Current biological approaches for management of crucifer pests.

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Abstract

Cabbage is considered as one of the most commonly found vegetables and it has been cultivated in large areas throughout the year. As it is mostly grown in large areas, higher rate of pest infestation likely to occur, which hinder its total production and consumption. However, continuous use of synthetic pesticides in agricultural pest management often leads to various negative impacts such as development of resistance by the pest, adverse effect on non target organisms and hazardous effect on environmemt. These drawbacks led to an alternative approaches for control of crucifer pests that are cost effective, biodegradable, low toxic effect on non-target organisms and eco-friendly. This review brings together all the information of different biological practices for management of crucifer pests and list of botanical insecticides and entomopathogenic microbes that are being reported. This will help in establishing the knowledge of limited studies on pest management using different biological control methods to more challenging research and conveys the importance of pest management system for taking research forward.

Introduction

Among the vegetables, Crucifers are important winter crop consist of cabbage, cauliflower, mustard, broccoli and radish. Cabbage, *Brassica oleracea* var. *capitata* L. is the main temperate vegetable crop that cultivates widely in different climatic regions around the world. Worldwide, India occupies the second position in the production of cabbage after China. Of the total area of vegetable grown in India, 5% is occupied by cabbage (State of Indian Agriculture, 2015-16)[1]. Cabbage is considered as one of the most important group of vegetables and it has been cultivated in large areas throughout the years. Since cabbage is more intensively cultivated, it resulted in higher rate of pest infestation, which hinders its total production and consumption[2]. Some of the major defoliating caterpillars that cause significant damage to the crucifers are *Pieris brassicae* (L.) (Cabbage Butterfly) (Lepidoptera: Pieridaae)[3], *Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)[4], *Brevicoryne brassicae* (L.), Cabbage Aphid (Hemiptera: Aphididae)[5] and *Trichoplusia ni*. (Hubner) Cabbage looper (Lepidoptera: Noctuidae)[6] .

Protection of vegetable crops from numerous insect pests primarily depends on the use of synthetic pesticides. However, prolonged and excessive use of synthetic pesticides has led to several side-effects like development of resistance by the pest, adverse effect on non-target organisms and hazardous effects on environment. All these problems bring the sustainability of ecosystem to danger[7]. As the population of resistant pest and detrimental effects on environment rises, it requires constant support to search for an alternative control measures to reduce their spread. One promising way is to incorporate the use of biological sources such as botanical insecticides in pest management system which has resulted less negative impacts on ecosystem[8] .

Botanicals insecticides are chemical compound derived from plants that has the properties to kill, inhibit and repel the target pest[9, 10]. These substances that are being produced naturally can be extracted and used in the formulation of commercial insecticides. Using extracts of plant material like leaves, stem, root, bark and seeds as insecticidal substances for management of crop pest has been practised since two millennia ago and continue the same in organic farming[11]. Some of the repellent plants can produced toxic substances and play an important role to protect against insects and pathogens[12]. To develop a commercially available insecticide, first the study of toxicity under the laboratory condition against the target species is needed [13] and the next step is to study in an experimental field plot or greenhouse[14] .The modern method of controlling insects using latest technology stated that some plant is quite effective as synthetic insecticides and showed fewer effects on non-target organisms. This paper reviews the management of crucifer pests using current pest management strategies such as biological control practices, botanical insecticides and entomopathogenic microorganisms.

Overview Of Pests Of Cabbage

Many insect pests hamper cabbage cultivation and the most destructive pest is *Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae), which can reduced the yield of cabbage by 80% if huge number of pests appeared in the field [15]. Other major insect pests on cabbage and cruciferous crops are cabbage cluster caterpillar, *Crocidolomia pavonana* (F.) (Lepidoptera: pyralidae)[16], Cabbage webworm, *Helulla undalis* (F.) (Lepidoptera: Crambidae), Cabbage aphids (*Brevicoryne brassicae* (L.), imported cabbage worm (*Pieris rapae*), cabbage butterfly, *Pieris brassicae* (L.)[17], Tobacco caterpillar, *Spodoptera litura* (F.), and cabbage looper, *Trichoplusia ni* (Hubner) (Lepidoptera, Noctuidae)[18] .They infested the crucifers mostly in dry seasons and larvae start infesting the crops from their young stage and attacked the head at maturity[19] *C. pavonana* fed on the under surface of the leaves by leaving the veins causing skeletonization of leaves. *P.xylostella* larvae initially fed on the leaves causing small holes and entirely damaged the cabbage. *T.ni* defoliate the leaves by burrowing through 3–6 layers of cabbage. *H.undalis* usually damage on outer surface of cabbage and continue feeding into the terminal bud damaging the entire cabbage plant [19,20] .

