Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs

BY

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CERTIFICATE-I

This is to certify that the dissertation entitled, **"Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs"** submitted for the degree of **Doctor of Philosophy** in the subject of **Entomology to** Chaudhary Charan Singh Haryana Agricultural University, Hisar is a bonafide research work carried out by **Ms. Lalita Panwar**, Admn. No. **2014A19D,** under my supervision and guidance and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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It is certified that the dissertation submitted by **Ms. Lalita Panwar**, Admn. No. **2014A19D**, a Ph.D. student of Entomology has been checked and found as per specifications of the format circulated by Dean, PGS vide Memo. No. PGS/A-1/09/6926-90 dated 26/08/2009.

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LIST OF ABBREVIATIONS

%	:	per cent
/	:	per
@	:	at the rate
®	:	Registered trademark
°C	:	degree celsius
CD	:	Critical difference
cfu/g	:	colony forming unit per gram
cm^2	:	centimetre square
CV	:	cofficient of variance
et al.,	:	et alibi (and others)
etc.	:	Et cetera (and the other things)
Fig.	:	Figure
g	:	gram
GWM	:	*Galleria mellonella*
H.P.	:	Himachal Pradesh
hrs	:	hours
i.e.	:	id est (that is)
LC	:	Lethal Concenration
ml	:	milliiter
ppm	:	part per million
RH	:	Relative Humidity
SE(d)	:	Standard error of the Differences
SE(m)	:	Standard error of the mean
spp.	:	Species
viz.,	:	namely
w.r.t	:	with respect to

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CHAPTER- I

INTRODUCTION

Honey bees are associated with man since his advent on the Earth. The first visible proof of this association is found in rock paintings attributed to Neolithic man (Eckert and Shaw, 1976) and classification of bees given by the Indian Physician named Charaka (1200-1000 BC). Honey bees find mention in scriptures and legends of Egyptians, Greeks and Babylonians. The oldest of the sacred book in India, the Rig-Veda, which was probably written between 3000-2000 BC, contains many references to bees and honey. The Gods Krishna, Vishnu and Indra were called honey bees as *Madhava* or nectar bomb. Vishnu represented as a bee resting on the Lotus flower (Ransome, 1937). Honey bees are also mentioned in Vedas, Ramayana and the book of Proverbs, the Quran and other ancient books (Singh, 1962). Honey bees give honey and wax which are defined as "liquid gold of nature" and "gold bullion", respectively. These products are incomparable to anything else in terms of nourishment, healing properties and other utilities. The Kings and the government in ancient times accepted them as payment of taxes and tributes. Even today, the 'Bee Keeping Development' a Journal for sustainable beekeeping, accepts bees wax towards subscription of the Journal charges. In addition to honey and wax production, honey bees/bee hives also produce propolis, pollen and bee venom that contain biologically active substances which are used in industries and medicinal cures (Magid, 1960). Bees wax is one of the most useful product of honey bees and used in the pharamaceutical industry, dentistry, cosmetics and several other industries including Apiculture. Wax, especially combs, contain many fragments of feeding nutrients like proteineous or pollen, exuviae of bee stages and honey, therefore, are attacked by various pests including wax moth, which is most devastating (Ebadi, 1980).

Presently beekeeping industry is facing many challenges throughout the world. Among these, a major constraint in beekeeping developmental programmes is the damage caused to the honey bee colonies by various enemies and diseases. Honey bees are attacked by many diseases and pests, which cause weakness of colonies and low honey production. The important diseases include bacterial diseases (American Foul Brood, European Foul Brood), fungal diseases (Chalk Brood) and viral diseases (Sac brood). Bees are also attacked by many insect pests such as Greater wax moth (*Galleria mellonella* L.), Lesser wax moth (*Achroia grisella* F.), Indian meal moth (*Plodia interpunctella* Hb.), Mediterranean flour moth (*Ephestia kuhniella* Zell.), Fig moth (*Ephestia cautella* Walk.), Dried fruit moths (*Vitula serratilinella* Rag. and *V. edmansi* Pack.), Codling moth (*Carpocapsa pomonella* L)., Bumble bee moth (*Aphomia sociella* L.), Death's head hawk moth (*Acherontia styx* Westw.), Wingless fly and Small hive beetle. Among these, *Galleria mellonella* L. is one of the most

devastating and economically important pest in the world (Burges, 1978; Chang and Hsieh, 1992) and it even finds mention since the period of Aristotle (284 BC) in his writings on agricultural subjects. Although *G. mellonella* is a useful insect in insect pathology, physiology studies and in fish baits, yet it is responsible for causing heavy losses to beekeepers throughout the world. Larvae of *G. mellonella* are excellent *in vivo* model and have been used with a variety of fungi and anti-fungal agents. It is preferred in entomological studies, because of its nutritional needs, ecological adaptation and development characteristics. It is also used as a host in favour of many hymenopteran species such as solitary endoparasitoid wasps, *Pimpla turionellae* (L.) and *Itoplectis naranyae (*Ashmead), which attack various lepidopteran pupae and prepupae (Coskun *et al*. 2005) because the natural host of *P. turionellae* are difficult to mass rear and moreover, it is a polyphagous parasitoid, therefore, it is possible to utilize wax moth as an alternative that are easily cultured in the laboratory by mass rearing for the pathogen of the parasitoid. Interesting study conducted by the Bombelli *et al*. (2017) who reported new solutions for bio-degradation of Polyethylene (PE) by larvae of *G. mellonella*, producing ethylene glycol.

The greater wax moth in larval stage feeds on comb wax and damages it severely. The larvae of the wax pest causes considerable damage to combs left unattended by bees. Combs in weak or dead colonies and in storage areas are subject to attack by greater wax moth (Caron, 1992). The adult female moths fly at night and deposit masses of eggs on the unprotected honey combs and in the cracks between hive bodies. After a few days, eggs hatch; larvae crawl on the combs and begin their feeding activity (Hood, 2010). They damage or destroy the combs by boring through the comb cells so as to feed on cocoons, bee exuviae (cast skins), and pollen. As they chew through the wax, they spin silken galleries for protection. Full-grown caterpillars vary in colour but are generally dirty white. The moths are grayish to purplish brown, having dark markings and lead coloured tips on the forewings, pale brownish or yellowish hind wings. The wings are held flat over the back when at rest (Chang and Hsieh, 1992).

Galleria mellonella is a cosmopolitan pest causing serious economic damage to honey bee combs during storage (Paddock, 1918; Williams, 1997; Gillard, 2009; Ellis *et al*., 2013). A normal healthy hive/colony keeps the wax moth under control by ejecting the larvae but weakened bee colony with small population is overcome or over powered by wax moth infestation destroying the brood combs, ultimately destroying the whole bee colony. The caterpillars of wax moth feed on combs, pollen, larval exuviae and other proteinaceous matter both in storage as well as in live honey bee colonies (Caron, 1999). The pest larval stage feeds on wax and pollen stored in combs of active honey bee colonies (Milam, 1970), freshly extracted combs, impure wax, slum gum, wax capping and queen rearing materials containing wax in the storage (Williams, 1978). The entire comb is covered with a mass of webbing and

fecal matter of the larvae; a condition described as "*Galleriasis*." Later black excreta of the pest can also be noticed entangled in the web. It does not attack adult bees but destruct the combs of a weak colony by chewing the comb, spinning silk lined tunnels through the comb cell walls and over the face of the comb, which prevent the bees to emerge from the sealed comb cells as their body get entangled in silken web, so emerging bees die due to starvation, as they are unable to escape from their cell.

Among the natural enemies, the greater wax moth is the most devastating pest of honey bees. In India, it is observed that infestation occurs throughout the year in both higher and lower altitudes, but peak infestation is recorded during May to September (monsoon). Combs of all the species of *Apis* bees are freely attacked by wax moth (Nagaraja and Rajagopal, 2009). During severe infestation, the combs are being found to be destroyed, which force the bee colonies to abscond. Mahindre (1983) reported about 90 per cent infestation in the combs of *A. dorsata* by wax moth. However, Brar *et al*. (1985) recorded 16 to 19 per cent infestation in *A. mellifera* colonies in north India. Damage varied with the level of infestation and the time that has elapsed since the infestation first began. Sometimes, the stored combs may be destroyed; the frames and combs become filled with a mass of tough and silky web. In ideal conditions for wax moth development, a super of combs may be rendered useless in about a week. Damage occurs mainly in the hot and humid months of the year when wax moths are most active. However, considerable damage can still occur during the cool part of late autumn and early spring as greater wax moth can produce a large amount of metabolic heat, which can raise the immediate temperature around them by up to 25°C above the normal environment temperature. The weak colonies or abandoned combs are easily attacked more often by *G. mellonella* (Kapil and Sihag, 1983; Basavarajappa, 2011). Wax moths posses a serious problem to honey bee colonies in India during dearth period of flora *i.e.* in monsoon, which results in escaping absconding of bees from the colony (Brar *et al.,* 1985). Larvae of wax moth tunnel through the honey combs, consuming the bees wax and stored food materials. Colonies of *Apis cerana indica* have been reported to abscond due to infestation with the wax moth (Leong, 1990). Maximum infestation of wax moth has been recorded during July to September, generally in the brood frames and occasionally in the super frames (Gupta, 1987).

Physical methods of cooling and heating of store empty combs were used for controlling *G. mellonella* in absence of honey bees. Cooling was more effective and more practically feasible since excessive heat destroyed combs and spoiled honey (Burges, 1978). They also reported that the most rapid control of wax moth larvae was obtained by deep freezing at -17°C, but temperature just above or just below freezing (as found in domestic refrigerators) were also effective with an exposure period of 10 to 21 days. Many synthetic chemicals were attempted to control wax worm in both live hives and storage conditions.

