes aeneus* Fab. The biology significantly varies on cauliflower, cabbage, mustard, radish, knol-khol, turnip, beetroot, amaranthus and weed host. There was no variation in the egg period. Larvae developed much faster (8.5days) and pupate on cauliflower. Pupal period was shorter and adult emergence was more on cauliflower. Fecundity was higher on mustard (366 eggs/female), followed by cauliflower, cabbage, radish and knol-khol. The larvae consumed and gained more weight on cauliflower than on other host plants reported by Kalyanasundaram (1995).

Sunflower, radish, tomato and marigold produced more amounts of pollens and some unknown volatiles to attract the coccinellids. Goel *et al.* (2004) reported that cauliflower intercropped with safflower, marigold and tomato were superior over monoculture in reducing aphid population on cauliflower. Low incidence of insect pests in intercropping system with non-host plants compared to sole crop may be attributed to change in microclimatic conditions of particular ecosystem, which created difficulties to the pest in host selection through masking effects or chemical repellency due to intercrops (Gupta and Chourasia, 2004).

The parasitism rate and the caterpillar infestation were studied by intercropping *Dendranthema* flowering plants with some cruciferous crops. These flowering plants increased significantly the rate of *C. plutellae* parasitism in the adjacent plots. It reached to 42.96 per cent in treatment plot and 18.19 per cent in the control. Although there was no significant difference in number of diamondback moth larvae per plant, 29.09 per cent in population reduction was occurred in treatment plot. Therefore, intercropping of *Dendranthema* flowering plants is effective in cruciferous crop cultivation reported. Guan-Soon (1991) found that refuge or shelter plants will become important in the control of DBM as they provide food for the survival of parasitoids, particularly in avoiding excessive pesticide sprays. These plants include many species of wild flowering plants and cultivated legumes (e.g. beans and peas). Planting selected flowers into brassicaceous crops could enhance control of the diamondback moth by parasitic wasps suggested by Malaysia Riley (2006).

2.4.3. Other crops

Patel and Yadav (1992) revealed that the larval population of *Helicoverpa armigera* Hübner was more on marigold than main crop tobacco intercropped at 2:6 rows. Ramert (1993) found that intercropping with lucerne reduced the infestation of carrot rust fly, *Psila rosae* Fab. in carrot compared with monoculture. Planting collards in field peripheries may be an effective tactic to manage *P. xylostella* in crops such as cabbage or broccoli, because collard plants are more attractive to *P. xylostella* than other crucifer vegetables (Mitchell *et al,.* 1997). Virk *et al.* (2004) reported that beans, maize, okra, sunflower and pigeon pea act as a trap crop increasing parasitation of *Trichogramma chilonis* Ishii in cotton. Potting *et al.* (1999) reported that *P. xylostella* damaged *B. napus* plants was attractive to the parasitoid *C. plutellae*. The induced compounds should contain the chemical information needed by predators and parasitoids to locate their hosts.

Reddy *et al.* (2006) observed when chilli was intercropped with either brinjal, bhendi, garlic, onion, marigold, maize or beans, sucking pests of chilli crop were low compared to monoculture of chilli crop. Scholz and Parker (2004) found that intercropping cotton with sorghum encouraged the establishment and population growth of *Trichogramma* spp. and two species of predatory beetles in cotton. Inoculative releases of *Trichogramma* spp. were able to establish the parasite in cotton intercropped with sorghum better than in cotton alone and predatory beetles moved from sorghum to cotton.

Sharma *et al.* (1992) revealed that interplant maize/cowpea acted as source of predator due to diverse microhabitats, greater availability of food sources such as prey, nectar and pollen, all of which encouraged colonization and buildup of natural enemies, compared with cotton monoculture having lesser biodiversity. Surulivelu (2006) reported that intercropping with black gram and chillies reduced the intensity of bollworms infestation in cotton.

Chamuene *et al.* (2007) revealed sorghum, pigeon pea and *Crotalaria orchroleuca* G. Don strip intercropped with cotton had fewer *H. armigera* and *A. gossypii* infested plants and abundant population of natural enemies like syrphids, green lacewings and spiders. Elanchezhyan *et al.* (2008) evaluated 13 crops as intercrops in brinjal and found that population of natural enemies like coccinellids, syrphids and spiders were high in brinjal intercropped with cluster bean, recording 4.3, 3.1 and 1.9 number per plant, respectively as compared to brinjal pure crop. Damage done by fruit borer and whiteflies were very low and also less incidence of *Aphis gossypii* in intercropped brinjal.