Current biological control of Crucifer pests

Habitat management

Habitat manipulation or management is one of the most sustainable ways of managing pests by promoting their natural enemies [21]. It involves different approaches like intercropping, push pull method and insectary plant. Intercropping can be achieved by planting secondary or tertiary crop near the main crop or by incorporating non crop plants for certain specific functions for example, providing nectar and pollen for predator and parasitoids[22]. There are many reports on effective intercropping control method such as plantation of tomato inside the cabbage plot reduced the population of many adult butterflies of *P.xylostella* and *P.rapae* as compared to the monoculture cabbage plot. It is likely due to confusing visual cues and volatiles receive from tomato which masks the cabbage. However, it was reported that there was inconsistency between the damage index and population of pest. As suggested by Xu, Q. C *et al.*

[23] decreasing pest population in intercropping plots in turn increase the pest damage index in monoculture plot. The cause of this might be due to the variation in nitrate concentration of outer layers of cabbage leaves which is higher in intercropped plot than monoculture plot. Another study concluded that, tropical basil (*Ocimum gratissimum* L) can reduce the population of three cabbage pest (*H. undalis, P. xylostella L.* and *S. littoralis*) when grow in an alternate row with cabbage[24]. Intercropping of *Oscimum sanctum* L. with *Brassica rapa* H. can reduce the pest population of *H. undalis, S. litura* and *Phyllotrea sinuate F* as compared to contro plot [25]. In another study, using of onion and tomato as an intercropped plant with cabbage as host plant could be taken as the most reasonable and inexpensive pest management strategy when compared to other methods [26]. With these studies, intercropping of certain plants like tomato, tulsi etc. with cabbage can be used preferably as an alternative for synthetic pesticides in management of cabbage pests

Enhancement of insectary plant species

Insectary plants are those plant species that attract beneficial arthropod i.e., predators of crop pest by releasing volatile compound and enhance their population by providing them the nectar[27, 28]. Nectar acts as a food source that supports the growth and development of beneficial arthropod. However nectar produced by all flowering plants are not able to support the predators as some flower produce volatile that may repel them[29,30]. Thus selection of suitable flowering plants should be considered for the benefit of proper biological control[22]. And it is necessary to recognize the flowering plant species that support only the predators, without assisting the pests[31]. Another study concluded that floral resources can be used as a biological control of cabbage moth, *Mamestra brassicae* (L.) (Lepidoptera: Noctuidae) by benefitting the pest enemies like parasitoids with its nectar. It has been reported that the three flowering plants *Fagopyrum esculentum* (L.) (Polygonaceae), (Fig.1) *Centaurea cyanus* (L.) (Asteraceae) *and Vicia sativa* (L.) (Fabaceae) significantly heightened the parasitization rate of parasitoid wasp, *Microplitis mediator* Haliday. (Hymenoptera: Braconidae). As a result of a large number of parasitoids, the parasitization of *M.brassicae* by the parasitic wasp *M.mediator* amplified without enhancing the longevity and fecundity of the pest *M. brassicae* [32.] Apparently, the unfed parasitic wasp doesn't waste their energy for host searching if they are found closer; rather they directly parasitize the hosts in lack of food [33].

Regulating the planting period of Crucifers:

Regulating planting period of crucifers would be able to control certain insect infestations and can help in reducing the use of synthetic insecticides. Variables in climatic conditions play a significant role in the population of crucifer's pest since they have a short generation time and rapid reproductive rates[34]. It also greatly depends on the temperature (Fig.2) which may lead to an increase in infestation by rapid rises of pest population or reducing mortality of pest[35]. Impact on crop performance by planting dates is because of the changed in abiotic and biotic factors. In the cabbage field plot, the pest population started increasing from February and the highest peak occurred in April. Multiplication of pests preferred the hot climatic condition (off-season) but in cold condition (Nov-Feb) very few insects infest the cabbage[36]. According to Tanyi[37] late plantation of cabbage (April) reduce the pest population of cabbage looper larvae, webworm larvae and *P. xylostella* when compared to normal and early plantings. This method is considered a feasible, cost-effective pest management strategy that can be implemented by the farmers. Studies in Karnataka by Viraktamath *et al.*[38] reported that *P.xylostella* highly damage the leaf of cabbage planted in the first week of January in comparision with those planted in the first week of December but the head of cabbage were not marketable in both cases. From these studies, it concluded that temperature plays an important role in regulating the pest population of crucifers as hot and dry condition increases the pest population as compared to cold condition [39].