These synthetic insecticides cause tainting of honey and other hive products, in addition to their side effect on bees. Use of chemical insecticides such as sulphur, para dichloro benzene and calcium cyanide is harmful to bee population (Whitecomb, 1967). In this context, use of plant products as botanical insecticides is emerging as a major thrust area in controlling *G. mellonella*. Many natural plant species products possess various insecticidal activities. Being the natural plant products, the plant-based insecticides, are safer and, hence, their use against pests has gained importance all over the world (Alkofahi *et al.,* 1989; Hiremath, 1994).

In general, plants with pesticidal properties can be commercially used. Possibilities for controlling wax moth including some manipulations in the hive (*i.e.,* keeping beehives clean and debris be exploited in three ways, firstly by using parts of the plant in powder form or as crude extracts in water or in organic solvents, secondly as purified extracts (like rotenone and Margosan-O) and finally as a key to synthesize a chemical compound which then could be produced industrially (Downum *et al*., 1993). Other treatments to stored combs such as, physical, biological and chemical methods can also be used (Caron, 1992). To control the greater wax moth menace, different kinds of chemicals, need to manage this pest. Although, the use of these chemicals is somewhat easy and effective, some precautions of safety of environment and contamination of bee products used to be considered. In addition, some of these materials appear to be ineffective against eggs of the wax moth (Fraser, 1997) in most cases these chemical measures may not be safe due to their residual problems left behind in the hive or combs. Several non-chemical methods can also be used for controlling the wax moth. Efforts are being made in different parts of the world to replace existing fumigation based control methods against *G. mellonella*, with an environment friendly treatment those would afford long term protection against the pest. A very little information is available on the seasonal incidence and management of greater wax moth after the use of non-chemical methods and botanicals. Keeping these above facts in view, the present study entitled "Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs" was planned with the following objectives.

Objectives:

1. To study the seasonal incidence of *Galleria mellonella* L. in *Apis mellifera* live colonies with different bee strengths and number of stored empty combs.
2. To test the effectiveness of different plant extracts against *Galleria mellonella* L. larvae.
3. To test the effectiveness of different chemical and non-chemical treatments against *Galleria mellonella* L. in stored combs.

CHAPTER- II

REVIEW OF LITERATURE

Greater wax moth is a serious pest of honey bee colonies and stored bee combs in tropical and sub tropical climates, where warm temperature favours their rapid development (Hachiro and David, 2000). The available literature pertaining to the present study includes, seasonal incidence of *Galleria mellonella* L. in *Apis mellifera* colonies and stored combs, correlation with meteorological parameters, efficacy of different plant extracts to control the incidence of wax moth larvae and effectiveness of different chemical, non chemical and botanical treatments against *G. mellonella* in stored combs.

2.1.1. Seasonal incidence of *Galleria mellonella in Apis mellifera* colonies and stored combs

Fletcher (1911) reported peak infestation of wax moth in June and July under Indian conditions. Paddock (1918) in Taxas (United State), observed peak period of infestation from April to October. However, Earp (1925), observed the pest infestation throughout the year in the warmer part of New Zealand. Poilane (1933) while studying possibility of domesticating different species of honey bee in Indo-China region reported that the hives of *Apis indica* Fab. were attacked by wax moths and termites. Similarly, Ramakrishna and Ramachandran (1934) observed *G. mellonella* causing serious damage to *A. indica* colonies in the South India.

In Ethiopia, Kannangara (1940) noted that wax moth infestation occurred in June after the first honey flow season, which coincided with the dearth period. According to Grout (1946), the infestation of wax moth in the United States was more or less uniform throughout the year.

Sharma (1949) noticed peak activity of the moths during summer in North India, as they could not bear the cold temperature of winter. In Himachal Pradesh (India) wax moths are active from March to October (Garg and Kashyap, 1998) but its peak activity in various states in India has been reported from June to November (Ramachandaran and Mahadevan, 1951; Brar *et al.,* 1985; Gupta 1987).

Warren and Huddleston (1962) in Karnatka observed severe damage by wax moth in spring or autumn when the colonies were weak. According to Nessa *et al.,* (1980), the main period of infestation of wax moth in Bangladesh was from August to December. Sihag (1982) recorded maximum infestation of the pest during bee floral dearth period of June and July in Haryana. The similar pest activity period was reported by Brar *et al.,* (1985) under Punjab conditions in *A. mellifera* colonies with the peak colony infestation of 16.2 to 19.3 per cent.

In Haryana, Gupta (1987) observed maximum infestation of *G. mellonella* from July to September in *A. mellifera* colonies. The number of wax moth larvae in the hive varied from

4 to 138 with the most suitable temperature for the development of the moth being 35°C and relative humidity (RH) 70 per cent.

Shylesha (1987) noted the incidence of wax moth in *Apis cerana* throughout the year in Bangalore with the maximum larval population of 336.36 per infested hive while in the Indian hive bee apiary at Dharwad, (Karnataka) egg lying of *G. mellonella* was noticed from March to August and on an average of 312 eggs per colony were found in three bee colonies in July. The larval stage of the pest was found throughout the year with the peak population during May to August, which coincides with the floral dearth period in the area. In *Apis dorsata* colonies, high rate of infestation by *G. mellonella* was observed during July-August at Bangalore, which resulted in premature migration of the bee colonies. The deserted combs with a high incidence of the pest infestation served as a source of infestation for new bee colonies (Jyothi *et al.,* 1990).

The wax moth larvae cause major losses to commercial beekeepers every year. Almost all colonies of Asian honey bees are prone to moth infestation (Adalakha and Sharma, 1975; Brar *et al.,* 1985). In *A. dorsata* combs, seasonal infestation of wax moth differed from the domesticated bees. In H.P. wax moth population started building from March, reaching its peak in August and then showed decline till February (Thakur, 1991).

Thakur (1991) further reported that the wax moth infested all stages of brood combs, cells, pollen and honey stored regions. Severe infestation leads to the suspension in brood rearing, foraging activity and ultimately desertion of colony. Weak colonies are more prone (53%) to wax moth infestation as compared to strong colonies (11%). Other workers (Kreb, 1982; Jyothi *et al.,* 1990) reported even 100 per cent of the pest infestation in deserted combs.

In South India, maximum infestation of this pest was noticed during the floral dearth period (Viraktamath, 1989). The pest hibernated in larval (about 70%) and pupal stages (about 30%) in stored combs. Tropical climate might have favored overlapping generations during different seasons. Therefore, controlling the wax moth without harming the bees and bee colony has great economic importance (Turker *et al*., 1993).

Brar *et al*. (1985) reported that in *Apis mellifera* apiaries in Punjab, the greater wax moth infestation started in June and increased progressively to acquire peak in September and thereafter decreased to minimum in November.

Abrol and Kakroo (1996) showed that the maximum infestation was noticed between August to October (*Apis mellifera* apiaries in Punjab). These studies were comparable with the earlier records of Ramachandaran and Mahadevan (1951).

Swamy *et al*. (2005) who reported that maximum infestation was during July to October, May to October and March to December, respectively.

At Jammu, activity of *G. mellonella* was observed from May to September with peak infestation during August. The number of larvae per colony ranged from 40 to 350 and

number of pupa from 15 to 104, whereas only 1 to 3 adults per colonies were found (Abrol and Kakroo, 1996). The maximum larval population of wax moth in *A. mellifera* colonies at Ranital in Kangra valley of Himachal Pradesh was reported to be 12 and 15 larvae per three colonies during first fortnight of August in 1993 and 1994, respectively (Verma and Raj, 1996) while later on *A. cerana* colonies the corresponding of the pest larvae were 25 and 29 reported to be per three colonies (Verma and Raj, 2001). The maximum pest population was recorded to be 6 larvae per three colonies during second fortnight of July, 1993 and 7 larvae per three colonies during second fortnight of August, 1994 in *A. mellifera* colonies at Palampur (Himachal Pradesh) (Verma *et al.*, 1998).

MAAREC (2000) suggested that when we remove and store drawn comb, we increase the opportunity for a wax moth infestation. The warmer the temperatures, the more vigilant we must be. Simply trying to put frames in plastic bags would not be enough because eggs could already be present. Storing drawn comb outside in the open air would not suffice either unless you are in an area of freezing winter temperatures.

Swamy (2000) observed that in *A. cerana*, maximum population of wax moth larvae differed during month and different years. It was (90.68) in June 1996, 199.33 in April, 1997 and only 49.55 in March 1998 in bee colonies at Bangalore.

Ansary *et al.* (2001), reported the infestation of *G. mellonella* to *A. cerana* combs was the highest in June (59.33%) in Bangladesh at Mirpur, (Dhaka). However, in Himachal Pradesh (India) severe outbreak of *G. mellonella* in *A. mellifera* colonies was observed during August 2002 with an average of 46 caterpillars per individual comb (Singh, 2003).

The pest infestation occured during most of the seasons in different geographical region due to its overlapping generations in a year. Abandoned combs and weak colonies were important reservoirs for the multiplication of *G. mellonella* population in Karnataka. The pest was active from March to October in H.P. (Garg and Kashyap, 1998) and continued up to November in Southern India, Punjab and Haryana (Ramachandaran and Mahadevan, 1951; Brar *et al.,* 1985; Gupta 1987).

In South India, maximum infestation of the pest was recorded during the floral dearth period (Viraktamath *et al*., 2005) which coincided with the weak strength in the colony.

Swamy (2008) recorded the incidence of *G. mellonella* in strong and weak colonies of *A. cerana*. Swamy reported that the infestation of wax moth was observed throughout the year in the weaker colonies with the highest per cent infestation being in October to February (100%), whereas the infestation was found to be lower during August (28.57%) followed by June and July (33.33%). All the strong colonies were completely free from the wax moth during October, June and July.

Varshneya *et al*. (2008) recorded the seasonal incidence of *G. mellonella* in *A. mellifera* colonies and indicated that greater wax moth started infesting bee colonies from

July and increased progressively from January i.e. 26th standard week (SW) and acquired its peak in month of September (36th to 39th SW) in entire bee hive colonies having different number of brood frames.

