CHAPTER II
REVIEW OF LITERATURE

The information regarding the evaluation of different biopesticides against *Helicoverpa armigera* (Hubner) (Noctuidae: Lepidoptera) on chickpea is very scanty, even though attempts have been made to review the available literature, which have direct or indirect relation with the present investigations on compatibility of *B. bassiana* with different insecticides, evaluation of different biopesticidal spray schedules, determination of effective dose and application time of *B. bassiana*, persistent and cumulative effect of *B. bassiana* against *H. armigera* are presented under the following headings:

2.1 Compatibility of *B. bassiana* with different insecticides

2.2 Evaluation of different biopesticidal spray schedules against *H. armigera* on chickpea

2.3 Determination of effective dose and time of application of different biopesticides against *H. armigera*

2.4 Persistent and cumulative effect of different biopesticides against *H. armigera* on chickpea

2.1 Compatibility of *B. bassiana* with different insecticides

Gafurova (1973) recommended *B. bassiana* plus chlorpyriphos or carbaryl for effective control of codling moth.

Rama Mohan Rao (1989) stated that chlorpyriphos has been reported to strongly inhibit the growth and sporulations of *B. bassiana* at lower than recommended field doses.

Batista *et al.* (1996) tested the compatibility of fipronil to *B. bassiana* and reported that the insecticide did not affect spore production and viability of conidia but caused a slight decrease in the diameter of the colony.
Almeida and Diniz (1998) observed that the colony diameter of *B. bassiana* was significantly reduced with deltamethrin, methamidaphos, lambda cyhalothrin and endosulfan in comparison with untreated control.

Gupta *et al.* (2002) found that *B. bassiana* fungus was found moderately resistant to chlorpyriphos and monocrotophos, which did not exhibit more than 50% growth inhibition at 1000 ppm. Endosulfan and quinalphos were relatively less tolerant even at lower concentration.

De-Oliveira *et al.* (2003) reported that insecticides cyfluthrin, alphacypermethrin and thiamethoxam caused no inhibition of vegetative growth, sporulation and viability of conidia in *B. bassiana*, while insecticides deltamethrin, triazophos, chlorpyriphos, fenpropathrin and endosulfan caused moderate to high inhibition.

Ashutosh *et al.* (2005) assessed the compatibility of insecticide chlorpyriphos at different concentrations with *B. bassiana* and reported that the insecticide showed decreased radial growth of fungus with increase in the concentration.

Ambethgar *et al.* (2009) showed that only chlorpyriphos at subnormal concentration was found to be slightly harmful to *B. bassiana* with 47.6% growth inhibition.

Amutha *et al.* (2010) reported that among the insecticides tested for their compatibility, only chlorpyriphos 20 EC was rated as relatively less toxic to *B. bassiana*, while, spinosad (45 % SC), econeem (1%), quinalphos (25 EC), and thiodicarb (75 WP) were slightly toxic.

Laurici *et al.* (2010) proved that URPE-6 and UFPE-19 isolates of *B. bassiana* were compatible with insecticides such as chlorfenapyr, spinosad, indoxacarb, abamectin and neem.

Gnanaprakasam *et al.* (2011) tested the fungitoxic effect of endosulfan, chlorpyriphos, dimethoate and quinalphos with *B. bassiana* and concluded that all the tested concentrations inhibited the germination (9.0-81.19%), vegetative growth (0.5-62.9%) and sporulation (7.0-99.9%) of *B. bassiana* by the insecticides, respectively but dimethoate exhibited minimum inhibitory effect.
Gowrish (2013) observed the lowest (23.22%) inhibition of colony diameter of B. bassiana in sample treated with 0.0018 % concentration of spinosad 45 SC at 14 days after inoculation whereas, the highest (47.76%) per cent inhibition of colony diameter was found in samples treated with 0.0054 % concentration.

Usha et al. (2014) reported that among the pesticides tested for the compatibility of B. bassiana, chloropyrifos was proved to be highly detrimental to all the isolates at 1x and 0.5x concentrations whereas, the other pesticides monocrotophos and quinalphos were also categorized as either highly toxic or moderately toxic to all the isolates at all concentrations.

2.2 Evaluation of different biopesticidal spray schedules against H. armigera on chickpea

Balasubramanian et al. (1989) recorded 46.2 to 51.3% reduction in larval population of H. armigera by spraying HaNPV @ 250 LE/ha on chickpea.