Push-pull strategies

In push pull method, one repellent plant is planted within the crop to repel the pest and another attractant plant species is planted in the surrounding field to attract the pest [22]. The "push-pull" strategy is a technique that brings together both negative and positive impulse to repel the pests from the host plant and consequently trap the herbivores by the trap plants grows at the surrounding of host target[39]. At present, this method has been implemented approximately by 70,000 agronomist[40]. Presently, the most effective technique of agricultural pest management, the push-pull method, was practiced successfully and developed in Africa. It required low efforts and it's an organic agricultural pest management system[41]. The techniques include both the combined use of trap crops and intercrops. The plant used as trap crops and intercrops must be suitable for the farmers and should be able to damage the natural enemies[42]. Some of the repellent plants that have been used as a push for controlling stem borers in maize are molasses grass *Melnis minutiflora* (P.Beauv), silver leaf desmodium *Desmodium unicinatum* (Jacq.)DC or green leaf desmodium *Desmodium intortum*(Mill.), that can pull away target pests to the trap plants mainly Napier grass (*Pennisetum purpureum* Schumach.) or Sudan grass (*Sorghum vulgare* var *sudanense* Hitchc.)[43]. An example of trap plant is *Barbara vulgaris* (W.T.Aiton), which was reported and can attract the cabbage pest, *Plutella xylostella* but there were complications in field management practices as the plant is not suitable growing in arable fields[44]. Another case is using of onion and tomato (Fig. 3) as an intercropped plant with cabbage as host plant could be taken as the most reasonable and inexpensive pest management strategy when compared to other methods. Successful method of intercropping method using onion and tomato is probably due to the confusing volatiles and visual signals that can in return repelled the cabbage pests[26].

Pheromone based product for cruciferous pest management:

Pheromones are a low molecular weight volatile organic molecule produced by insect to produce a behavioral response from other individual of the same species[45]. According to Witzgall *et al.*[46] more than 1,600 pheromones and sex attractants have been reported. Sex pheromones are mainly used to control the pest in an agricultural field. One of the advantages of using pheromone in pest management system is showing no adverse effects on non-target and beneficial insects as they have higher degree of specificity to one specific insect species only[47]. Management of pest population can also be done by using synthetic pheromones where it can mask the natural pheromones produced by the lepidopteran pest and disrupt the olfactory communication of opposite sex which results in mating disruption. Mating disruption using synthetic pheromone has been considered as a feasible pest management technique[48]. However the efficacy of mating disruption is highly dependent on population density of pest as large number of pest populations are more difficult to control than less populations[49]. It has been reported that DBM sex pheromones isolated from the female moths i.e, (Z11-hexadecenal, Z11-hexadecenyl acetate in the range of 8+2 to 4+6 and addition of 1% Z11-hexadecen-1-ol were used in mass trapping of male moths in a cabbage field[50].

Botanicals against Crucifer pests control

India is among the leading country that gains insight in developing natural botanical insecticides as most of the people still focused on indigenous traditional knowledge for controlling insect pest in the field [51]. Botanicals are natural chemical compounds derived from plants[52]. They showed different biological activities such as repellents, insecticides, fungicides and bactericides[53]. Some of the plants that have been reported to protect crucifer crops against insect pests are shown in (Table 1).

Botanical insecticides served as effective and safer alternatives of synthetic insecticides, as they are readily available and safer for the non-target organisms and for the environment[54-56]. Some common chemical compounds reported from plants are Pyrethrins, Nicotine, Rotenone, Azadirachtin, Limonene, Limone, Linalool, Citronellal, Artemisinin, Diterpene, Coumarins, Annonin[57, 58]. According to 2012 report, Ministry of agriculture approved nine botanicals insecticides along with garlic and neem extracts. Those seven botanical insecticides include *Cymbopogon spp*. Spreng., *Sophora spp*.L., *Annona squamosa* L., *Tripterygium wilfordii* Hook.F., *Apocynum venetum* L., *Eucalyptus globulus* Labil., *Milletia pinnata* L. They have been commercilaised by Ministry of Agriculture[59]. Studies have reported that azadirachtin from Neem (*Azadirachta indica)* and lantanine from *Lantana camara* exhibit defensive mechanism against insects pests. Azadiractin is considered as one of the most effective botanical insecticide and helped in management of many agricultural pests[60, 61]. Some of the insecticidal plant used in management of pests in cabbage and cauliflower are leaf extract of *Aloe brevifolia, Melia azedarach*[62]*. Eupatorium adenophorum, Lantana camara*[63], Worm wood *(Artemisia maritime)*[64]*.* Although some agricultural organisations often recommended using botanical insecticides over synthetic pesticdies there are some drawbacks like having poor scientific evidences on the efficacy and safety of botanical insecticides[65]. One of the factors that control the efficacy of the botanical insecticides mainly depends on concentration of active constituents and its varying contents [66]. Variable concentration of active constituents mainly resulted from the varying concentration of secondary metabolite contents which is caused by an extensive factor like the genotype of plants, different environmental factors and plant developmental stage[67]. Besides the above factor, an important factor could be due to the storage condition as the active constituents present in botanical insecticides may deteriorate gradually while storing[65]. Some other factors like a method of application of bioactive compound and a structural membrane of the target pest and its body conformation is responsible for altering the bioactivity of compounds and its toxicity [68]. It has been reported that the synergistic activity of plant essential oil constituents based on, insecticidal activity on 3rd instar larvae of the cabbage looper, may help in penetration-enhancing effect into the insect integument. Lemongrass consists of citral as the main active compound but some minor constituents also observed greater insecticidal activity than citral against the cabbage looper, *Trichoplusia ni*. so it indicates that greater efficacy of lemongrass oil than its main component in an isolated way gives an idea of positive (synergistic) interactions[69] and it was also reported that the combination of three major components (thymol, p-cymene and linalool) of thyme oil which were obtained from *Thymus vulgaris* (Thyme) the binary mixtures have shown synergistic activity against the third instar larvae of tobacco cutworm, *spodoptera litoralis* [69].