The overall average number of wax moth infected combs in a colony was found to be 1.16 combs which were higher than average infested combs (0.9) reported by Amsalu *et al.,* (2011). It is further magnifying that ecological differences have their own impact on the rate and seriousness of wax moth attack to a particular colony.

Kumari and Jha (2013) observed the pest infestation in the bee hive as well as stored combs. The maximum area (cm^2) 40.74, 42.93 of infestation in both the cases was found in the September while the lowest in June (3.42, 4.41), respectively, in 2011 and 2012. It might be due to the high temperature and humidity in the environment. Frames fully covered with bees recorded least infestation due to the self-defense behaviors of worker bees.

Raghunandan and Basavarajappa (2014) reported that the colonies with weak population were more prone to *G. mellonella* infestation and it was more in semi-arid region during summer (30.80% colonies) followed by rainy season (23.40%). However, the infestation was less 11.00 and 6.6 per cent during summer and winter seasons, respectively, in Malnad, Mysore (Karnataka). The prevalence of *G. mellonella* infestation is common, however, the intensity depended on colony strength and prevailing ecological conditions.

Kebede *et al.* (2015) carried out a cross-sectional study from April 28 to May 30, 2009 in four village of Kafta Humera (Ethiopia) to determine the prevalence of wax moth in modern hive colonies. According to the study, the overall prevalence of wax moth larvae in modern bee hive was found to be 27.4% and the nature of severity was differentiated and categorized into three groups as 11.4%, 15.3% and 0.65% as light, moderate and severely affected colonies, respectively.

Sohali (2017) determined the seasonal abundance of *G. mellonela* larvae in hives of honey bees located in district Sargodha (Punjab in Pakistan). Data showed that the maximum moth abundance occurred during the regional dearth period, *i.e.*, May to November. The peak abundance (14.8±3.9 wax moth larvae/hive) occurred in August.

2.1.2. Effects of bee strength on wax moth infestation

Tsegaye *et al.* (2014) studied the efficiency of different five different techniques for preventing the wax moth infestation in local conditions, to purposively selected wax moth susceptible colonies. They revealed that 66.7% of the colonies absconded from colonies where no control treatments due to wax moth infestation. Colonies supplementary feeding was given to 16391.30 bee population were significantly better than other treatments in preventing serious wax moth attacks while the control group possessed the lowest population (12588.23) of bees. They further elucidated that strong colonies had better strength to defend pest attacks. Even though the overall average number of wax moth infected combs were 1.16

combs per colony. The tobacco leaf smoke to the bee combs had the lowest infected of (0.39) combs. Highest (471) number of counted wax moth larva was found in control group while tobacco leaf smoking was with the lowest (43) larval count. They finally concluded that supplementary feeding to the colonies and appropriate use of tobacco leaf smoke could be used as a combined recommendation in reducing the damage.

2.1.3. Correlation of weather parameters with the seasonal incidence of *Galleria mellonella*

According to Stairs (1978) larvae did not undergo significant development at 18°C and stopped to develop 40°C. Chauvin and Chauvin (1985) observed that at 10 per cent RH, larvae died within 48h, at 20 per cent RH the mortality was high but larval life span was extended relative to 80 per cent RH. Jyothi and Reddy (1994) reported that larvae at 8°C temperature did not develop, those at 18°C remained alive up to 222 days but died without pupating. Extension of larval period from 40 to 60 days and pupal period from 13.9 to 18 days were reported when *G. mellonella* was subjected to 28°C and 38°C rearing conditions.

Abrol and Kakroo (1996) observed that the infestation of greater wax moth from May onwards attained peak population during September, declined thereafter up to January. However, in another study, maximum population of wax moths was recorded during the first fortnight of August (Verma and Desh Raj, 2001; Verma *et al.,* 1996). During September (late rainy season) to October (early autumn season) the average minimum and maximum temperature was 28.8°C, 16.6°C and relative humidity was 81.6 per cent, 43.2 per cent, respectively, which were found to be very congenial for the development of greater wax moth.

Jyothi (2003) reported that optimum temperature for the growth and development of the wax moth was found to be 26 ± 2°C. Gupta (1987) reported that the maximum infestation of wax moth in *A. mellifera* colonies was recorded during July-September and the most favorable temperature was 35°C combined with 70 per cent RH. Wax moth population declined to minimum in December and no infestation was recorded in winter, spring and summer season. This absence of the pest infestation may be attributed to the presence of abundant bee flora coupled with favorable weather conditions that result in best brood rearing and avoid the infestation of wax moth from winter to summer season. It was noticed that greater wax moth started infesting bee colonies from the last week of June when bee flora started declining and weather conditions became unfavorable for bees.

Swamy *et al.* (2005) studied seasonal variations of *G. mellonella* in combs of *A. cerana* during the summer and winter seasons and found that summer season was more suitable than winter for the development and multiplication of the wax moth in this spp. of honey bee colonies.

Varshneya *et al*. (2008) indicated that population of wax moth larvae showed significant positive correlation with minimum temperature, maximum RH, minimum RH and rainfall, whereas significant negative correlation existed with bright sunshine hours *i.e.*, the

greater wax moth population decreased with the increase in bright sunshine hour. However, in most of the cases no correlation existed between greater wax moth population and sunshine.

Kumari and Jha (2013) tested the efficacy of different nonchemical methods to minimize the pest infestation in the hive as well as stored raised combs. It was indicated that the wax moth infestation was highest in the month of September (40.74%, 42.93%) while lowest in the month of June (3.42%, 4.41%) respectively. It might be due to the high temperature and humidity in the environment.

Swamy *et al*. (2013) observed the influence of temperature and humidity on biology of the greater wax moth was studied in laboratory. He concluded that with an increase in the temperature and relative humidity regimes, there was a corresponding decrease in the total duration of greater wax moth live stages. However, the hatching of larvae increased with increase in temperature and relative humidity. The lowest relative humidity regime at 35°C and 20°C had adverse effects on the bee colony and the moth failed to lay eggs.

Swati and Verma (2016) studied the honey bee (*A. mellifera*) pests in residential and migratory apiaries and its relation with weather parameters were conducted in five blocks of Morena district in Gird Zone of Madhya Pradesh. Occurrence of *G. mellonela* was significantly higher in migratory apiaries in all the blocks except in Morena and Joura. Incidence of wax moth in all the five blocks except in Morena and Joura was significantly higher (13.6) in migratory apiaries as compared to residential apiaries. Incidence of wax moth larvae was not correlated with the weather parameters except for minimum temperature (r= 0.758).

Sohali *et al*. (2017) found that the minimum and maximum temperatures were strongly correlated with wax moth abundance and consequently, the per cent of hives with moth damaged combs.

2.3. Effectiveness of different plant extracts on wax moth larvae

Liu (1995) also reported that the tracheal mites, *Nosema* disease and chalk brood diseases in bees were controlled by neem (*Azadirachta indica*) products based. The toxicity of the crude extract of twig and leaf of the medicinal plant *Aglalia odorata* to the larvae of *G. mellonella* indicated that the crude extract of twigs and leaf of plant was more efficient as a stomach poison than the crude leaf extract alone (Piyapong *et al.* 1997).

Shashidar and Basalingappa (2000) reported the mean larval mortality ranging from 55.33 to 92.23 per cent with Neem whereas with Tulasi and Pongamia it ranged from 51.67 to 69.21 and 46.73 to 59.64 per cent, respectively. (Larry, 2004) attributed high wax moth larval mortality with neem extract posses insecticidal, growth regulatory and antifeedent properties in neem against insect- pest. Neem seed bitter (NSB) was found to have reduced the oviposition and development of the pests (Sontakke and Dash, 1996; Larry, 2004).

Zaitoun (2007) used the ethanolic extracts of twenty one medicinal and health plants to examine their effects on the development of the *G. mellonella* and on workers honey bee.

Feeding the wax moth larvae on most of the extracts, prolonged the larval stage duration from 2-40 days more over the control (no extract feeding). Six extracts prolonged pupation period from 2-5 days more than the control. Extracts of *Abrus precatorius*, *Laurus nobilis*, *Petroselinum sativum* and *Plantago psyllium* showed the insecticidal effects against the wax moth; they killed 95-100 per cent of the tested wax moths larvae without adverse effects on worker bees, except in the case of *A. precatorius*.

Ahmed *et al.* (2008) tested aqueous Neem Seed Extract (NSE) at different concentrations, (viz., 0.5, 1, 2, 3 and 4%) against *G. mellonella* and reported that the post spray with 4% aqueous NSE, mean mortality of the pest larvae was (83.33 per cent), followed by 73.33, 56.67, 50.00, 50.00 per cent with 3.0, 2.0, 1.0 and 0.5 per cent NSE, respectively as compared to mortality in control (3.33). The mortality had significant statistical difference at different concentrations at various post treatment intervals. NSE at 3 and 4 per cent concentrations had no significant difference among each other at all time in the pest mortality intervals. Weight loss in drawn combs was less in treatment with neem seed extract at 3 and 4% as compared to all other lower concentrations (Izhar-ul-Haq *et al.,* 2008).

Surendra *et al*. (2010) found that use of natural plant products played important role in the management of the *G. mellonella* under laboratory conditions. It was revealed that the larval mortality of wax moth varied significantly with three different plant product concentrations. Mortality was high with neem seed extract (ranging from 84.81±2.7 to 93.65±3.25 per cent at different concentrations) followed by Tulasi (*Ocimum sanctum*) leaf extract showing moderate larval mortality for different instars ranging from (65.36± 4.36 to 73.41±4.46 per cent). The corresponding mortality by the use of Pongamia (*Pongamia pinnata*) seed extract was low (31.10±3.38 to 52.1±19.85 per cent). This neem product performed better under all the experimental conditions.