Gopalakrishnan and Narayanan (1990) reported that B. bassiana @ 1.0 × 10^7 conidia per millilitre was pathogenic to all the stages of H. armigera caused 60 – 100% mortality of larvae and 100% mortality of eggs.

Sarode et al. (1994) concluded from their field experiment that two applications of HaNPV @ 500 LE/ha (first at 50% flowering stage and next 15 days later) were superior to single spray of HaNPV (50% flowering) at the same concentration and two spray of HaNPV @ 200, 300 and 400 LE/ha in reducing infestation with regard to pod damage, grain damage and yield of pigeon pea.

Broza and Sneh (1994) concluded that application of B. thuringiensis sub spp. kurstaki @ 5000 g/ha (8000 UJmg) in 150-200 liters of water against H. armigera maintained pest populations to levels below economic threshold in tomato.

Wright and Knauf (1994) found the least efficacy of B. bassiana @ 750 ml/ha against Heliothis zea.

Sarode et al. (1995) observed that application of HaNPV @ 500 LE/ha plus neem extract 6% recorded maximum reduction in larval population (79.8 and 65.2%), at 7 and 14 days after spraying, respectively.
Jayanthi and Padmavathamma (1996) reported that the groundnut pest, *H. armigera* was found to be equally susceptible to *B. bassiana* @ $1.0 \times 10^9$ spores per milliliter.

Gupta and Babu (1997) reported the reduction of larval survival to 37% over the pretreatment count after 96 h of 1 or 1.5 kg formulated material/ha of *B. thuringiensis* var. kurstaki against *H. armigera* in tomato crop.

Saxena and Ahmad (1997) concluded that under field condition *B. bassiana* @ $2.68 \times 10^7$ spores per milliliter recorded lower (6 %) pod damage by *H. armigera* as compared to untreated control (16.3 %) in chickpea.

Sharma *et al.* (1997) evaluated the efficacy of *HaNPV*, *Trichogramma chilonis*, monocrotophos and endosulfan against *H. armigera* on chickpea and reported that *HaNPV* registered the highest mortality of *H. armigera*.

Sanap and Pawar (1998) found that spray application started from initiation of flowering and subsequent two sprays at fortnightly intervals with first two sprays either with *HaNPV* @ 250 LE/ha or Neem Seeds Kernel Extract (NSKE) were most effective in controlling *H. armigera* and resulted in 26.94% increase in yield.

Ahmad *et al.* (1999) showed that two application of *HaNPV* either alone or insecticides resulted in effective control of *H. armigera* infesting chickpea with a significant increase in yield. Mean pod damage in treated plots ranged between 4.2 and 6.7% as compared to 10.9% in control.

Cherry *et al.* (2000) concluded that *HaNPV* @ $1.5 \times 10^{12}$ POB/ml found to be the most effective in controlling *H. armigera* larvae in chickpea than standard chemical insecticide endosulfan or *B. thuringiensis* in two successive years.

Kulat *et al.* (2001) conducted a field experiment for the management of *H. armigera* on chickpea cv. G-5 and observed that *HaNPV* 500 LE/ha and Dipel 8L were found effective in restricting the development of larval population of *H. armigera* on chickpea.

Kumar and Prasad (2002) found that *HaNPV* was most effective bio-pesticide against *H. armigera* which recorded the lowest pod damage (67.17 to 92.49%) and the highest grain yield of chickpea.
Singh and Yadav (2005) tested some microbial agents against *H. armigera* on chickpea. The treatments comprised *B. bassiana* @ 1.0x10^8 spores/ml, *HaNPV* @ 250 LE/ha and endosulfan at 0.7 kg/ha. They found that *B. bassiana* and *HaNPV* proved more effective in reducing pod damage and enhancing productivity of chickpea.

Pote and Chavan (2006) reported that all the bio-pesticidal treatments (*Neemark, HaNPV*, and Delfin) sprayed at pod formation stage were found equally effective as that of chemical spray of endosulfan and quinalphos in reducing the incidence of *H. armigera* and increasing the grain yield of chickpea.

Hossain (2007) revealed that the lowest (5.86%) pod damage due to *H. armigera* was observed in *HaNPV* treated plot, which was efficiently reduced the pod damage as compared to synthetic chemical, cypermethrin (5.75%) in chickpea.

Singh and Yadav (2007) concluded that the maximum (42.2%) larval mortality after one week of spraying was achieved in *B. thuringiensis* after first spraying and 42.8% after second spraying which was closely followed by *HaNPV*. Whereas, both the neem based formulations were on par among each other but significantly superior over control.