Rao *et al.* (2012) revealed that the peak activity of coccinellids was recorded during the formation of capsule in all intercropping systems. The coccinellid population varied significantly across intercropping systems throughout the crop growth period. Systems like castor + cluster bean, castor + cowpea, castor + black gram, castor + green gram, and castor + groundnut had significantly higher populations of coccinellids than the other intercropping systems. The fluctuation of the spider population was significant among intercropping systems, and the spider activity was significantly higher in castor + cluster bean (0.41 per plant). Sule (2013) found that intercropping cowpea with sorghum significantly reduced aphid and thrips population than in sole cowpea varieties at the age of 30 and 40 days.

Chakravarthy *et al.* (1997) reported that increased parasitism might be due to the availability of nectar, pollen and existence of favorable microclimate in intercropped zones of agro ecosystem and increased natural enemy *viz.,* coccinellids and chrysopids by conservation. Gurr *et al.* (2004) reported that flowering plants could increase the fecundity and longevity of parasitic hymenoptera and predators. In addition to increasing natural enemy fitness, improved nutrition may had also enhanced foraging behavior and increased the female-based sex ratio of parasitoid offsprings. They also indicated that a wide variety of natural enemies utilized non-prey food sources. For example, pollen and nectar had been demonstrated to be highly attractive to variety of predators including syrphids, coccinellids and chrysopids. The main insect pests recorded were *Diabrotica* spp. (Coleoptera: Chrysomelidae), *Carpophilus* sp. (Coleoptera: Nitidulidae) and *Pagiocerus frontalis* (Coleoptera: Scolytidae), and their overall abundance did not differ among crop diversity treatments. However, there was a significant adverse effect of crop diversity on the maximum abundance of both *Carpophilus* and *Pagiocerus*. The main beneficial arthropods were *Paratriphleps* sp. (Hemiptera: Anthocoridae), ladybirds and spiders, and their density did not differ among treatments. Maize yield did not decrease with increasing plant diversity. The reported benefits of intercropping, together with the associated efficiency in land use, make this traditional agricultural practice a valuable alternative to the use of pesticides, particularly for resource-poor farmers suggested by Gianoli (2006).

Venugopala Rao *et al.* (1995) observed low incidence of *H. armigera* in cotton intercropped with cluster bean and cowpea and enhanced abundance of natural enemies. Van Denberg and Cock (1995) observed irreplaceable mortality of *H. armigera* due to natural enemies in cotton in western Kenya due to ants, the predominant crawling predators, whereas anthocorids were predominant flying predators. In Southern India, intercropping system of cowpea and onion in cotton was recommended for the conservation of natural enemy complex including chrysopids, ladybird beetles and syrphid flies. Increasing crop diversity normally favoured the population of the natural enemies of pests (Edwards *et al*., 1992).

Mote *et al*. (2001) recorded more number of predators and parasitoids from cotton + cowpea intercropping system and minimum sucking pests and bollworm damage. Dhanasekaran (2014) reported that cotton intercropped with okra, sunflower, cowpea and maize resulted in lower infestation of *P. gossypiella* on flower, boll and locule of cotton. Preference ratio of *P. gossypiella* was high for bhendi and low for cowpea. These intercropping systems also registered higher population of predatory coccinellids, kapas yield and highest cost benefit ratio. Bharathi and Muthukrishnan (2014) found that cotton intercropped with cow pea, green gram and black gram resulted in lower population of *P. solenopsis*.

Similarly, okra + cowpea and okra + sunflower intercropping systems influenced for the highest population of natural enemies on okra. Okra + coriander and okra + maize also resulted for moderate population of natural enemies on okra. However, okra + marigold, okra + alfalfa and okra had effected for minimum population of natural enemies on okra. Occurrence ratio for natural enemies, yield and cost benefit ratio were high on okra + cowpea, okra + sunflower and okra + maize intercropping systems, and low on okra + coriander, okra + marigold and okra + alfalfa intercropping systems (Deebika, 2016).