Eldin *et al*. (2012) studied the toxicological effects of three plant extracts in controlling *G. mellonella.* The results indicated that there were significant differences in the weights of larvae and pupae as well as the emerged adults between sprayed treatments and untreated control treatment. The mortality per cent of wax moth larvae were 33.3, 36.6 and 50% for the 0.2, 0.3 and 0.4% neem concentrations, respectively compared with mortality in control 0.0%. Mortality per cent of pupae were 100% at the three neem concentrations, while it was only 10 per cent in control treatment. The mortality per cent of wax moth larvae were 23.3, 36.6 and 50 per cent for the 0.2, 0.3 and 0.4 per cent of *Chenopodium* (Bathu) extract concentrations, respectively compared with in control 0.0%. Mortality percentages of pupae were 100 per cent at the three concentration of *Chenopodium* extract while it was only (16.6) in control treatment. The mortalities of wax moth larvae were 26.3, 33.3 and 46.6 per cent for the 0.2, 0.3 and 0.4 per cent of Camphor concentrations, respectively and control (0.0 %).

Mortality of pupae were 93.3, 96.6 and 100 per cent at the three of Camphor concentrations, respectively, while it was only 13.3 per cent in control treatment.

Ahmad *et al*. (2014) studied the control of *G. mellonella* by using the aqueous extract of different neem plant parts viz., neem leaf extract (NLE), neem seed extract (NSE), NSE+NLE, Naphelene balls (NB) and control. The treatments were significantly different from each other in controlling the pest. The mean efficacy (no. of larvae killed) have been determined to be X=11.74 with NSE; X=13.99 in NLE; X=4.06 in NSE+NLE; X=15.83 in NB and X=44.08 in control, respectively. The mortality or control of wax moth after application of various treatments showed significantly differed (F=110, F>P=0.00) for controlling the wax moth. NSE+NLE combination gave significant higher mortality over all other treatments.

Pitan *et al*. (2015) evaluated the effectiveness of methanol, n-hexane and aqueous leaf extracts of *Ocimum gratissimum, Carica papaya, Tithonia diversifolia, Ageratum conyzoides* and *Azadirachta indica* in the management of four insect pests of honey bees namely; acrobat ant (*Crematogaster lineolata*), small hive beetle (*Aethina tumida*), lesser wax moth (*Achroia grisella*) and greater wax moth (*Galleria mellonella*) in the laboratory. Test of contact toxicity of the extracts was conducted by topical application of 2ml of treatments at 10 per cent w/v on four insects using standard method. N-hexane extracts of all the plants caused 100 per cent mortality of all the insects within 6 hour. Methanol extract caused 90 per cent and 100 per cent mortality of all the insects except small hive beetle (*A. tumida*). Aqueous extract of all the plants cause 100 per cent mortality of acrobat ant (*C. lineolata),* but induced no mortality of *A. tumida.* Mortality of all these insects treated with aqueous extracts of the plants varied between 15 to 100%.

Sanad and Mohanny (2015) studied the toxic effect of different concentration Mint, Cinnamon, Clove extract and Egyptian and Chinese sources of bee propolis on late instar larvae of the *G. mellonella*. The highest cumulative mortality percentage of wax moth larvae three days after application was recorded with the treatment of Mint extract (70%) followed by Chinese propolis and cinnamon extracts (60%). Clove and Egyptian propolis treatment gave only 50 and 40 per cent reduction, respectively.

2.4.1. Effectiveness of different chemicals treatments against *G. mellonella* in stored combs

Atwal and Sharma (1967) and Verma *et al.* (1997) reported that the use of sulphur and cleaning of beehives assisted in reducing wax moth population. Effectiveness of sulphur fumigation on *G. mellonella* larvae was tested by Ahmed *et al*., (1993) and Calderone (2000). They observed that sulphur fumigation could be used for controlling wax moth.

Anderson and Burys (1988) suggested prevention of the destruction of stored combs by the greater wax moth by periodically fumigated with Paradichloro benzene, a white crystalline compound diffusing slowly when exposed to air. First fumigation once supers

become infested and second fumigation should be given two weeks later. The supers should be checked periodically and fumigated when necessary and the fumigation room should be well ventilated. It is a repellent and also kills larvae and adults of the GWM and is used one table spoon per super.

Methylbromide (CH_3Br), a colourless volatile liquid (in tins or cylinders) is also used for control of wax moth. As Carbon bisulphate (CS_2), Sulphur dioxide (SO_2), Ethylene dibromide (EDB) and Hydrogen Cyndine (HCN) was also be used in the control of the greater wax moth (Anderson and Burys, 1988). However, Methyl bromide plus HCN are deadly poison and are not used for small scales fumigation of stored bees wax comb.

Ayman and Atef (2007) reported that formic acid fumigation was the most effective material onto check the hatchability of wax moth eggs. They also recommended methyl salicylate, clove oil, formic acid and basil oil with one ml/comb/week to protect stored raised wax moth combs from wax moths infestation.

Munshimbwe *et al*. (2011) suggested that 80% solution of acetic acid used to controlled wax moths in stored raised bee comb. Fumigation with acetic acid killed adult moths, their eggs and larvae. After the honey is extracted, chambers with empty combs and top-bars should be piled up in stacks up five hive bodies. The space (joint) between hive bodies and the boxes was closed/taped with paste paper to form an airtight seal. Cotton wool 15×15cm or any similar absorbent material soaked in 80 per cent acid is placed on top of the uppermost comb top bar in the stack, before the lid is sealed, using 25ml of 80 per cent acetic acid per hive body in the stack. The top of the stack is covered with an airtight hive roof and the stack is left undisturbed for two weeks. The fumigation could be repeated at intervals of 2-3 weeks. Two week after fumigation, the stacked hives bodied are dissembled and top-bars to exposed to air about 2 days before the comb are used.

Yadav *et al*. (2012) tested efficacy of various chemical and non-chemical methods against *G. mellonella* in *A. mellifera* raised and stored bees wax combs. Aluminium phosphide @ 62.5mg proved to be the best treatment with minimum damaged comb area (19.55 cm^2 per comb for 90 days of storage). Dusting of dried neem leaves powder on stored combs was found to be the least effective treatment with the corresponding high comb damage being 1065.39 cm^2.

Babarinde *et al.* (2013) reported that treatment containing aluminium phosphide tablet (3g) was incorporated as a chemical method of control and the treated empty honey bee combs were stored for two month. Among all the treatments used, the hermetically stored combs and aluminium phosphide (AlP) fumigation had the best result and comb retained their freshness till two months of storage. The number of emerged moth in opened untreated combs as control was higher (61.00) than in other treatments but significantly higher than the number of emerged moth observed in salt-treated comb in opened containers. Wax and slum gum

weight were not significantly affected by the treatments. Hermetic storage is therefore recommended as a better method of controlling wax moth in stored honey bee combs after the extraction of honey than AlP tablets, due to the possibility of residue of AlP tablets in the treated honeycomb.

2.4.2. Effectiveness of different non-chemical treatments against *G. mellonella* in stored combs

Ramachandaran and Mahadevan (1951) reported that once infestation sets in, it is difficult to control *G. mellonella.* Best defense is to maintain strong, healthy colonies, closing all cracks and crevices of the hive and reduction of the size of hive entrance gaves effective control of wax moth. Good sanitation need to be maintained inside the hive particularly on bottom board. Also maintain the control of hive pest diseases and other pests which might make the colony weak. Pesticides reduced the strength of bees, brood area and killed forager bees (Rana and Goyal, 1991; Menon, 1992; Abrol and Kumar, 2000) so their use should be avoided. Excess combs/frames in the hive should be removed especially during floral dearth. Destruction of the wax moth larval tunnels is an effective way to kill larvae in live colonies in initial stages. Destruction of severely attacked combs is also recommended to check wax moth population. Battu and Singh (1977) and Shimanaki (1987) suggested that for reducing the attack of wax moth within the hives, the bottom board should be cleaned at periodic intervals.

Sarwar (2016) reported that the best defense against wax moths is to maintain strong, healthy colonies and provide just minimum appropriate number of combs according to size/strength of colony. Strong colonies could defend themselves against wax moth, whereas weak colonies could not, so weakened colonies be united to strengthen them. During the winter, store empty honey and brood combs in an unheated shelter to prevent wax moth damage. During periods when wax moths are problematic (summer and fall) store empty honey supers, brood combs, and comb honey in a freezer or exposed to light twenty four hours in a day. He further recommended that apiaries be moved away from heavily wax moth infested areas so that the adult moths are deprived of bees and local populations of predator would kill them are thus pest is reduced.

2.4.2.1. Low temperature treatment:

All the stages of wax moth (*viz*., egg, larvae, pupae and adults) were killed by exposure to high temperature range of 46-49^{o}C for 18 minute or low temperature range of -18 °C to 15 °C for two hours (Cantwell and Smith, 1970). Niam and Bisht (1972) reported that temperature of 55°C for one hour was fateful to all stages of wax moth. Burges (1978) observed that temperature of just below freezing point hampered the growth of the larvae and at 17 °C all the wax moth larvae were killed.

Low temperature treatment avoided the comb “sagging” problem, even fire damage which sometimes occurs when combs are treated with heat the cold treatment is a promising option for wax moth control. It avoids most physical damage, is cheaper and pollution free. It

is previously reported that the freezing temperatures and exposure times required to kill the greater wax moth larvae were -15°C for 2 h; -13°C for 3 h; or -7°C for 4.5 h. The ability of the wax moth to resist freezing could varied at different developmental stages (Shimanuki, 1987; Charriere and Imdorf, 1999).

Hood (2010) advertised that cold storage of beekeeping equipment should be at 7°C for 4.5 h, 8-12°C for 3 h, or -15°C for 2 h to exterminate all life stages of wax moth.

Zhou (2016) determined the optimal cryo-preservation method for eradication of the *G. mellonella* from honey bee comb. To pursue this goal, mortality rates of *G. mellonella* eggs, larvae, pupae and adults were studied after treatment at -15°C or -20°C for varying durations. The results showed that larvae, pupae and adults all died after they were subjected to low temperature treated for one hour at either -15 or -20°C. Wax moth eggs, on the other hand, had strong frost resistance. It was only when the treatment time was increased to 10 h that all *G. mellonella* eggs were killed. Freeze tolerance of 7-day-old eggs was higher than that of 1, 3 and 5 day-old eggs.