Kale and Men (2008) studied the bioefficacy of different microbial insecticides against *H. armigera* in chickpea and reported that *HaNPV* (250 LE/ha) and *B. thuringiensis* (750 ml/ha) were the most efficacious to restrict the population of test insect and recorded the lowest larval population of 1.45 and 1.72 larvae/10 plants, respectively.

Rijal *et al.* (2008) reported that the number of *H. armigera* larvae observed in plots treated with *M. anisopliae* and *B. bassiana* were significantly lesser than the control plots during vegetative, flowering and pod setting stage of chickpea.

Singh *et al.* (2009) reported that two sprays of *HaNPV* @ 400 LE/ha were found effective in managing the population of *H. armigera*.

Altaf *et al.* (2010) experimented to develop an IPM approach for the management of pod borer, *H. armigera* in chickpea. Out of seven modules studied,
Module-5 consisting of sequential first spray with \( HaNPV @ 500 \leq \text{ha} \) and second spray after seven days interval with cypermethrin @ 1 ml/1 gave the best protection.

Bhushan et al. (2011) reported that Neem Seed Kernel Extract (NSKE 5%) was found as the most effective in reducing the larval population (0.37 larvae/plant) and pod damage (10.8%) in chickpea.

Narasimhamurthy and Keval (2012) found that \( HaNPV @ 500 \leq \text{ha} \) was most efficient to reduce the larval population of \( H. \ armigera \) with 50.77 to 54.78% mortality in pigeonpea.

Kaur and Singh (2013) studied the efficacy of \( HaNPV @ 350 \leq \text{ha} \) for tomato fruit borer in comparison with profenophos 50 EC @ 1.5 lit/ha and the untreated control at 10 days interval. They reported that the \( HaNPV @ 350 \leq \text{ha} \) resulted in significantly higher larval reduction and fruit damage than untreated control on tomato.

Mane et al. (2013) reported that three days after spraying, \( HaNPV @ 350 \leq \text{ha} \) was equally effective with quinalphos 25 EC @ 2 ml/lit and azadiractin 1500 ppm @ 2ml/lit in reducing the larval population of \( H. \ armigera \) in sunflower. Seven days after spraying, maximum larval reduction (58.89 %) was observed in profenophos 50 EC @ 1 ml/lit followed by quinalphos 25 EC @ 2 ml/lit and \( HaNPV @ 350 \leq \text{ha} \), which were at par with each other.

Phukon et al. (2014) revealed that the neem oil and \( B. \ bassiana \) were equally effective for the reduction in fruit damage in tomato up to 91.12 and 88.74%, respectively as compared to cypermethrin treated plot (92.20 %).

Poomalai et al. (2014) investigated the bio-efficacy of \( HaNPV \) against \( H. \ armigera \) in cotton. The results showed that among the three treatments, \( HaNPV @ 500 \leq \text{ha} \) was significantly reduced the larval population and boll damage than chemical treatment cypermethrin 25% EC + quinalphos 25% EC.

Taggar et al. (2014) revealed that among the various treatments \( B. \ bassiana @ 1.5 \leq \text{kg/ha} \) recorded the lowest larval population (3.50 larvae/plant) followed by native \( B. \ thuringiensis \) isolate @ 1.5 kg/ha, \( B. \ bassiana @ 1 \leq \text{kg/ha} \) and \( B. \ thuringiensis @ 1.5 \leq \text{kg/ha} \). However, significantly lowest per cent pod damage (25.57%) was observed
in *B. thuringiensis* @ 1.5 kg/ha followed by *B. bassiana* @ 300 mg/litre and native *B. thuringiensis* isolate @ 1.5 kg/ha in pigeonpea.

Pandey and Das (2016) found that among different biopesticides, *B. bassiana* @ 1 litre/ha (1x10^{12} spores/ml) was the most effective biopesticide, as it recorded lowest larval population (6.68 larvae/5 plants).

Kumar and Kaur (2017) reported that the commercial formulations of *B. thuringiensis* and *B. bassiana* have significantly reduced the larval population (0.07 and 0.47 larvae/plant) of capitulum borer, *H. armigera* in sunflower.

Ojha *et al.* (2017) evaluated certain bio-pesticides against *H. armigera* under field condition and concluded that the minimum (7.56%) pod damage was observed in case of *HaNPV* @ 350 LE, *HaNPV* @ 250 LE (8.62%) and half dose of *HaNPV* @ 350 LE + half dose of *B. thuringiensis* var. kurstaki (9.46%).