2.5. Synergistic effect of allyl-isothiocyanate (AITC) along with sex pheromone lure in field and laboratory

The better understanding of pest dynamics and potential, their seasonal abundance in different locations, knowledge on effective lures and traps can serve as base information for developing forecasting models. Pests included in the study were *Helicoverpa armigera* (Hübner) on tomato, *Earias insulana* Boisduval on okra, *Leucinodes orbonalis* Gueneeon on brinjal, *Spodoptera litura* (Fabricius) on potato and *P. xylostella* on cabbage reviewed by Prasannakumar *et al.* (2009) and they also reported the larval incidence of *H. armigera* on tomato commenced in the 43rd standard week (October 4th week). The maximum fruit damage recorded was 4.72 per cent. The initial damage on buds and flowers was recorded during 43rd standard week. The fruit borer moth catches reflected on the larval incidence, i.e. when moth catches increased the number of fruits damaged decreased. However, there was a gap of four weeks between the two. That is to say the moth catches were indicative of larval incidence and management practices are to be initiated within two weeks of the commencement of moth catches.

The diamondback moth, *P. xylostella* larval incidence commenced during July 4th week, when the crop was five weeks old (7.21 larvae/ head) and reached maximum (11.50 larvae/ head) three weeks before the maximum (31.23 moths/ trap) trap catches. The incidence and trap catches decreased gradually as the crop matured and reached the lowest incidence (1.13%) with the trap catches 1.36 moths/trap during 44th (November first week) standard week. These results suggested that the moth catches were indicative of the field incidence. The larval incidence and moth catches decreased as the crop matured. A similar trend in the DBM moth catches was reported by Chandramohan (1995) and Reddy and Urs (1996).

In field tests in Hungary, Slovenia and Bulgaria, in allyl isothiocyanate-baited traps significantly attracted more beetles of *Phyllotreta cruciferae*, *P. vittula*, *P. undulata*, *P. nigripes, P. nodicornis, P. balcanica, P. atra, P. procera, P. ochripes, P. diademata* and *Psylliodes chrysocephalus* (Coleoptera: Chrysomelidae) captured than in unbaited control traps. With the exception of *P. cruciferae*, this is the first report on significant field attraction by allyl-isothiocyanate for these species. The species spectrum captured included six important agricultural pests. At all sites a great portion of the catch (ranging from 30 to 98%) was *P. cruciferae*, irrespective of the plant culture. The second most abundant species present at most sites was *P. vittula* observed by Toth and Ujvary (2007). The DBMs are weak flyer but are readily carried by prevailing winds and are thus highly dispersive and long distance migrations leads to *P. xylostella* has continuous generations in the tropics and sub-tropics (Fu wei *et al.,* 2013; Chapman *et al.,* 2002).

The five traps, *viz.,* Delta, PCI, ICRISAT, Water trap and improved water trap were evaluated for diamondback moth catch both in seedling beds and main fields of cabbage, cauliflower and knol-khol at three locations *viz.,* one trap per four beds was set up at a height of 30 cm above the seedling canopy and observations on the trap catches were recorded at weekly intervals for four weeks after sowing (Chisholm *et al.,* 1979). Ando *et al.* (1979) reported that sticky (delta) traps baited with sex pheromone were the effective traps to capture diamondback moth.

2.5.1. Use of olfactometer in behavioural bioassay of insect pests

Semiochemicals helped natural enemies locate and recognize their host or prey (Lewis and Lewis, 1977; Vet and Dicke, 1992). Therefore, knowledge of the nature of these chemicals and their functional roles is important in the design of programs that use parasitoids and predators as biological control agents. Insects respond to different olfactory cues like volatiles from repellant plants (e.g., phytophagous insects), host odours (e.g., parasitoids and predators), and pheromones for mate searching and aggregation. Olfactometer and wind tunnels are often used to monitor the responses of insects to odour cues. Multiple arm olfactometer like Y-tube, U-tube, four-arm, or six-arm olfactometer are generally used to detect and measure insect responses to multiple odour cues. Specific behavioural responses like antennal movements and other taxis are monitored in wind tunnel studies. They are also of use in wind tunnel bioassay experiments to test the ability of insects to detect and settle on plants (Mensah *et al.,* 2005).