Microbial control agent against Crucifer pest

Microbial biopesticides are products developed from microorganisms like bacteria, fungi, nematode and viruses that are used to control the agricultural pest and also play an important role as an alternative tool to chemical pesticides for their eco-friendly nature [70]. According to NBAIR 2017 report, minimum of 15 biopesticides based on microbes have been developed in India with 970 commercial formulations registered. Some of the microbial control agents against crop pests are discussed here (Table 2).

Fungi species which are pathogenic to insect pests are called entomopathogenic fungi. The most commonly used entomopathogenic fungi are *Beauveria bassiana, B. brongniartii, Metarhizium anisopliae, Lecanicillium lecnii, Hirsutella thompsonii, Cladossporium oxysporium* and *Isaria fumosorosea.* Based on the report of entomopathogenic bacteria, the most commercially used microbial pesticide is *Bacillus thuringiensis* [71]. More than 30 products developed from the sub species *kurstaki* of *B.thuringiensis* are effective against Bollworms, Loopers and other lepidopterans while two viruses namely Helicoperva armigera nucleopolyhedrovirus and Spodoptera litura mucleopolyhedrovirus were registered to control two lepidopteran pests i.e, Bollworms (*Helicoverpa* spp.) and Armyworms (*Spodoptera litura)*[72].

Although microbial pesticides have many advantages for control of crucifer pest, several factors limits the commercial production and their efficacy also varies among the stage of larvae, strains, environmental condition and target pests. The efficacy of these products is highly effective when applied to the young larvae (first and second instars larva) and reapplication when insect population increases[73-75]. Some of the factors that limit the commercialization of microbial pesticides are discussed here. Low microbial counts is one of the factors, as rapid production of entomophthoralean fungi species is quite low due to difficulty in development of conidia and its short-lived which makes impossible in creating a period of vast applications. For this one should try to increase the production of resting spores and competent mycelia of entomophthoralean species by developing effective methods which will ultimately increase the efficacy of these fungi[76]. Another factor is the shelf life of entomopathogenic microbes, where storage facilities are not yet developed in rural areas. Poor solubility of the some of the formulations in water is also one of the challenges[77, 78]. Despite of all the challenges, several methods needs to be followed like enhancing the microbial production and formulation, learning the proper idea of microbial pesticides being incorporated into integrated systems and their relations with the external environment, accepting the advantages like efficacy, safety etc. while comparing with synthetic pesticides and approved [76].

Conclusions

As biological control of pest can be an alternative to synthetic pesticides, effectiveness and maintenance of developing control method for crucifer pests must be considered. Some of the criteria that should be encountered for developing a proper biological control methods are 1) adopting proper guidelines to the farmers about various approaches of pest management in a comprehensive manner, 2) providing awareness programme for the negative impacts of used of synthetic pesticides for better cooperation of the farmers 3) having proper taxonomical knowledge on insectary plants, trap crops and insecticidal plants and 4) maintained authentic research data during laboratory practices to be commercialised later. These approaches can provide the importance of the economic benefits of using biological control method over synthetic products and will gain insight of accepting the sustainable way of crucifer pest management. The ultimate challenge will be to adopt the use of biological pest management technologies in a cost effective manner so that farmer can easily access those approaches. .

Declarations

Conflict of interest

The authors have no conflict of interest to declare.

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Tables

e 1 List of some of the insecticidal plants used in the management of crucifer pests.

.	Plant species (Common name & Family)	Parts of the plant	Target pest	References
	Acorus calamus (L.) (Sweet flag) Asteraceae	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae) & *Spodoptera frugiperda* J.E Smith, Fall armyworm (Lepidoptera: Noctuidae	Kumar *et al.* [79]
	Ageratum conyzoides (L.) (White weed) Asteraceae	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (D BM) (Lepidoptera: Plutellidae) & *Brevicoryne brassicae* (L.), Cabbage Aphid (Hemiptera: Aphididae).	Rioba and Stevenson [80]
	Alpinia galangal (L.) (Thai ginger) Zingiberaceae	Rhizomes	*Spodoptera frugiperda* J.E Smith, Fall armyworm (Lepidoptera: Noctuidae)	Datta *et al.* [81]
	Alpinia katsumadai Hayata. (Blue ginger) Zingiberaceae	Seeds	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Hwang *et al.* [82]