### 2.2.1 Yield and Economics

Shukla *et al.* (1996) conducted field trial to determine the efficacy of three doses (250, 300 and 350 LE/ha) of NPV for the control of *H. armigera* infesting chickpea. All *HaNPV* concentrations produced a significantly higher grain yield (1.26 to 1.33 t/ha.) as compared to untreated control plots (1.17 ton/ha).

Gowda and Yelshetty (2005) conducted an experiment by using commercial formulations of microbial agents for the management of *H. armigera* on chickpea. The per cent pod damage did not vary among the treatments but the highest (10.36 q/ha) grain yield was recorded in *HaNPV* treated plots followed by *B. thuringiensis* var. kenya (9.40 q/ha) and *B. thuringiensis* var. kurstaki (8.70 q/ha).

Hossain (2007) found that the highest yield (1,856 kg/ha) of chickpea grains was obtained from *HaNPV* sprayed plots as compared to the other treatments.

Jhalendra *et al.* (2008) conducted a study to evaluate the efficacy of two most virulent native isolates of insect pathogenic fungi (*M. anisopliae* and *B. bassiana*) and compared with four commercial biopesticides including NPV against chickpea pod borer, *H. armigera*. The chickpea yield was significantly higher in the plots treated with *M. anisopliae* and *B. bassiana* than control, however lesser than NPV alone treated plots.
Bhushan et al. (2011) recorded maximum yield (15.9 q/ha) and cost benefit ratio (1:2.47) in the NSKE treated plots and suggested that these integrated pest management components can be incorporated for the *H. armigera* management in chickpea.

### 2.3 Determination of effective dose and time of application of different biopesticides against *H. armigera*

#### 2.3.1 Determination of effective dose

##### 2.3.1.1 *B. bassiana*

Gopalkrishnan and Narayanan (1990) studied a dose mortality relationship between the *B. bassiana* and *H. armigera*, and observed 60 to 100% mortality of larva and cent per cent mortality of eggs with $1.0 \times 10^7$ conidia per milliliter suspension.

Prasad *et al.* (1990) found that *B. bassiana* was the most virulent and recorded the lowest LC$_{50}$ of $2.17 \times 10^5$ conidia per milliliter against second instar larvae of *H. armigera*.

Manjula and Padmavathamma (1999) concluded from laboratory experiment that the mean per cent mortality of *H. armigera* larvae was highest (76.84%) at high concentration (1x$10^9$ spores/ml) of *B. bassiana*. However, the reduction in concentration ($10^5$, $10^6$, $10^3$ and $10^1$ spores/ml) also reduced significantly the mean larval mortality (66.13, 51.38, 44.22 and 42.93%), respectively.

Saxena and Ahmad (1997) tested *B. bassiana* at different concentrations under field conditions to control *H. armigera*, and determined that the concentration of fungal spores in spray fluid had definite negative correlation with the pest incidence. They recorded 6.8% pod damage in chickpea at dose of $2.68 \times 10^7$ spores per millilitre. Whereas, untreated control recorded 16.3% pod damage.

Rathod (2002) carried out an experiment using *B. bassiana* ($1.18 \times 10^4$, $1.18 \times 10^6$, $1.18 \times 10^8$ and $1.18 \times 10^{10}$) to control *H. armigera* (eggs, instars I, II, III, IV and V). Second and third instars of *H. armigera* were found more susceptible to the pathogen than other larval stages whereas, the fungus was pathogenic to all stages of pest (2-72%) at $1.18 \times 10^{10}$ (conidia/ml).
Baraiya (2003) concluded that *B. bassiana* @ 3.5 g/litre proved to be the most effective dose, among five doses tested against all the developmental stages of *H. armigera*.

Pandey (2003) studied the pathogenicity of *B. bassiana* in eggs and pupae of *H. armigera*. The results revealed that when *B. bassiana* @ 5 x 10^6 conidia/ml was sprayed on the eggs of *H. armigera*, the fungus caused mean egg and pupal mortality of 40.8%.

Dhembare and Siddique (2004) tested the pathogenicity of *B. bassiana* against *H. armigera* and found that per cent larval mortality was increased with increase in spore concentration.

Mishra and Simon (2012) tested five different concentrations of 0.15%, 0.20%, 0.25, 0.30% and 0.35% against *H. armigera* in chickpea and revealed that the mortality started after two to three days of treatment and larval death was occurred through various morphological deformities in body part which went up to 74.75% with highest dose of 0.35%.