Kwadha *et al*. (2017) reported the interruption of the developmental cycle of the greater wax moth can be accomplished by exposing beekeeping equipment and bee combs to temperatures above (heating technique) or below (freezing technique) the tolerance range of the greater wax moth. In large-scale farming, infested combs are isolated from the hive, stacked together in an insulated second hand houses and exposed to higher temperatures of approximately 45-80 °C for a period of 1-4 hours, while for small-scale farming, the combs are kept in hot water for 3-5 h. However, it must be noted that heating sags and distorts wax. Infested combs can also be exposed to cold rooms or refrigerator equipment such as home freezers set at -7°C to -15°C for 2-4.5h. These techniques are advantageous, since growth and development of greater wax moth is dependent on environmental factors such as temperature.

2.4.2.2. Neem oil, neem leaf extract, neem leaf powder and related botanical plants

The neem tree, *Azadirachta indica* (Meliaceae) is native to South-East Asia and grows in many countries throughout the word (Schmutterer, 1990). Neem compounds have insecticidal, nematicidal, fungicidal, antiviral, repellant, antifeedant and growth inhibiting modes of actions (Stoll, 2000). Azadirachtin is made up of number of closely related 7 isomers called Azadirachtin A to Azadirachtin G. Isomer A is the most abundant in the seed kernel (Schmutterer, 1990).

The harmful effect of intact parts or extracts from neem leaves, bark and primarily seeds on insects have been known for a long time (Schmutterer, 1995). The same author reported that besides repelling larvae and deterring them from feeding, crude extracts are responsible for the reduced growth and for the disturbances in larval-adult development, sometimes after only contact by the insect. Schmutterer (1990) suggested that the Azadirachtin modified the programs of insect by influencing hormonal system, especially that of the ecdysone. The effects of Azadirachtin are

both dose and time dependant, prevent both ecdysis and apolysis and can cause death before or during molting (Mordue and Blackwell, 1993).

Mahgoub (2005) tested the neem seed water extract on the larvae of the greater wax moth and revealed that it caused 60% mortality. Seed of neem contains the highest concentration of Azadirachtin and all other biologically active chemical compounds present in *A. indica* (Jacobson, 1989; Koul *et al.*, 1990; Schmutterer, 1990). Other tissues of *A. indica* known to contain these compounds at lower levels are bark, leaves and heart wood (Ascher, 1993).

Kumari and Jha (2013) conducted experiments for the evaluation of storage methods of raised combs on wax moth. It was revealed that maximum comb area infestation/damaged occurred in frames stored in chambers kept in store without fumigation (T_1) whereas minimum infestation was in case when the frames were stored in the polythene sheet with fumigation. Frame stored in polythene sprayed with 3 per cent neem oil after drying in shade (T_8) proved its superiority as the next best treatment in minimizing the wax moth infestation.

Abou El-Ela (2014) evaluated the oils of six plants (*viz*., clove; *Eugenia aromatic*., basil; *Ocimum basillicum* L., thyme; *Thymus vulgaris* L., blue gum; *Eucalyptus spp*., spearmint; *Minth viridis* L., Lemongrass oil; *Cymbopogon citrates* Hort.) and six aromatic fragments (namely; methyl salicylate, eugenol, menthol, thymol, camphor and naphthalene against *Acheroia gresilla* F. Paradicholorbenzene, acetic and formic acids were used as check.. The LC_{50} were determined against the last larval instar of the pest. It was revealed that methyl salicylate, formic acid, clove and basil oils were highly effective.

Microbial and botanical pesticides were also evaluated for the management *G. mellonella* under stored condition by Bhopale *et al*. (2014). Maximum mortality of *G. mellonella* was observed by the treatment of *Bacillus thuringiensis* var. *kurstaki* (Halt) followed by Pongamia oil (3%) and neem oil. Lowest pest mortality was observed due to *Bacillus thuringiensis* local strain-2 and dried neem leaf. Maximum mortality was observed in case of 3rd instar larvae for most of the treatments.

The insecticidal activity of the essential oils peppermint, *Mentha piperita* L., geranium; *Pelargonium graveolens* L., basil; and *Ocimum basilicum* L. were investigated by Elbarky *et al.* (2015) in laboratory against early fourth instar larvae of the *G. mellonella*. The tested plant oils prolonged the larval-pupal periods and reduced both pupation and percentage of adult emergence. *O. basilicum* scored the highest larval mortality followed by *M. piperita* then *P. graveolens*. Other developmental aspects as survival and sex ratio were clearly affected by increasing the concentration increments of plant oils.

Different concentrations of Neem Azal-T/S were used in an artificial diet (natural bees wax combs) to study the mortality of the *G. mellonella*. While the diet was being prepared, neem formulation was distributed at concentrations of 0.25, 0.5, 1, 2, and 4 per cent. The obtained results showed that the different concentrations of Neem Azal- T/S mixed in the

prepared artificial diet had a significant efficacy against the tested 2nd instar larvae. An elongation of the 2nd larval instar was clear in comparison with the control, even at the least tested concentration (0.25%). Neem Azal-T/S at 4, 2, 1, and 0.5 per cent caused 100% mortality for all tested larvae. When using 4 per cent and 2 per cent, all the tested larvae died in the 2nd instar, 5th instar respectively while some of the larvae were tolerant and lived till the 6th instar at 1.0 and 0.5 per cent, concentration. Feeding the larvae on beeswax combs treated with 2 per cent Neem Azal-T/S, caused 100% mortality when fed on very old wax. When the diet was old wax treated with 2 per cent Neem Azal-T/S, 91 per cent mortality was recorded while the diet was new wax treated with 2 per cent Neem Azal-T/S, 90 per cent mortality was recorded (Elbehery *et al.*, 2016).

Rahman *et al*. (2017) tested different management strategy such as use of plant products viz. *A. indica* (15 g and 20 g/hive), *Melia azadirachta* (15g and 20g), neem oil (2% and 3%), neem seed kernel extract (NSKE) at 3 per cent and 5 per cent and *kuraj* oil at 25 and 3 per cent concentration, *B. thuringiensis var.Karstaki* @ 0.5% and 1% sprayed in the infested comb by *G. mellonella* and mechanical device such as keeping the comb in deep freezer at -7°C and -12°C for 5 h were also used. Among the treatments *B. thuringiensis* var. *karstaki* at 1 per cent concentration was found to be most effective in minimizing the percent comb infestation and cumulative mortality was found to be 93.32 per cent followed by sulphur fumigation @ 28 g/hive mortality of 89.98 per cent, neem oil at 3 per cent concentration gave mortality of 79.99 per cent. Basedow *et al.* (2012) reported similar results while evaluating *Bacilus thuringensis aizawai* and neem for controlling the larvae of *G. mellonella***.**

2.4.2.3. *Bacillus thuringiensis* var. *kurstaki*:

Tutkun (1987) observed the effect of *B. thuringiensis* sub. sp. *thuringiensis, aizawai* and *kurstaki* on larvae of the greater wax moth combs of *Apis mellifera* in the laboratory and all the formulation were applied twice with interval of one week on combs infested by 3rd and 4th larvae of the wax moth, the damage was reduced by 65.6 per cent, 50.8 per cent and 43.5 per cent for the three preparations respectively. The effects of Certan®, a commercial formulation of *B. thuringiensis sub. sp. aizawai*, on survival and development of the first three larval instar of *G. mellonella* were investigated in the laboratory, Certan® at 26.3, 52.6 and 105.2 g/litre was effective against all three instars, the second instar being most susceptible, complete mortality was caused within 4 days after treatment (Eldinahdul, 1988).

Bacillus thuringiensis sub sp. *aizawai* applied in the bee wax with a concentration of 1.1×10^{8} (cfu/g) resulted in higher mortality percentage (90%) followed by 40% for the concentration 1.1×10^{7} (cfu/g). The least mortality percentage (20%) was caused by 1.1×10^{6} (cfu/g) concentrations. Accordingly, the highest efficacy percentage (88.8%) was given by the first concentration. Eldinhadul (1988), reported that the effect of Certan® (a commercial

formulation of Bt_a) applied at different concentrations on the first three larval instars of the greater wax moth, caused high mortality percentage in few days.

Mahgoub (2005) found that the efficiency of the *Bacillus thuringinesis* suspension against the larvae of the greater wax moth increased with the increase in concentration and the highest mortality was obtained with the concentration 1.1×10^7cfu/g.

Bhopale *et al*. (2013) evaluated the effect of botanicals and microbial pesticides for the management of *G. mellonella* under stored condition. They found that Maximum mortality of wax moth was due to the treatment of *Bt kurstaki* (Halt) followed by Pongamia oil (3%) and neem oil (3%). Lowest mortality was observed due to the *Bacillus thuringiensis* local strain-2 and dried neem leaves powder.

Taredahalli (2013) studied the potentiality of *Bt* isolates (viz., C7, A3, A7, N12, F2 and M2) on the stored honey combs against the *G. mellonella*. The protection range provided by the isolates varied from 89.5-44.3 per cent and the isolate M2 (89.52 per cent) and standard HD-1 (88.89 per cent) rendered very good protection to the combs from wax moth damage.

CHAPTER-III

MATERIALS AND METHODS

The present investigation entitled, **"Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs"** was carried out at Research farm, Apiary and Apiculture Laboratory of the Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar. Hisar is located at 29.09°N and 75.43°E in Western Haryana. The average annual rainfall at Hisar is around 450 mm, most of which occurs during the months of July to August, dust-storms here are experienced during summer months and hail-storms during February to April. This chapter elucidates the materials used and methodology adopted for conducting various experiments to fulfill the objectives of the presently planned studies. Materials and methodology followed are presented as under.

Technical programme of work

Place of work: Research farm, Apiary and Apiculture Laboratory of the Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar.