Annona cherimolia Mill. (Cherimoya) Annonaceae	Seeds	*Spodoptera frugiperda* J.E Smith, Fall armyworm (Lepidoptera: Noctuidae	Castillo-Sánchez *et al.* [83]
Annona squamosal (L.) (Sugar apple) Annonacea	Seeds	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Leatemia & Isman [84]
Artemisia annua (L.) (sweet worm wood) Asteraceae	Seeds	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Okwute [85]
Aspidosperma pyrifolium Mart. (Pereiro) Apocynaceae	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Torres *et al.* [86]
Azadirachta indica A Juss. *(*Indian lilac) Meliaceae	Leaf	*Pieris brassicae* (L.) (Cabbage Butterfly) (Lepidoptera: Pieridaae)	Sharma & Gupta[87]
Bobgunnia madagascariensis (Desv.) (Snake bean plant) Fabaceae	Fruit	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae))	Mazhawidza & Mvumi [5]
Bunium persicum Boiss. (Black jeera) Apiaceae	Fruits	*Trichoplusia ni*. (Hubner), Cabbage looper (Lepidoptera: Noctuidae)	Khanavi *et al.*[88]

.	*Cephalotaxus sinensis* (Rehder & E.H.Wilson) (Plum yew) Cephalotaxaceae	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Ma *et al.* [89]
.	*Clerodendrum inerme* (L.) (Glory bower) Lamiaceae	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Yankanchi & Patil [90]
.	*Corymbia citriodora* (Hook.) (Lemon scented gum) Myrtaceae	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Filomeno *et al.* [91]
.	*Cucurma longa (L.)* (Turmeric) Zingiberaceae	Rhizomes	*Trichoplusia ni*. (Hubner), Cabbage looper (Lepidoptera: Noctuidae)	de Souza Tavares *et al.* [14]
.	*Cymbopogon citratus DC Stapf.* (Lemon grass) Poaceae	Leaf	*Trichoplusia ni*. (Hubner), Cabbage looper (Lepidoptera: Noctuidae)	Tak and Isman [92]
.	*Cymbopogon schoenanthus* (L.)	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (DBM)	Sanda *et al.* [93]

	Spreng (West Indain Lemon grass) Poaceae		(Lepidoptera: Plutellidae)	
.	*Dodonaea viscose* (L.) Jacq (Hopseed bush) Sapindaceae	Seeds	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	QIN *et al.* [94]
.	*Elettaria cardamomum (L.)* (Green cardamom) Zingiberaceae	Whole plants	*Brevicoryne brassicae* (L.), Cabbage Aphid (Hemiptera: Aphididae).	Jahan *et al.* [95]
.	*Eupatorium adenophorum* (Spreng.) (Crofton weed) Asteraceae	Aerial part	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Adebisi *et al.* [96]
.	*Eupatorium adenophorum* (Spreng.) (Crofton weed) Asteraceae *and Lantana camara* (L.) (Lanatana) Verbenaceae	Aerial parts	*Pieris brassicae* (L.) (Cabbage Butterfly) (Lepidoptera: Pieridaae))	Khan *et al.* [97]
.	*Apium nodiflorum* (L.)	Aerial	*Trichoplusia ni*. (Hubner),	Afshar *et al.*

	(Fools water cress) Apiaceae	parts	Cabbage looper (Lepidoptera: Noctuidae)	[6]
.	*Jatropha gossypifolia* (L.) (Cotton leaf Physic Nut) Euphorbiaceae	Leaf	*Spodoptera frugiperda* J.E Smith, Fall armyworm (Lepidoptera: Noctuidae	Bullangpoti *et al.* [98]
.	*Lantana camara* (L.) (Lantana) Verbenaceae	Leaf	*Brevicoryne brassicae* (L.), Cabbage Aphid (Hemiptera: Aphididae)	Mvumi & Maunga [99]
.	*Maerua edulis* (Gilg & Gilg-Ben) (Courbonia) Capparaceae	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Mazhawidza & Mvumi[5]
.	*Melia azedarach (L.)* (Chinaberry tree) Meliaceae	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae), (Diamondback moth)	Kumar *et al.* [62]
.	*Melia volkensii* Gurke. (Melia) Meliaceae	Seeds	*Trichoplusia ni*. (Hubner), Cabbage looper (Lepidoptera: Noctuidae)	Akhtar *et al.* [100]
.	*Melia volkensii* Gurke. (Melia) Meliaceae	Seeds	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae) &	Akhtar & Isman [101]