Karkar *et al.* (2014) revealed that the higher dose of *B. bassiana* (10^8 conidia/g) @ 3.5 g/litre proved to be the most effective dose among five doses (1.5 to 3.5 g/lit) tested against the third instar larvae of *H. armigera* in pigeonpea.

Bajya *et al.* (2015) found that *B. bassiana* 1.15% WP @ 3000 g/ha and 2500 g/ha were highly effectual in controlling pod borer populations after two sprays of both the seasons.

### 2.3.1.2 HaNPV

Gundannavar *et al.* (2004) tested the laboratory efficacy of *HaNPV* @ 10^6 and 10^3 POB/ml against *H. armigera*. The results showed that *HaNPV* @ 10^6 POB/ml inflicted mortality to the extent of 50 to 100% within 5 to 8 days of treatment. However, at the lower concentration (*HaNPV* @ 10^3 POB/ml), larval mortality was 66.67% even after 10 days of exposure period.

Srinivasa *et al.* (2008) carried out *in vitro* studies on dosage mortality response of *H. armigera* to different commercial formulations of *HaNPV*. The result showed the lowest LC_{50} value (3.12 X 10^3 POB/ml) for BPMS formulation, which indicated
its higher virulence compared to other formulations. The \( \text{HaNPV} \) of PCI, MBP and ZARS-G were on par with each other with \( 9.5 \times 10^5, 9.4 \times 10^5, 15.6 \times 10^5 \) POB/ml and highest LC<sub>50</sub> value was recorded with \( \text{HaNPV} \) formulations of PDBC \( (11.42 \times 10^6 \) POB/ml).

Mahesh \textit{et al.} (2012) studied the effect of four different concentrations of NPV@ \( 1 \times 10^8, 1 \times 10^7, 1 \times 10^6 \) and \( 1 \times 10^5 \) POB/ml against five larval instars \( \text{viz.}, 1^{st}, 2^{nd}, 3^{rd}, 4^{th} \) and \( 5^{th} \) of \( \text{H. armigera} \) to evaluate mortality and viral yield. They suggested that \( \text{HaNPV} \) @ \( 1 \times 10^7 \) ml should be applied to \( 3^{rd} \) instar larvae \textit{in vitro} to achieve maximum larval mortality \( (78.33 \%) \) and highest viral yield \( (4.319 \times 10^9 \) POB/g of cadavar). Mortality percentage reduced with a corresponding reduction in virus dosages in all studied instars.

Bhamare \textit{et al.} (2014) revealed that higher larval mortality was noticed with the application of \( \text{HaNPV} \) @ 500 LE/ ha \( (56.66\%) \) and 450 LE/ ha \( (50.00\%) \). In both doses, the lowest adult emergence and higher percentage of abnormalities were also noticed.

\subsection*{2.3.1.3 \textit{B. thuringiensis}}

\textit{B. thuringiensis} formulations, Biobit @ 1.0 and 1.5 kg/ha (Shankar \textit{et al.}, 1992) and Halt @ 1.0 kg/ha (Bakhetia \textit{et al.}, 1992) were found effective against \( \text{H. armigera} \) in pigeonpea.

The higher dose of \( \text{B. thuringiensis} \) @ 600 g/ha against \( \text{H. armigera} \) was reported effective by Chundurwar and Seeras (1994).

Mathur \textit{et al.} (1994) reported that two sprays of \( \text{B.t. var. kurstaki} \) (Delfin) @ 1.5 kg/ha proved to be very effective against \( \text{H. armigera} \).

\subsection*{2.3.2 Application time}

\subsubsection*{2.3.2.1 \textit{B. bassiana}}

Meneses (1989) recommended that maximum mortality of pest was observed when \( \text{B. bassiana} \) @ 2 kg per hectare applied early in the morning.

Gowda \textit{et al.} (1994) studied the effect of solar heat treatment on inactivation of the muscardine fungus \( \text{B. bassiana} \). They concluded that solar heat treatment was
significantly able to reduce the conidial germination compared to control (90.90%). As the duration of exposure of sunlight increased, the conidial germination and larval (silkworm) mortality were decreased.

Baraiya (2003) reported that application of *B. bassiana* at evening (5.00 P.M.) was found as most efficient application time to achieve better effectiveness of *B. bassiana*, followed by *B. bassiana* application at morning (8.00 A.M.) against *H. armigera* in cotton.