Years of study: 2015-16 & 2016-17

3.1. MATERIALS: Equipments and other materials used in the study:

Sr. No.	Material/equipment	Usage
1.	**Envelopes**	To collect the different plant species from the field, used for making plant extracts after drying them in shade condition
2.	**Acetone**	85 per cent acetone was used to prepare the extract of plant species material (leaves and stem) ground for testing their effects on the greater wax moth
3	**Whitman No. 1 filter paper**	Used for suspension of plant extracts in the flask
4.	**Grinder**	Used for grinding the plant material (leaves and stem) into powder form for making extracts
5.	**Balance**	An electronic, single pan balance was used to weigh the ground plant material
6.	**Baby Knapsack sprayer**	Used to spray different preparations on the raised empty bee combs
7.	**Combs of *Apis dorsata***	*Apis dorsata* combs were provided for feeding to the wax moth larvae in a glass jar and maintaining the needed culture of the wax moth larvae
8.	**Glass jar**	Newly emerged females and males wax moth were collected in glass jar (15×15×20 cm) for the mating and oviposition purpose of rearing wax moth larval culture
9.	**Muslin cloth**	Muslin cloth pieces of 20×20cm were used to cover the glass jars so that the newly emerged wax moths could not escape through it
10.	**Incubator**	Used for egg incubation at 30°C, relative humidity (RH) of 70% and 24 hours darkness until emerging of adult stages of the pest
11.	**Forceps**	Used for capturing (or collecting) the 5th instar larvae of the wax moth from the glass jar into the petriplate for testing the effectiveness of the plant extracts
12.	**Deep freezer**	It was used for freezing the combs at 0°C, -5°C, -10°C and -15°C for 24 hours
13.	**Bee veil**	A standard bee veil was used for working with the honeybee colonies
14.	**Camera**	Used to take photographs related to the present research
15.	**Miscellaneous**	The other materials used during the studies were record book, scale, marker pen, tape, tissue papers, rubber bands, glass rods beakers, jars and distilled water etc.

3.2. METHODS

3.2.1. Seasonal incidence of greater wax moth, *Galleria mellonella* L. in *Apis mellifera* L. colonies with different bee frame strengths

For recording seasonal incidence of greater wax moth, five colonies each with 4, 6, 8 and 10 frame bees strength were selected. Selection was made from among the colonies with the same queen age. All the colonies used for experiment for each strength were equalized with respect to bee strength, brood (unsealed and sealed) and food, stores (pollen, nectar and honey). For the purpose, each comb after brushing off the bees was held against the sunlight and observations at an interval of 21 day intervals were recorded on the number of larva, pupa and adult wax moth for recording incidence of greater wax moth in the colonies. Extent of damaged comb area was recorded in cm^2. Sugar solution 1:1 (sugar:water) was given to the bee colonies during dearth period @ 300g, 450g, 600g and 750g sugar after an interval of 7 days. Each treatment was replicated five times. Temperature and Relative Humidity (% RH) data were collected from observatory of the Department of Agril. Meteorology, CCS Haryana Agricultural University, Hisar and these weather parameters data were correlated with seasonal incidence and extent of wax moth damage.

3.2.2. Seasonal incidence of greater wax moth, *Galleria mellonella* L. in stored combs.

3.2.2.1. Fumigation of combs to be used for experiment

All the combs to be used for experimental purpose were initially fumigated with aluminium phosphide (Celphos) tablets (3g each). For this purpose, 9 combs were placed (put) in each chamber and a stack of 4 chambers were made and all the cracks and crevices were plugged with mud. After doing so one tablet of celphos (3g) was tied in a piece of muslin cloth and placed on the top bars of uppermost chamber which then was covered with inner cover and made air tight by mud plaster and finally covered with top cover. The fumigated combs were used for experimental purpose after 7 days.

For recording seasonal incidence of greater wax moth in stored combs; 7, 8, 9 and 10 empty combs (without bees) were stored in hive bodies (chambers) which were placed on bottom board and covered with inner cover. Each of the chamber with frames was made air tight by mud plastering to seal cracks and crevices (joints). After making the chamber airtight, it was covered with top cover. Fortnightly observations were recorded on, number of larvae, pupae and adults in experimental stored combs. Extent of comb area damaged was recorded in cm^2. Each treatment was replicated five times. Temperature and Relative Humidity (%) data were collected from observatory of the Department of Agril. Meteorology, CCS Haryana Agricultural University, Hisar and this data were correlated with seasonal incidence and extent of damage. The experiments were conducted five times for recording observations during both the years from June to October, 2016 and 2017.

3.2.3. To test the effectiveness of different plant extracts against *Galleria mellonella* L. larvae

3.2.3.1. Culturing of greater wax moth

Naturally infested honey bees combs with wax moth larvae were obtained from farmer apiary and taken into the laboratory of the Department of Entomology. To rear wax moth larvae, newly emerged wax moth females and males were collected in glass jar (15×15×20 cm) and provided sugar syrup for feeding. For feeding sugar syrup, cotton swab was dipped in the sugar syrup and hanged inside with the muslin cloth cover of glass jar by using a thin bent/ hooked iron wire. After mating, females were released in glass jar which was covered with muslin cloth of 20×20cm to deposit eggs. A piece of hard paper was also put in the glass jar for female moth to lay egg upon it. The eggs were incubated in incubator or a warm room at 30°±2C, RH of 70 per cent with comb piece for feeding of larvae until the emergence of adult moth. Directly after emergence, 30 adults *i.e.,* 15 male and 15 female of the same age were collected in another glass jar, provided with sugar syrup feeding and incubated under the same conditions to get the eggs for next generation. The larval stages or culture of the pest was thus prepared to fulfill the requirement.

3.2.3.2. Procedure for preparation of plant extracts

For preparing plant extract, thirteen plant species belonging to nine different plant families were used to examine their effects on the development of the greater wax moth *Galleria mellonella* for this experiment (Table 3.2). The tested plant species were collected from research farm of the CCS HAU, Hisar. For preparation of plant extracts, leaves, stems and/or seeds of the collected plant material were dried under shade. After drying, each plant material was ground into powdered form by an electric grinder, separately. Samples of 20g of each plant were mixed with 100 ml of acetone (85%) and kept for 10 minute (Zaitoun, 2007).

Table 3.2. List of Botanical materials used for preparing plant extract against *Galleria mellonella*

Sr No.	Common name	Scientific name	Family	Plant part used for extract
1.	Isabgol	*Plantago psyllium*	Plantaginaceae	Isabgol husk
2.	Urad	*Vigna mungo*	Leguminoceae	Leaves and Stem
3.	Moong	*Vigna radiata*	Leguminaceae	Leaves and Stem
4.	Til	*Sesamum indicum*	Pedaliaceae	Leaves and Stem
5.	Alsi	*Linum usitatissimum*	Linaceae	Leaves and Seed
6.	Barley	*Hordeum sativum*	Gramineae	Leaves and Stem
7.	Pea	*Pisum sativum*	Fabaceae	Leaves and Stem
8.	Chickpea	*Cicer arietinum*	Fabaceae	Leaves and Stem
9.	Garden vetch	*Vicia sativa*	Fabaceae	Leaves and Stem
10.	Pumpkin	*Cucurbita moschata*	Cucurbitaceae	Leaves and Seed
11.	Mustard	*Brassica juncea*	Brassicaceae	Leaves and Stem
12.	Raddish	*Raphanus sativus*	Brassicaceae	Leaves and Root
13.	French bean	*Phaseolus vulgaris*	Fabaceae	Leaves and Stem

The plant-solvent mixture was stirred gently with glass rod. Each of the plant solvent mixture thus obtained was filtered using 125mm of filter paper (Filtermann®). The mixtures were then strained in flasks. The marc/residual (damped solid material) was pressed gently with hand and discarded later and liquids are clarified by filtration or decantation. The decanted solution again filtered by Whitman No.1 filter paper and finally 45ml of solution were prepared and used further for experimental purpose.

3.2.3.3. Testing the effect of plant extracts on the wax moth larvae

For testing the effect of plant extracts on the wax moth, the fifth larval instars were chosen and collected from the culture jar. A thin film was made from 45ml solution of each with acetone prepared plant extract in three Petriplates (15cm diameter) and left for 15 minute. Subsequent to drying, 5 larvae (fifth instars) were released in each Petriplate. Each petriplate was supplied with five pieces of wax comb (1cm×1cm×1cm) and incubated at 28±1^{o}C temperature and 60 per cent RH. Each plant extract treatment was replicated thrice along with an acetone film alone as a control. Petriplates were daily observed for dead or unusual sign appearing on the larvae or pupae until the adult emergence.

3.2.4. To test the effectiveness of different chemical and non chemical treatments against *Galleria mellonella* L. in stored combs

Out of 10 treatments in each treatment, 7 combs (without bees) were stored in hive body (chamber) which was placed on bottom board and covered with inner cover. The chamber with frames was made air tight by mud plastering. After making the chamber airtight, it was covered with a top cover. Observations were recorded on the extent of damaged area in cm^2 at fortnightly interval. There were five replications each in both the years from June to October, 2016 and 2017.