Proffit *et al.* (2011) conducted about effects of leaf volatiles of different tomato varieties on attraction and oviposition behavior of *Tuta absoluta* (Meyrick) females, and determined that tomato leaf odor encouraged mated females to fly upwind, followed by landing as well as egg-laying. Also, it was found that the pest preferred culture tomato variety, *S. lycopersicum* rather than wild tomato variety, *S. habrochaites*. Also, Fadime-Uzun *et al.* (2015) was demonstrated that female adults of *T. absoluta* laid their eggs on or often found alongside the rachis of tomato more than those of eggplant and pepper as well as tendency in the olfactometer system. It was understood because *T. absoluta* lay more eggs on tomato than other host plants that the plant attracted the pest more than other plants by its leaf odor in the olfactometer system.

Four-armed olfactory chambers provided a relatively unconfined central area in which organisms move freely and into which four olfactory treatments or controls could be introduced. Many of these, however, did not permit a stream of directed, steady flow of odours to the test insects, in turn requiring expensive flow meters, valves, and mass and volumetric gas flow controllers. Therefore, designing a simple and inexpensive olfactometer assumed significance. Kogel *et al.* (1999) had studied the attractiveness of plant volatiles to western flower thrips using the Y-tube Olfactometer. In Y-tube olfactometer, the females of the tomato strain preferred odour from tomato plants, whereas females of the cucumber strain were art selective. In two-choice experiments, females of tomato strain stayed on tomato leaves when a choice was offered between tomato and cucumber, whereas females of the cucumber strain showed significant preference for cucumber.

According to Vinson (1981) and Weseloh (1981), many parasitic Hymenoptera used olfactory cues and responses to orient first towards a potential host habitat and second towards their host. Vet *et al.* (1983) found out an airflow olfactometer for measuring behavioural olfactory responses of hymenopterans parasitoids and other small insects. Reddy *et al.* (2002) studied olfactory responses of *Trichogramma chilonis* Ishii and *C. plutellae*, and the predator, *Chrysopa* potential biological control agents for the diamondback moth to host pheromone, larval frass, and green leaf cabbage volatiles. Among the green leaf volatiles of cabbage, only Z3- 6: Ac elicited significant responses from *T. chilonis, C. plutellae*, and *C. cornea*, but *C. plutellae* also responded to E2-6: Ald and Z3-6: OH. When these volatiles were blended with the pheromone, responses were similar to those elicited by the pheromone alone, except for *C. carnea* males, which had an increased response. These results indicated that the sex pheromone and larval frass volatiles from *P. xylostella*, as well as volatile compounds from cabbage may be used by these natural enemies to locate diamondback moth host plant.

Turlings and Benrey (1998) reported that the host plants not only tested as odour sources, but also in another aspect of the parasitoids behaviour, mate finding. Males of two parasitoid species *Cotesia marginiventris* (Cresson) and *Microplitis rufiventris* Kokujev, were attracted to the odour of their conspecific females. Males of both species were able to perceive and respond to female-produced pheromones, but they did not seem to make use of plant volatiles for mate finding and did not use learning as a means to associate potential mates with an experienced odour. Tamo *et al*. (2006) compared the responses of three generalist larval endo parasitoids, *C. marginiventris*, *M. rufiventris* and *Campoletis sonorensis* (Cameron) to the induced odours of maize, cowpea, and cotton using a six- inn olfactometer and tested the responses of native females as well as of females that were first conditioned by parasitizing host larvae feeding on one of the plant species.

Dai *et al.* (2008) reported that males and females of the *P. xylostella* were investigated for electroantennogram responses to 13 volatiles from brassicaceae in the laboratory, and showed stronger responses to benzaldehyde, phenyl acetaldehyde, allyl-isothiocyanate, (*Z*)-3-hexen-1-ol and (*Z*)-3-hexenyl acetate than to mono terpenes volatiles. Findings of Prasannakumar *et al.* (2011) in the field trials, with pheromone traps indicated a negative correlation between pheromone trap catches and field damage, in case of tomato fruit borer moth (*H. armigera*) (r=-0.69), okra shoot and fruit borer moth (*E. insulana*) (r = -0.54) and brinjal shoot and fruit borer moth (*L. orbonalis*) (r = -0.54). There was a significant positive correlation between potato cutworm (*S. litura*) moth catches (r = 0.82) and per cent damage indicating that trap catches are an index of pest infestation and density. The *P. xylostella* catches and mean number of larvae/cabbage head (r = 0.07) were related positively, but not significantly, indicating that trap catches are not an index of pest density or infestation.