		Trichoplusia ni. (Hubner), Cabbage looper (Lepidoptera: Noctuidae)	
Muntingia calabura (L.) (Panama berry) Muntingiaceae	Fruits and flowers	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Bandeira *et al.* [102]
Origanum vulgare (L.) (Oregano) Lamiaceae	Aerial parts	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Nasr *et al.* [103]
Otostegia persica Boissier, (Tinjut) *Lamiaceae* & *Peganum harmala* (L.) (wild rue) Zygophyllacea	Seeds	*Brevicoryne brassicae* (L.), Cabbage Aphid (Hemiptera: Aphididae)	Shafiei *et al.* [104]
Oxandra xylopioides Diels. (*Annonaceae)*	Leaf	*Spodoptera frugiperda* J.E Smith, Fall armyworm (Lepidoptera: Noctuidae	Castillo-Sánchez *et al.* [83]
Panax ginseng (Meyer) (Chinese ginseng) Araliaceae	Leaf and Stem	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Yang *et al.* [4]

Pharbitis purpurea (Morning glory) Convolvulacea	Seed kernels	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Xu *et al.* [105]
Ricinus communis (L.) (Castor bean) Euphorbiaceae	Seed kernels	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Kodjo *et al.* [106]
Rosmarinus officinalis L. (Rosemary) Lamiaceaea	Aerial parts	*Trichoplusia ni*. (Hubner), Cabbage looper (Lepidoptera: Noctuidae)	Tak *et al.* [92]
Satureja hortensis L. (Summer Savory) Meliaceae & *C*uminum cyminum L. (Cumin) Apiaceae	Leaf	*Pieris brassicae* (L.) (Cabbage Butterfly) (Lepidoptera: Pieridaae)	Khorrami *et al.*[107]
Vitex negundo (L.) (Chinese Chase tree) Lamiaceae	Leaf	*Plutella xylostella* (L.), (Diamondback Moth (DBM) (Lepidoptera: Plutellidae)	Yankanchi & Patil [108]

e2 List of some of the entomopathogenic microbes used in the management of crucifer s.

Entomopathogenic microbes	**Target pest**	**Types of Microbes**	**References**
Bacillus thuringinesis Berliner *ssp* kurstaki	*Trichoplusia ni.*	Bacterium	Ramanujam *et al.* [109]
Bacillus thuringinesis var. galleriae	*Helicoverpa armigera* and *Plutella xylostella*	Bacterium	Singh *et al.* [110]
Beauveria bassiana – Myco Jaal	*Plutella xylostella* and *Pieris brassicae*	Fungus	Ghosh *et al.* [111] Srinivasan *et al.*[112] & Singh *et al.* [113]
Beauveria brongniartii	*Spodoptera litura*	Fungus	Lin *et al.* [114]
Cabbage looper (TrniSNPV)	*Trichoplusia ni*	Virus	Singh *et al.* [110]
Chromobacterium subtsugae	*Plutella xylostella*	Bacterium	Martin *et al.* [115]
Diamond back moth GV (PlxyGV)	*Plutella xylostella*	Virus	Singh *et al.* [110]
Egyptian cotton leafworm NPV (SpliNPV)	*Spodoptera littoralis*	Virus	Singh *et al.* [110]
Granulosis Virus	*Pieris rapae*	Virus	Ramanujam *et al.*[109]
Heterorhabditis bacteriophora	*Plutella xylostella* and *Pieris brassicae*	Nematode	Rodriguez *et al.* [116] & Abbas *et al.* [117]
Isaria fumosoroseus	*Plutella xylostella*	Fungus	Huang *et al.* [118]
Nomuraea rileyi	*Spodoptera litura*	Fungus	

			Lin *et al.* [114]
Nuclear Polyhedrosis Virus	*Mamestra brassicae*	Virus	Kunimi, Y. [119]
Photorhabdus luminescens	*Pieris brassicae*	Nematode	Mohan *et al.* [120]
Steinernema carpocapsae	*Plutella xylostella*	Nematode	Baur *et al.* [121] & Sunanda *et al.*[122]
Steinernema glaseri	*Pieris brassicae*	Nematode	Abbas *et al.* [117]
Xenorhabdus nematophila	*Plutella xylostella*	Nematode	Razek *et al.* [123]