Table 3.3. Treatment for surface contact up of various chemical and non chemicals against *G. mellonella* in stored combs

Sr. No.	Treatment	Procedure
T_1	Acetic acid spray	Combs was sprayed with acetic acid (80%) solution (20ml acetic acid per 10 liter of water) and repeated at an interval of fortnight. One hundred ml of solution was sprayed on each comb covering both the side of comb.
T_2	Formic acid spray	Comb was sprayed with formic acid (85%) solution (8ml formic acid per 10 liter of water) and repeated at an interval of fortnight. One hundred ml of solution was sprayed on each comb covering both the side of comb.
T_3	Aluminium phosphide fumigation	One tablet of aluminum phosphide (3 gram) tied in muslin cloth was placed on top bar in hive body containing seven combs. The treatment was repeated at an interval of fortnight.
T_4	Low temperature treatment	Combs were freezed only once at the initiation of the experiment at 0°C, -5°C, -10°C and -15°C for 24 h in the deep freezer and then kept airtight in the bee hive chambers. The observations were

Plate 1: Combs covered with newspaper for storage

Plate 2: Fumigation with aluminium phosphide tablet for storage

Plate 3: Dusting of neem leaf powder on combs

Plate 4: Spraying neem oil on combs

		recorded at fortnightly interval.
T_5	Hive chambers separation with newspaper	Hive bodies with 7 frames in each chamber was stacked separated with newspaper. Each stack had two chambers. Newspapers were changed at an interval of fortnight.
T_6	Separation of combs with newspapers	For the purpose, hive bodies with 7 combs were used and each comb was wrapped in newspapers individually and then stored in hive body. Newspapers were changed at fortnightly interval.
T_7	Neem oil spray	Spray solution of neem oil (3%) was prepared by mixing 30ml of neem oil in 970ml of water and sprayed the comb. One hundred ml of solution was sprayed on 7 individual combs covering both the sides of comb. Spray was repeated at fortnightly interval.
T_8	Broadcasting neem leaves powder	Neem leaves were collected from the neem tree and left for drying in shade at room temperature for 15 days. After drying, leaves were ground by a grinder into a powdered form. This dried neem leaf powder @ 40g per comb was uniformly dusted on combs and dusting was repeated at fortnightly interval.
T_9	Neem Seed Kernel Extract (NSKE) spray	For preparing NSKE, mature fallen neem fruit berries were collected. The seeds were put in a plastic drum with full of water for 7 days for removing pulp of the seed. After that, the neem seed kernel were washed with fresh water and left under shade to dry. The kernels were milled into fine powder by using grinder. 50g of dried neem seeds powder and 100ml of water were put in plastic container and stirred with a piece of wood, the whole mixture was left overnight, then agitated for 10 minutes and filtered through a fine piece of muslin cloth to get fine suspension. Decoction was extracted by pressing the muslin sack (bag) for 10-15 minutes and repeated washings with water and final volume was made 1000ml by adding water. One hundred ml of NSKE was uniformly sprayed on individual comb covering both the sides of comb. Spray was repeated at an interval of a fortnight.
T_{10}	*Bacillus thuringiensis var. kurstaki* spray	Spray suspension was prepared by mixing 5g of *Bacillus thuringiensis var. kurstaki* (Dipel) in one liter of water and 100ml of solution was sprayed on individual comb covering both the sides of combs. Spray was repeated at fortnightly interval.
T_{11}	Control	No treatment was given. Even water was not sprayed.

The comb area damage caused by the larvae of *G. mellonella* was recorded using brood measuring frame having wire grid squares, each measuring one inch squares in size. The number of squares covering the infested area completely or partially were counted as damaged and then converted to cm^2 by multiplying with 6.45. The per cent infestation was worked out by dividing the total damaged area by 1600 and multiplied with 100. The infested comb area was recorded from both sides of each comb. After every treatment, comb area infestation in all the treatments was also recorded fortnightly.

Statistical analysis:

All the research data pertaining to the seasonal incidence in colonies and stored combs, correlation of population with weather parameters, effects of plant extract and management of greater wax moth by different methods were subjected to Analysis of Variance.

CHAPTER- IV

RESULTS

The present investigations entitled **"Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs"** were carried out during 2015-16 and 2016-17 at Research farm, Apiary and Apiculture Laboratory of the Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar. The results of the different aspects of investigations have been presented in this chapter.

4.1.1. Population of Greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 4-frame bees strength during 2015-16 and 2016-17

Population of greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 4-frame bees strength during 2015-16 and 2016-17 are presented in the Table 4.1. Data in the Table 4.1 revealed that in 4- frames bee strength colonies, the population of wax moth (larval, pupal as well as adult) varied during different months of 2015-16 and 2016-17. During both the years, population of greater wax moth (larval, pupal as well as adult) started increasing from April and increased till July; thereafter, (from August) the population started declining and declined till March. During 2015-16 (Table 4.1), the highest larval population (13.60) was recorded in the month of July followed by June (13.00), August (12.40), September (11.20), May (9.60), October (9.00), November (7.00), December (6.60), January (5.80) and April (4.00) while the lowest population of larvae was recorded in the month of March (3.00) which was at par with the population in February (3.20). The highest (10.60) number of pupae were recorded in the month of July followed by June (10.00), August (9.80), September (8.80), May (7.40), October (7.40), November (5.40), December (5.20), January (5.00) and April (3.80) while lowest number of pupae were recorded in the month of March (2.80) which was at par with the population in February (3.00). Highest number of adults (8.60) were recorded in the month of June followed by July (8.00), August (7.60), September and May (6.60), October (6.00), November (4.00), December (3.60), April (3.60) and January (3.40) which significantly differed from the lowest population of adult in March (2.60) and February (2.80).

Data in the Table 4.1 also revealed that during 2016-17, the maximum larval population (13.40) was recorded in the month of July followed by June (12.60), August (11.80), September (11.00), May (9.00), October (8.80), November (6.60), December (6.00), January (5.60) and April (3.80) while the minimum population of larvae were recorded in the month of March (2.80) which was at par with the population in February (3.00). The maximum number of pupae (10.60) were recorded in the month of July followed by June

(10.00), August (9.80), September (8.60), October (7.40), May (7.20), November (5.20), December (5.00), January (4.60) and April (3.60) while minimum number of pupae were recorded in the month of March (2.40) which was at par with the population in February (3.00). Maximum (8.00) number of adult were recorded in the month of July followed by June (7.80), August (7.20), September (6.20), May (6.00), October (5.60), November (3.60), December and April (3.40) and January (3.20) which significantly differed from the minimum population of adult in March (2.40) and in February (2.60).

Table 4.1. Population of Greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 4- frame bees strength during 2015-16 and 2016-17

Year / Month	2015-16				2016-17			
	Stages of wax moth				Stages of wax moth			
	No. of larvae	No. of pupae	No. of adults	Mean	No. of larvae	No. of pupae	No. of adults	Mean
November	7.00 (2.82)	5.40 (2.52)	4.00 (2.21)	**5.46 (2.52)**	6.60 (2.75)	5.20 (2.48)	3.60 (2.12)	**5.13 (2.45)**
December	6.60 (2.75)	5.20 (2.47)	3.60 (2.12)	**5.13 (2.45)**	6.00 (2.63)	5.00 (2.43)	3.40 (2.08)	**4.80 (2.38)**
January	5.80 (2.60)	5.00 (2.44)	3.40 (2.05)	**4.73 (2.36)**	5.60 (2.56)	4.60 (2.36)	3.20 (2.01)	**4.46 (2.31)**
February	3.20 (2.04)	3.00 (1.99)	2.80 (1.94)	**3.00 (1.99)**	3.00 (1.99)	3.00 (1.99)	2.60 (1.89)	**2.86 (1.96)**
March	3.00 (1.97)	2.80 (1.87)	2.60 (1.92)	**2.80 (1.92)**	2.80 (1.92)	2.40 (1.83)	2.40 (1.83)	**2.53 (1.86)**
April	4.00 (2.19)	3.80 (2.15)	3.60 (2.12)	**3.80 (2.15)**	3.80 (2.15)	3.60 (2.12)	3.40 (2.07)	**3.60 (2.11)**
May	9.60 (3.25)	7.40 (2.89)	6.60 (2.75)	**7.86 (2.96)**	9.00 (3.15)	7.20 (2.85)	6.00 (2.64)	**7.40 (2.88)**
June	13.00 (3.74)	10.00 (3.31)	8.60 (3.06)	**10.53 (3.37)**	12.60 (3.68)	10.00 (3.31)	7.80 (2.96)	**10.13 (3.32)**
July	13.60 (3.81)	10.60 (3.40)	8.00 (2.98)	**10.73 (3.40**	13.40 (3.79)	10.60 (3.40)	8.00 (2.98)	**10.66 (3.39)**
August	12.40 (3.65)	9.80 (3.27)	7.60 (2.92)	**9.93 (3.28)**	11.80 (3.57)	9.80 (3.27)	7.20 (2.85)	**9.60 (3.23)**
September	11.20 (3.49)	8.80 (3.11)	6.60 (2.75)	**8.86 (3.11)**	11.00 (3.46)	8.60 (3.08)	6.20 (2.67)	**8.60 (3.07)**
October	9.00 (3.15)	7.40 (2.88)	6.00 (2.64)	**7.46 (2.89)**	8.80 (3.12)	7.40 (2.88)	5.60 (2.56)	**7.26 (2.86)**
Mean	**8.20 (2.96)**	**6.58 (2.69)**	**5.30 (2.45)**	-	**7.86 (2.90)**	**6.45 (2.67)**	**4.95 (2.39)**	-
Factors		**C.D.**	**SE(d)**	**SE(m)**		**C.D.**	**SE(d)**	**SE(m)**
Month		1.00	0.50	0.35		0.86	0.43	0.30
Stages		0.50	0.25	0.17		0.43	0.21	0.15
Month × Stages		1.73	0.87	0.62		1.49	0.75	0.53

Each value represents mean of five observations
Figures in parentheses are √(n+1) transformed value

During both the year, mean population of all stages of wax moth started increasing from April and increased till July thereafter (from August) the population started declined till March. In year 2015-16, mean population of all stages of wax moth was found highest in July (10.73) followed by June (10.53), August (9.93), September (8.86), May (7.86), October (7.46), November (5.46), December (5.13), January (4.73) and April (3.80) while the lowest population were recorded in the month of March (2.80) and February (3.00). In year 2016-17, mean population of wax moth was found highest in July (10.66) followed by June (10.13), August (9.60), September (8.60), May (7.40), October (7.26), November (5.13), December (4.80), January (4.46) and April (3.60) while the lowest population were recorded in the month of March (2.53) and February (2.86). Irrespective of the different month, larval population was found highest (8.20 and 7.86) followed by pupae (6.58 and 6.45) and adults (5.30 and 4.95), respectively in year 2015-16 and 2016-17.