2.5.2. Use of GC-EAD/GC-EAG in behavioural bioassay of insect pests

GC-EAG analysis, as originally conceived by Moorhouse *et al*. (1969), has proven to be of great utility in identifying components of insect sex pheromones and kairomones (Cork *et al.,* 1990) even though the magnitude of EAG responses elicited by natural compounds was not necessarily related to their behavioral activity (Suckling *et al.,* 1996). EAG activity of marigold floral extracts and compounds identified in the extracts demonstrated that female *H. armigera* possessed chemoreceptors capable of detecting floral volatiles and this was subsequently confirmed by the wind-tunnel bioassay results (Bruce and Cork, 2001).

Seven active compounds were detected in air-entrained headspace samples of live flowers of *T. erecta* analyzed by gas chromatography (GC) linked to a female *H. armigera* electroantennogram EAG using polar and nonpolar capillary columns. These compounds were subsequently identified using GC linked to mass spectrometry as benzaldehyde, (S)-(-)-limonene, (R, S)-(±)-linalool, (E)-myroxide, (Z)-ocimene, phenylacetaldehyde, and (R)-(-)-piperitone. Electrophysiological activity was confirmed by EAG with a 1µg dose of each compound on filter paper eliciting EAG responses that were significantly greater than the solvent control from female moths of *H. armigera* reported by Bruce and Cork (2001). He also found that the electrophysiological or behavioral activity of benzaldehyde, (R, S)-(±)-linalool, (E)-myroxide; and (R)-(-)-piperitone specifically to *H. armigera*. Burguiere *et al.* (2001) also found benzaldehyde and (R,S)- (±)-linalool did elicit significant EAG responses from female *H. armigera.*

Smith and Villet, (2002) results showed that *C. glomerata* as well as *C. rubecula* females responded to several of the volatiles emitted by cabbage plants infested with either *P. brassicae* or *P. rapae* caterpillars. Twenty of the volatiles that were released from herbivore-damaged plants induced consistent responses in the GC-EAG experiments, using antennae of both *C. glomerata* and *C. rubecula.* Among these volatiles were C6 green leaf volatiles, and their aldehydes, -alcohols and -esters; monoterpenes; methyl salicylate; benzylcyanide; 2-penten-1-yl acetate and 3-ethyl-1, 5-octadiene, as well as one unidentified substance. From the list of 20 compounds that evoked an EAG response, 15 chemicals could be obtained in pure form for EAG study and the sensitivity of the wasp antennae for these compounds, as determined by off-line EAG confirmed the activity detected in the GC-EAG experiments.

In preliminary field testing in Israel, traps baited with a four-component synthetic blend of benzaldehyde, (S)-(-)-limonene, (R, S)-(±)-linalool, and phenylacetaldehyde caught more moths than unbaited control traps (P = 0.002), although the actual numbers of moths captured were low (Bruce *et al.,* 2011). It is anticipated that by addition of other behaviorally active compounds and a better understanding of the role of these chemicals in the behavior of *H. armigera* useful floral bait can be developed for use in monitoring female populations of this economically damaging pest. Floral odors might also be worthy of consideration in breeding programs where the objective is to breed out traits attractive to *H. armigera* reported by Bruce and Cork (2001).

2.6. Standardization of Push-Pull components against diamondback moth, *Plutella xylostella* (L.) management in cabbage and cauliflower

2.6.1. Plant-Insect Interactions

About 360 million years ago, around the time the Devonian era was giving way to the Carboniferous, the first seed-bearing plants arose. Since that time the gymnosperms (plants with exposed seeds) and angiosperms (flowering plants) have become the most diverse, numerous and widely distributed group of plants on the planet (Starr and Taggart, 2001). Perhaps not coincidently, the immense evolutionary radiation of insects also started around 360 million years ago. Several individuals in the scientific community have theorized that the evolution of seed-bearing plants has enhanced the rate of insect evolution and vice versa (Strong *et al.,* 1984). More recent research into this hypothesis that the interactions of insects and plants fuel the rapid evolutionary radiation of both of these groups has been conducted with phylogenetic test.