Figures

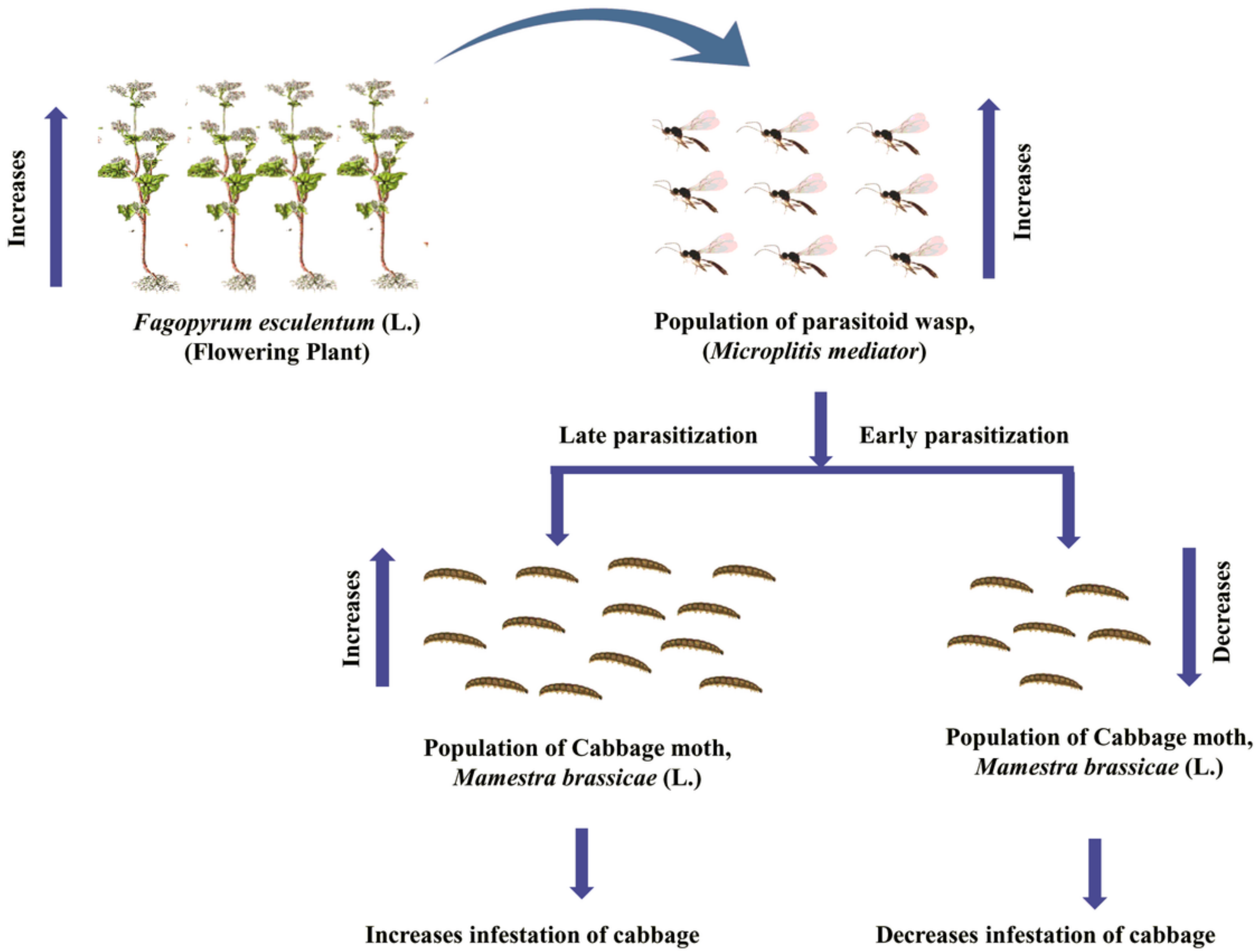

Figure 1

Effects of increased of flowering plants and parasitoids on cabbage pest. With an increase in floral resources from a flowering plant, Fagopyrum esculentum, Buckwheat, there is an increase in the parasitoid wasp, Microplitis mediator as they depend on floral nectar. As a result of a large number of parasitoid wasp, there is a significant increase in parasitization rate of cabbage moth, Mamestra brassicae by the parasitoids in an early spring which in turn manage the infestation of cabbage.