Tuan (2014) concluded that the conidia of *B. bassiana* were substantially inactivated after an hour of exposure to direct sunlight, when time of exposure was extended to 2 hr an enlargement of conidia occurred and total loss of viability was noted when conidia were exposed to direct sunlight for 3 hr.

**2.3.2.2 HaNPV**

Jayraj *et al.* (1987) could control *H. armigera* more successfully on chickpea and lablab bean, when *HaNPV* @ 250 LE/ha applied in the evening hours than in the morning.

**2.3.2.3 B. thuringiensis**

Mahapatro and Gupta (1999) found that *B. thuringiensis* spraying at evening hours (6 pm) resulted in most effective control of cotton bollworm complex.

Gray *et al.* (2011) studied the comparison of morning and evening larvicidal applications on black fly and concluded that *B. thuringiensis* subsp. *israelensis*, when applied against *Simulium appalanchiense* demonstrated no difference in larval mortality between morning and evening applications. These findings indicated that the larvae responded in a similar manner to the larvicidal during the late morning to early afternoon and evening to night.
2.4 Persistent and cumulative effect of different biopesticides against *H. armigera* on chickpea

2.4.1 Persistent effect

2.4.1.1 *B. bassiana*

Gardner *et al.* (1977) observed one-half of the original activity of *B. bassiana* was lost between 5 and 10 days after application. The average mortality of *S. litura* larvae resulted from exposure to the foliage treated with *B. bassiana* ranged from 83.2% on the day of application to no deaths on 10 days later.

Ignoffo *et al.* (1979) found the mortality of *Trichoplusia ni* larvae, fed Boverin (*B. bassiana*) treated soybean leaves collected immediately after spraying was 75.6 ± 3.5% and no larval mortality was recorded after 14 days of exposure to the elements.

James *et al.* (1995) observed *B. bassiana* conidia persisted in the field of alfalfa for at least 28 days, when approximately 10% of the original inoculum was still present. In the lower canopy, more conidia were present than on other plant parts and they persisted longer on the leaves in an alfalfa field.

Inglis *et al.* (1995) noted that simulated rain reduced the concentration of persistent and cumulative effect of *B. bassiana* against *H. armigera* conidia on lucerne leaves by 28 to 61%. Although there was a slight effect due to rain intensity for lucerne, there was no influence of either rain duration or crop type on the retention of *B. bassiana* conidia.

Pena *et al.* (1996) noted that *B. bassiana* treated plants had the greatest and most persistent effect on mortality (88%) of total broad mites per leaf.

Shelton *et al.* (1998) reported that *B. bassiana* persisted on treated cabbage leaves in screen house for more than two weeks and mycosis of *Plutella xylostella* larvae reared on these leaves was more than 50%, after 7 days of application.

Baraiya (2003) studied the persistent effect of *B. bassiana* and concluded that a significant and the highest larval mortality was recorded in sample collected on same day of *B. bassiana* application (12.00 %) and larval mortality was decreased in a
gradual manner on the subsequent leaf samples collected after 1\textsuperscript{st}, 2\textsuperscript{nd} and 3\textsuperscript{rd} day of application (9.99 to 5.00 \%) in cotton.

Khanpara (2004) found that the persistence of \textit{B. bassiana} @ 3.0 kg/ha became half within 3 days and caused the mortality in \textit{H. armigera} larvae up to 11 days in pigeon pea.

\textbf{2.4.1.2 \textit{HaNPV}}

Young and Yearian (1974) reported that \textit{HaNPV} was rapidly inactivated under field conditions on the upper leaf surface of cotton, soybean and tomato. Inactivation of the virus was most rapid on cotton with little activity remaining after 24 hrs. Persistence on tomato was significantly better than on the other hosts.

Sanjay \textit{et al.} (1992) experimented to screen certain adjuvants for improving NPV efficacy in the control of \textit{H. armigera} on sunflower and pigeonpea. The results showed that application of NPV @ 500LE/ha + boric acid 0.1\% or NPV @ 500 LE/ha + jaggery 0.5\% has significantly reduced larval population and increase the yield of pigeonpea over the application of NPV alone.

Gibba \textit{et al.} (2007) showed that the efficacy and persistence of NPV was increased when mixed with Petroleum Spray Oil (PSO) at the rate of 2\% (v/v). In the field experiments, mixing NPV with 1 and 2\% (v/v) PSO, increased larval mortality from 25.9 to 31.5 and 44.8\%, respectively. In addition, 1 and 2\% PSO mixtures with NPV increased persistence of efficacy from 1.1 to 1.6 and 2.5 days, respectively.