The establishment of push–pull strategies in insect pest control is a subject of great interest. The concept takes advantage of the fact that insects use a variety of semiochemical to locate food sources, oviposition sites, or blood hosts. Through the combinatory use of both deterring and attracting stimuli, the abundance of insect pests can be reduced in a given area by interfering with the ability of the target pests to find their preferred resource (push) and luring them to an alternative source where they are trapped and killed (pull). Push–pull was suggested as a means of integrated pest management, an alternative approach to combat growing insecticide resistance by using non-toxic, sustainable, and cost-saving components to affect the abundance of an insect pest. Dube *et al.* (1996) recorded a negative linear relationship between larval density of *P. xylostella* and abiotic factor at the pre-heading stage and the percentage of head initiation in between the larval density and crop growth. Most work on push-pull strategies has targeted pest behavior, so this review relates mostly to pests, rather than to the manipulation of beneficial organisms.

To explain the direct effects of vegetational diversity on specialist herbivores, Root (1973) proposed a resource concentration hypothesis which is adapted to consider the effects of intercrops on specialist herbivores. It states that herbivores will: (1) be less able to find their hosts because of visual and olfactory interference with their search pattern, (2) tend to stay for less time because of the disruptive effect of landing on non-host plants, and (3) have lowered survival and fecundity in diverse agricultural systems. The key idea was that the lower concentration of the host resource (and its dilution with non-host plants) will impose extra constraints on population growth. The resource concentration hypothesis predicts that specialist herbivorous insects should be more abundant in large patches of host plants, because they would find them more readily and stay there longer than in less concentrated host plant patches (Root, 1973).

The term push-pull was first conceived as a strategy for the insect pest management (IPM) by Pyke *et al.,* (1987) in Australia. They investigated the use of repellent and attractive stimuli, deployed in tandem, to manipulate the distribution of *Helicoverpa* spp. in cotton, thereby reducing reliance on insecticides, to which the moths were becoming resistant. The concept was later formalized and refined by Miller and Cowles (1990), who termed the strategy stimulo-deterrent diversion while developing alternatives to insecticides for control of the onion maggot. In this review, retain the original terminology and describe the principles and components of the push-pull strategy, summarize developments over the past 30 years since the term was coined, and discuss how the strategy may contribute to addressing the global demand for the reduction of toxic chemicals used in the environment as part of IPM strategies in the future.

Srinivasan and Krishnamoorthy (1991) also reported that intercropped cabbage could be successfully raised during the rainy season without insecticidal application, whereas two sprays with 0.05 % cartaphydrochloride were necessary during winter. Sivapragasam and Lokesh (1996) reported that the investigation on Indian mustard, *Brassica juncea* L. as a trap crop indicated that it can be used as hedge row in the cabbage ecosystem to provide habitat diversity and dilute pest populations on cabbage, in addition to helping to conserve natural enemies within the ecosystem. Plant architecture also plays a role in tritrophic interactions. Architectural traits of plant, which include stem or leaf dimensions, branching angles, surface complexity, and canopy spacing, may also "guide" enemy searching and influence either the time a predator spends on a plant or the overlap between predator and prey distributions (Ferran and Deconchat, 1992).

The use of olfactory and visual cues from plants, usually enhanced by learning, helps minimize this disruption and plays important and sometimes interacting roles in their searching for food and hosts. Thus, the provision of food sources such as floral and extra floral nectar by plants along with associated foraging signals plays a crucial role in the tritrophic interplay among plants, herbivores, and parasitoids. A broader understanding of tritrophic level interactions that encompasses parasitoid food considerations can enhance our ability to design effective biological control strategies reported by Lewis *et al.* (1977).