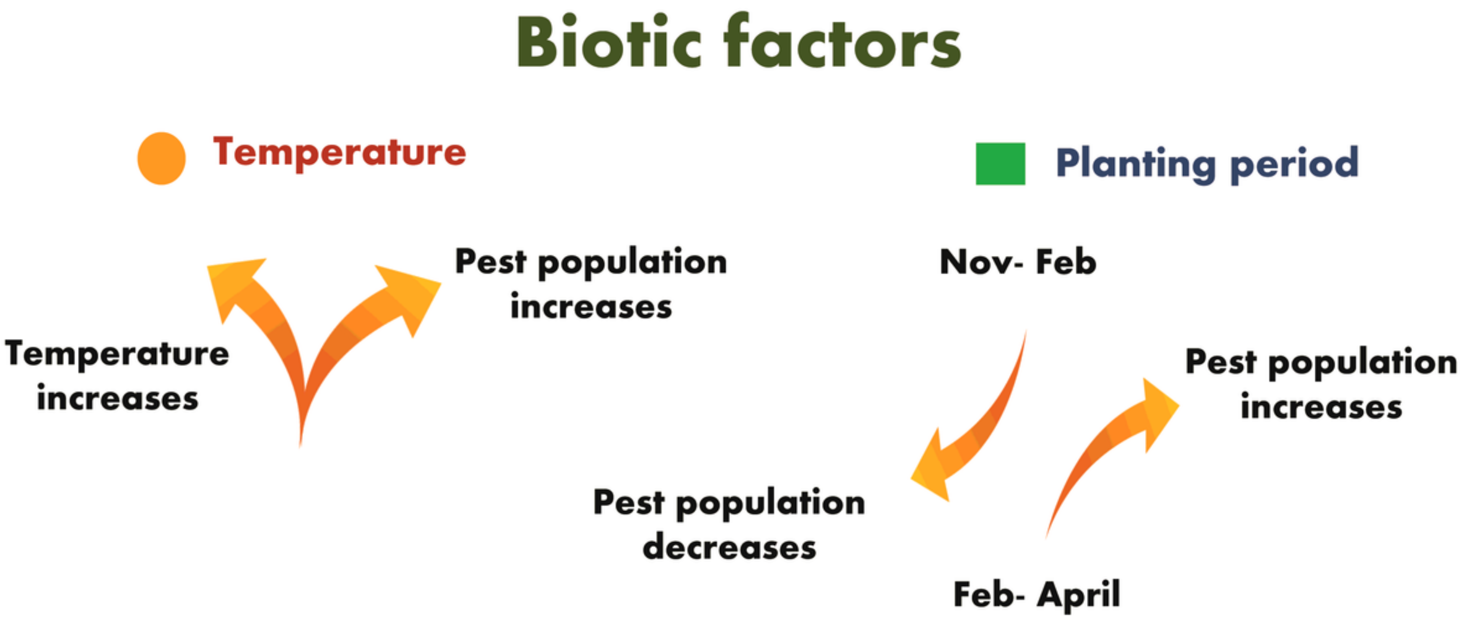

Figure 2

Role of biotic factors in the population of cabbage pests. Variables in climatic condition like temperature & planting period, play a significant role in the population of cabbage pests. Increase in temperature leads to an increase in infestation by rapid rises of the pest population. For a planting period, the pest population started increasing from February and the highest peak occurred in April. It happened because multiplication of pests preferred the hot climatic condition (off-season) but in cold condition (Nov-Feb) very few insects infest the cabbage.

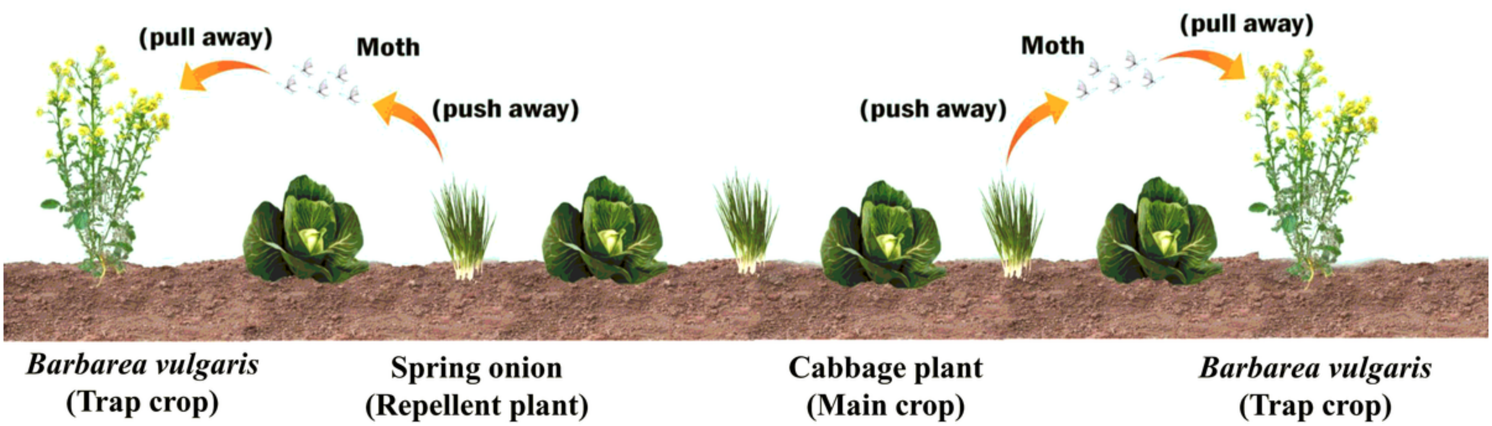

Figure 3

A schematic representation of the management of cabbage moth by using repellent "push" plant and trap "pull" plant. When Cabbage (maincrop) is planted with spring onion (repellent) non-host intercrop plant and simultaneously with attractive Barbarea vulgaris, Yellow rocket cress (trap plant) as a barrier plant, it reduces the infestation of cabbage by cabbage moth. This occurred by repelling away the cabbage moth, that were trying to feed on the cabbage, from the push plant using stimuli that alter the host fragrance and at the same time pull away by the trap plant using highly attractive stimuli.