\textbf{2.4.1.3 \textit{B. thuringiensis}}

Rajamohan and Jayaraj (1978) reported that the \textit{B. thuringiensis} sprays gave the best initial control but persisted for less than 10 days on cabbage.

Dabi \textit{et al.} (1979) reported cent per cent mortality of third and fifth instar larvae of \textit{H. armigera} within 96 hr of \textit{Bt} (Dipel) application @ 12.00 x 10\textsuperscript{9} IU/ha and 16.00 x 10\textsuperscript{9} IU/ha, respectively.

Leong \textit{et al.} (1980) studied the persistence and survival of \textit{B. thuringiensis} under field condition in California. They reported that solar radiation, leaf temperature and vapour pressure deficit affected \textit{Bt} endospore viability and
pathogenicity. They also suggested that the bioassay was the best indicator for the field persistence of Bt.

Beegle et al. (1981) observed that the persistence of insecticidal activity of B. thuringiensis var. kurstaki became half within two days on cotton leaves.

Many commercial preparations of Bt were observed to decline their effectiveness from the fourth day after spraying on crop canopy (Salama et al., 1983).

B. thuringiensis var. kurstaki was also reported to degrade very fast under field conditions with an average half life time ranging from 1.5 to 2 days (Wilson et al., 1983).

Salama et al. (1983) reported that the reason for decrease in persistency of B. thuringiensis was the sunlight and ultraviolet rays.

Abou Bakr et al. (1984) reported that newly hatched larvae suffered 80 % mortality by 4th day treatment when exposed to B. thuringiensis @ 2.5 x 10^9 spores/ml.

Sundarbabu (1985) also found that the spores of B. thuringiensis were rapidly inactivated by exposure of ultraviolet radiation.

Gardner and Horny (1987) reported that the persistence of B. thuringiensis (Dipel) on sorghum had fallen by 50% after 2 days, while after 7 days, no activity was recorded.

Gaikwad et al. (1988) observed that mortality (LC 50) of 2nd, 3rd, 4th and 5th instar larvae of H. armigera treated with Delfin WG was reduced along with day interval.

Bertona et al. (1994) reported that Delfin remained active for 7-10 days after application and its degradation was mainly due to light and temperature.

Sudarshan et al. (1994) found that the survival of B. thuringiensis strain on the leaves of cotton and okra for more than 28 days, while its survival (persistent) in phyllophers of mulberry, peanut, chickpea, tomato and rice was limited to about 3-5 days.
Patel (2000) reported that the efficacy of B. thuringiensis kurstaki became half within 3 days and caused larval mortality of H. armigera upto 5 days on chickpea, whereas Jethva (2000) observed the half life of Btk on castor leaves was 2 days and caused larval mortality of S. litura upto 4 days.

Persistence of B. thuringiensis kurstaki was studied in five crop ecosystem. It was observed to persist up to 4 days. Rice, bean, red gram, jute and mung bean gave Persistence Toxicity Index (PTI) of 10, 16.67, 13.33 and 6.63%, respectively (Pramanik et al., 2000).

Khanpara (2004) concluded that the persistence of B. thuringiensis @ 2.0 kg/ha became half within 3 days and caused the mortality in H. armigera larvae up to 7 days.

Asokan et al. (2008) found that the Insecticidal Crystal Proteins (ICP) of B. thuringiensis have relatively short persistence when applied as foliar spray and also concluded that B. thuringiensis was highly toxic to the important pests of cabbage, Plutella xylostella (0.36 ng/cm²) and Crocidoloutia binotalis (1.74 ng/cm²). Additionally, Bt had extended lysis (96 hours) and higher persistence (9 cfu/cm²) as compared to the rest of the transformants and B. thuringiensis var. kurstaki.

### 2.4.2 Cumulative effect

#### 2.4.2.1 B. bassiana

Feng et al. (1985) found that the first instar larvae of corn borer to be the most susceptible among five larval instars to B. bassiana. There was a little difference in 2\textsuperscript{nd}, 3\textsuperscript{rd} and 5\textsuperscript{th} instars, while the 4\textsuperscript{th} instar larvae were the most tolerant in all cases.

Lynch and Lewis (1978) concluded that B. bassiana was highly pathogenic to corn borer larvae. Hatching of treated eggs reduced to 29.5%, but larvae hatching from treated egg, had 80% mortality by the third larval stage.