The low incidence of pests in diverse agro ecosystems has often been attributed to the higher abundance of their predators and parasites, because a greater range of available microhabitats, of alternative prey for unspecialised predators and parasites, and of nectar sources as supplements to the diet of parasites could be more available. The longevity of *Copidosoma koehleri* Blanchard, an important parasite of potato tuber moth (PTM), *Phthorimaea operculella* (Zeller), was significantly increased when adults were caged on flowering plants of dill, borage, or coriander. Biodiversity could provide more shade, protection from desiccation by wind, lower mid-day temperatures, and other modifications of microhabitat. These modifications can affect herbivore movement and the activity of natural enemies (Andow, 1991). The use of lacewings in IPM programs has increased dramatically in recent years because of their broad distribution worldwide and rearing (Medina *et al.* 2001).

The push-pull (Khan *et al.,* 2000) or "stimulo-deterrent diversion" (Miller and Cowles, 1990) strategy is based on a combination of a trap crop (pull component) with a repellent intercrop (push component). The trap crop attracts the insect pest and, combined with the repellent intercrop, diverts the insect pest away from the main crop. A push-pull strategy based on using either Napier or Sudan grass as a trap crop planted around the main crop, and either desmodium or molasses grass planted within the field as a repellent intercrop, has greatly increased the effectiveness of trap cropping for stem borers in several countries in Africa (Khan *et al.,* 2000). Stem borers are the most important biotic constraint to corn production in Africa, and the push-pull strategy has allowed small farmers to control them while managing various parasitic weed species in the genus *Striga* (Khan and Pickett, 2004).

The IPM technology using Indian mustard as a trap crop, spraying of neem and pongamia soaps and pulverized neem seed powder extract for the control of major pests of cabbage was found to be economically viable as it enhanced the yield by 7.2 per cent and reduced the cost by 13.33 per cent and increased the net returns by 44 per cent (Gajanana *et al.,* 2004). In addition, the use of molasses grass as a repellent intercrop enhances stem borer parasitoid abundance, thereby improving stem borer control.

Push-pull strategies bring together various elements of different pest management tactics and provide a framework for their effective deployment. Habitat diversification strategies (intercropping and trap cropping) have attracted much interest as insect pest management strategies (Andow, 1991). For example, trap crops can be plants of a preferred growth stage, cultivar, or species that divert pest pressure from the main crop because they are more attractive (Shelton, and Badenes-Perez, 2006). The mechanisms underlying differential pest preference usually involve certain visual or semiochemical stimuli. Trap crops can therefore be used to deliver attractive pest-behavior-modifying stimuli. Biological control and especially conservation biocontrol are additional important strategies in IPM (Landis *et al.,* 2000) and can be used with push-pull strategies as population-reducing methods.

Hanumantharaya *et al.* (2010) made an attempt for management of cotton pests in cv. DCH-543 by biocontrol agents, botanicals and intercrop. Results revealed that intercrop with lucerne (1:1 row population), two sprays of NSKE (5%) on cotton at 38 and 60 DAS and release of *C. carnea* grubs @ 0.75 to 1.0 lakh/ha resulted in almost doubling of yields compared to untreated check. Ladybird beetles both adults and larvae feeds on aphids and therefore reduce the population of aphids. Ladybird beetles are stronger, larger and usually more intelligent than the prey and therefore attack several hosts in a short period of time (Chapman *et al*., 1981).

Leiner and Spafford (2016) result showed that a push–pull cropping approach may be an alternative management practice and could reduce reliance on pesticides. One potential push–pull scenario is the use of squash, *Cucurbita pepo* L. as a trap crop and watermelon, *Citrullus lanatus* (Thunb) as a deterrent intercrop to manage pickleworm on cantaloupe *Cucumis melo* L. This study investigated that the underlying mechanism required for the success of this management approach. Overall, it appears that squash may be more preferred as an oviposition substrate than cantaloupe or watermelon and may be a useful trap crop or pull. Traditional and cultural practices such as site selection, crop rotation, intercropping and seed selection, sowing date are used to reduce the infestation of insect pests of common beans in the field and in storage rooms. Natural enemies such as predators, parasitoids and pathogens can control the insect pests (Mpumi *et al.*, 2016).