Bioassay with B. bassiana and 2\textsuperscript{nd}, 3\textsuperscript{rd} and 4\textsuperscript{th} instar larvae showed that susceptibility of the fungus decreased with advance in age of the larvae of H. armigera (Prasad et al., 1990).

Results of an experiment carried out by Sivasankaran et al. (1990) revealed that B. bassiana showed more susceptibility against second and third instars larvae of...
H. armigera with mean mortality of third instar larvae from 50.6 to 65.0%. They also reported that mortality of larvae decreased with increase larval age or decrease in the dose of entomopathogenic fungus.

Manjula and Padmavathamma (1999) tested B. bassiana against different larval instars of H. armigera. They observed the highest mortality in first instar (69.86 %), and subsequent instars had significant reduction in mortality, which recorded 62.13, 57.29, 50.04 and 41.42% mortality in second, third, fourth and fifth instars, respectively.

Gundannavar et al. (2006) reported that the fungus exerted considerable pathogenicity of 52.5% mortality to the first instar larvae at 5th Days After Treatment (DAT) and the cumulative mortality steadily increased to reach 100% on 7th DAT at the highest spore load of $10^8$ conidia per ml, when larvae feeds on treated chickpea seedlings.

2.4.2.2 HaNPV

Pourmirza (2000) estimated Lethal Dose (LD$_{50}$) values for the first, second, third, early and late fourth larval instars and reported 5, 141, 1226, 5168 and 24553 polyhedra per larva, respectively. He reported that there was an uniform pattern of decrease in susceptibility to NPV with increased age over the first four instars followed by fifth instar.

Nachimuthu et al. (2007) studied the mortality of H. armigera and reported that larval mortality decreased as the age of the larvae increased in all the treatments. The time for 100% kill of third instar larvae was significantly reduced to 72 hrs, when compared to 168 and 120 hrs for the same dose of NPV for killing 4th and 5th instar larvae, respectively.

Jeyarani and Karuppuchamy (2010) carried out investigations to find out the effect of HaNPV against second, third, fourth and fifth instar larvae and discovered that treatment of HaNPV applied at LC$_{50}$ doses alone or a combination of HaNPV (LC$_{50}$) + HaNPV (LC$_{25}$) significantly caused higher mortality due to polyhedrosis. The LT$_{50}$ was found to be significantly the shortest as 99.52, 100.31, 102.92 and 104.46 hrs against second, third, fourth and fifth instar larvae, respectively.
Mahesh et al. (2012) reported that when five larval instars viz., 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th} and 5\textsuperscript{th} were fed on diet treated with four different concentrations (1x10\(^8\), 1x10\(^7\), 1x10\(^6\) and 1x10\(^5\) POB/ml) to cause the highest mortality and maximum viral yield. Findings suggested that HaNPV should be applied to 3\textsuperscript{rd} instar larvae \textit{in vitro} to achieve the highest larval mortality (78.33 \%) and maximum viral yield (4.319 \times 10\(^9\) POB/g of cadavar) at 1x10\(^7\) ml dose inoculum. Mortality percentage reduced with a corresponding reduction in virus dosages in all studied instars.

Hussain and Singh (2014) reported that the LC\textsubscript{50} values of HaNPV for 2\textsuperscript{nd} instar larvae of \textit{H. armigera} was 0.1603\% (0.19 \times 10\(^7\) POB/ml) with fiducial limit ranged from 0.22758 to 0.11300, while in case of 4\textsuperscript{th} instar larvae, the LC\textsubscript{50} value was 0.2225\% (0.26 \times 10\(^7\) POB/ml) and fiducial limit ranged from 0.29946 to 0.16541.

Songdou et al. (2015) studied the mortality, development time and pupal weight of \textit{H. armigera} in different instar larvae and recorded that mortality increased and development time was prolonged to different degrees along with increasing concentrations of HaNPV. The pupal weight was not differed significantly, between infected HaNPV and control insects. Although, it was differed significantly when 4\textsuperscript{th} instar was infected but was significantly 5\textsuperscript{th} instar was infected with HaNPV at concentrations of 10\(^9\) and 10\(^10\) POB/ml.

\textbf{2.4.2.3 \textit{B. thuringiensis}}

Gaikwad et al. (1988) observed that mortality (LC 50) of 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th} and 5\textsuperscript{th} instar larvae of \textit{H. armigera} treated with Delfin WG was reduced along with day interval.