2.6.2. Push- Pull Strategies -Cost: Benefit Ratio

In recent years, there has been considerable interest in development of plant protection programs that assure a more compatible use of chemical and biological methods of pest control. In these so-called ‘integrated control programs’ certain chemical control practices can destroy the pests without disrupting their effective natural enemies, thereby restricting subsequent pest increase. Among the most useful programs are those in which success depends upon the selection of pesticides that are less toxic to the most important natural enemies. Unlike the more complicated practices suggested for special timing or placement of toxicants to avoid pesticide contact with the natural enemies, this type of program requires less supervision and less knowledge of the differences in pest and natural enemy behavior (Hassan *et al.* 1985).

The analysis of land equivalent yield of different combination crops indicated that the combinations of tomato and cucumber produced the highest yield followed by French bean and cowpea combination in tea. Amoabeng *et al.* (2014) find out the botanical insecticides based on plant extracts were not widely used as crop protectants even though they can be produced simply from locally available plants. Many studies have examined efficacy but there is a paucity of information on the cost: benefit ratio of their use compared with conventional insecticides. Crude extracts of *Ageratum conyzoides* L. *Chromolaena odorata* (L.) *Synedrella nodiflora* Gaertn, *Nicotiana tabacum* (L.), and *R. communis* were on par with the synthetic insecticide, emamectin benzoat against insect pests of cabbage field experiments during the major and minor rainy seasons in Ghana.

The cost: benefit ratios of sprayed treatments were derived by comparing the cost of each plant protection regime against the additional market value of the treatment yield above that obtained in the control treatment. With the exception of plots sprayed with *N. tabacum*, the cost of plant protection using emamectin benzoate was higher than any of the botanicals in both seasons. The highest cost: benefit ratio of 1: 29 was observed for plots sprayed with *C. odorata* and was followed closely by *N. tabacum* treatment with 1:25 and emamectin benzoate with 1:18. In the minor season, plots sprayed with emamectin benzoate had the highest cost: benefit ratio of 1:15 and was followed closely by *N. tabacum* with 1:14. Botanical insecticides differed markedly in levels of pest control and cost: benefit but some were comparable to that from conventional insecticide use whilst being produced easily from locally available plant materials and are likely to be safer to use for smallholder farmers and consumers in developing countries.

Yamuna *et al.* (2015) reported that significantly higher maize equivalent yield (9863 kg/ha), land equivalent ratio (1.85), area time equivalent ratio (1.49), net returns (Rs 102371/ha) and Cost benefit ratio (4.37) were recorded with paired row maize intercropped with pigeon pea at 45/75 cm spacing compared to sole maize. Though intercropping resulted in significant reduction in the yield of sole crops it was better compensated by component crops in terms of total yield and income.

The technology has been described in detail (Khan *et al.,* 2014) and involves ‘push’ effects on insect pests, and at the same time exploiting conservation biological control by increasing foraging by parasitoid wasps. Both processes are based on the release of semiochemicals, from intercrops, that initiate stress signals associated with herbivore. These compounds include the homoterpenes or more correctly, tetranorterpenes that are formed when plants are damaged and reduce colonization by herbivores and recruit foraging parasitoids. The trap crop is a highly attractive plant that draws pests away from the main crop. Both inter- and trap crops have value as forage for farm animals. A leguminous intercrop developed for push–pull in the *Desmodium* genus fixes nitrogen and controls weeds, particularly the African witch weed *Striga hermonthica* (Del.) (Khan *et al.,* 2010). The companion cropping system adopted should involve intensification with minimal increase in main crop spacing. The overall yield must be greater per unit area compared with normal farmer practice, even where a trap crop is deployed, and must be assessed in terms of farmer benefit reported by Khan *et al.* (2012).

Crops are often less resistant than their wild ancestors because they have been selected for yield and human nutrition and have lost defence traits during domestication, especially when bred in a pesticide-treated background. Thus, there is a need to enhance plant defence capabilities in crop plants. This can be done through the conventional breeding and development of plant defence activator agrochemicals, but there are much wider possibilities via GM techniques. Crop protection via the seed can also be delivered by companion cropping as in the push–pull system, which makes agriculture more resilient to pest attack. However, companion crops need to be chosen on the basis of a scientific understanding of host and non-host plant interactions to ensure that they release the correct semiochemicals to protect the main crop. Innovative approaches to crop protection are needed to make agriculture more efficient in terms of resources used (land, water, energy, nutrients) by reducing waste. They are the key to the sustainable intensification of arable agriculture suggested by Pickett *et al.* (2014).