4.1.2. Population of Greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 6-frame bees strength during 2015-16 and 2016-17

Population of greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 6- frame bees strength during 2015-16 and 2016-17 are presented in the Table 4.2. Data in the Table 4.2 revealed that in 6- frames bees colonies, the population of wax moth (larval, pupal as well as adult) varied during different months of 2015-16 and 2016-17. During both the years, population of greater wax moth (larval, pupal as well as adult) started increasing from April and increased till July; thereafter, (from August) the population started declining and declined till March. During 2015-16 (Table 4.2), the highest larval population (12.40) was recorded in the month of July followed by August (12.00), June (11.80), September (10.00), May (8.20), October (8.00), November (6.00), December (5.80), January (5.40) and April (3.40) while the lowest population of larvae was recorded in the month of March (2.60) which was at par with the population in February (3.00). Highest number of pupae (8.80) were recorded in the month of July followed by June (8.40), August (8.00), September (7.40), May (6.80), October (6.60), November (4.60), December (4.40), January (4.00) and April (3.20) while lowest number of pupae were recorded in the month of March (2.40) which are at par with the population in February (3.00). Highest number of adults (7.40) were recorded in the month of June and July followed by August (7.00), September (6.00), May (5.60), October (5.40), November (3.40), December and April (3.00) which significantly differed from the lowest population of adult in March (2.40), February (2.60) and January (2.80).

Data in the Table 4.2 also revealed that during 2016-17, the maximum larval population (12.20) was recorded in the month of July followed by August (11.60), June (11.40), September (9.60), May (8.00), October (7.60), November (5.80), December (5.60), January (5.20) and April (3.40) while the minimum population of larvae were recorded in the month of March (2.40) which was at par with the population in February (2.80). The maximum number

of pupae (8.40) were recorded in the month of July followed by June (8.20), August (7.60), September (7.20), October (6.60), May (6.60), November (4.40), December (4.20), January (3.80) and April (3.20) while the minimum number of pupae were recorded in the month of March (2.20) which was at par with the population in February (2.80). Maximum (7.20) number of adult were recorded in the month of July followed by June (7.00), August (6.80), September (5.60), May and October (5.20), April and November (3.20) which significantly differed from the minimum population of adult in March (2.00), February (2.40), January (2.60) and December (2.80).

Table 4.2. Population of Greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 6- frame bees strength during 2015-16 and 2016-17

Year / Month	2015-16				2016-17			
	Stages of wax moth				Stages of wax moth			
	No of larvae	No. of pupae	No. of adults	Mean	No of larvae	No. of pupae	No. of adults	Mean
November	6.00 (2.63)	4.60 (2.36)	3.40 (2.09)	**4.66 (2.36)**	5.80 (2.60)	4.40 (2.31)	3.20 (2.04)	**4.46 (2.32)**
December	5.80 (2.60)	4.40 (2.32)	3.00 (1.99)	**4.40 (2.30)**	5.60 (2.56)	4.20 (2.27)	2.80 (1.94)	**4.20 (2.26)**
January	5.40 (2.52)	4.00 (2.23)	2.80 (1.94)	**4.06 (2.23)**	5.20 (2.48)	3.80 (2.17)	2.60 (1.88)	**3.86 (2.18)**
February	3.00 (1.98)	3.00 (1.96)	2.60 (1.89)	**2.86 (1.94)**	2.80 (1.93)	2.80 (1.94)	2.40 (1.83)	**2.66 (1.90)**
March	2.60 (1.89)	2.40 (1.82)	2.40 (1.83)	**2.46 (1.85)**	2.40 (1.83)	2.20 (1.76)	2.00 (1.73)	**2.20 (1.77)**
April	3.40 (2.09)	3.20 (2.04)	3.00 (1.98)	**3.20 (2.04)**	3.40 (2.08)	3.20 (2.04)	3.20 (2.04)	**3.26 (2.05)**
May	8.20 (3.02)	6.80 (2.78)	5.60 (2.56)	**6.86 (2.79)**	8.00 (2.99)	6.60 (2.75)	5.20 (2.48)	**6.60 (2.74)**
June	11.80 (3.57)	8.40 (3.06)	7.40 (2.89)	**9.20 (3.17)**	11.40 (3.51)	8.20 (3.02)	7.00 (2.82)	**8.86 (3.12)**
July	12.40 (3.65)	8.80 (3.12)	7.40 (2.89)	**9.53 (3.22)**	12.20 (3.63)	8.40 (3.06)	7.20 (2.86)	**9.26 (3.18)**
August	12.00 (3.60)	8.00 (2.99)	7.00 (2.82)	**9.00 (3.14)**	11.60 (3.54)	7.60 (2.93)	6.80 (2.79)	**8.66 (3.09)**
September	10.00 (3.31)	7.40 (2.89)	6.00 (2.63)	**7.80 (2.94)**	9.60 (3.25)	7.20 (2.86)	5.60 (2.56)	**7.46 (2.89)**
October	8.00 (2.99)	6.60 (2.75)	5.40 (2.52)	**6.66 (2.75)**	7.60 (2.93)	6.60 (2.75)	5.20 (2.48)	**6.46 (2.72)**
Mean	**7.38 (2.82)**	**5.63 (2.53)**	**4.66 (2.34)**	-	**7.13 (2.78)**	**5.43 (2.49)**	**4.43 (2.29)**	-
Factors		**C.D.**	**SE(d)**	**SE(m)**		**C.D.**	**SE(d)**	**SE(m)**
Month		0.65	0.33	0.23		0.60	0.30	0.21
Stages		0.32	0.16	0.11		0.30	0.15	0.10
Month × Stages		1.13	0.57	0.40		1.04	0.52	0.37

Each value represents mean of five observations
Figures in parentheses are √(n+1) transformed value

During both the years, mean population of all stages of wax moth started increasing from April and increased till July; thereafter, (from August) the population started declined till

March. In year 2015-16, mean population of all stages of wax moth was found highest in July (9.53) followed by June (9.20), August (9.00), September (7.80), May (6.86), October (6.66), November (4.66), December (4.40), January (4.06) and April (3.20) while the lowest population was recorded in the month of March (2.46) and February (2.86). In year 2016-17, mean population of wax moth was found highest in July (9.26) followed by June (8.86), August (8.66), September (7.46), May (6.60), October (6.46), November (4.46), December (4.20), January (3.86) and April (3.26) while the lowest population were recorded in the month of March (2.20) followed by February (2.66). Irrespective of the different month, larval population was found highest (7.38 and 7.13) followed by pupae (5.63 and 5.43) and adults (4.66 and 4.43), respectively in year 2015-16 and 2016-17.

4.1.3. Population of Greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 8-frame bees strength during 2015-16 and 2016-17

Population of greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 8- frame bees strength during 2015-16 and 2016-17 are presented in the Table 4.3. Data in the Table 4.3 revealed that in 8- frames bees strength colonies, the population of wax moth (larval, pupal as well as adult) varied during different months of 2015-16 and 2016-17. During both the years, population of greater wax moth (larval, pupal as well as adult) started increasing from April and increased till July; thereafter, (from August) the population started declining and declined till March. During 2015-16 (Table 4.3), the highest and similar larval population (8.80) was recorded in the month of June and July followed by May (7.60), August (7.20), September (7.20), October (6.20), November (3.80), December (3.60), January (3.20) and April (3.20) while the lowest population of larvae was recorded in the month of March (2.40) which was at par with the population in February (2.60). Highest and similar (8.00) number of pupae were recorded in the month of June and July followed by August (6.40), May (6.20), September (6.20), October (5.60), November (3.40), December (3.20), January (3.00) and April (3.00) while lowest number of pupae were recorded in the February and March (3.00). Highest number of adults (7.00) were recorded in the month of July followed by June (6.80), August (6.40), September (5.40), May (5.00), October (4.80), April (3.00), November (2.60), December (2.40) and January (2.20) which significantly differed from the lowest and similar population of adult in March (2.00) and February (2.00).

Data in the Table 4.3 also revealed that during year 2016-17, the maximum larval population (8.20) was recorded in the month of July followed by June (8.00), May (7.00), August (7.00), September (6.80), October (6.00), November (3.80), December (3.40), January (3.20) and April (3.00) while the minimum and similar population of larvae were recorded in February and March (2.40). The maximum number of pupae (7.40) were recorded in the month of June followed by June (7.00), August (6.40), September (6.00), May (5.80), October (5.00) and November (3.00), December (2.80) and April (2.80) while the minimum number of

pupae were recorded in March (2.20), February (2.40) and January (2.60) respectively. Maximum (6.00) number of adult were recorded in the month of August followed by September (5.20), June (5.00), July (5.00), October (4.40), May (3.80), November (2.40) December (2.20) and January (2.00) which significantly differed from the minimum population of adult in April (1.40), March (1.60) and February (1.80).

Table 4.3. Population of Greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 8- frame bees strength during 2015-16 and 2016-17

Year / Month	2015-16				2016-17			
	Stages of wax moth				Stages of wax moth			
	No of larvae	No. of pupae	No. of adults	Mean	No of larvae	No. of pupae	No. of adults	Mean
November	3.80 (2.18)	3.40 (2.09)	2.60 (1.89)	**3.26 (2.05)**	3.80 (2.18)	3.00 (2.00)	2.40 (1.83)	**3.06 (2.00)**
December	3.60 (2.12)	3.20 (2.04)	2.40 (1.83)	**3.06 (2.00)**	3.40 (2.07)	2.80 (1.94)	2.20 (1.78)	**2.80 (1.93)**
January	3.20 (2.04)	3.00 (1.98)	2.20 (1.78)	**2.80 (1.94)**	3.20 (2.04)	2.60 (1.88)	2.00 (1.73)	**2.60 (1.88)**
February	2.60 (1.88)	2.40 (1.83)	2.00 (1.72)	**2.33 (1.81)**	2.40 (1.83)	2.40 (1.83)	1.80 (1.65)	**2.20 (1.77)**
March	2.40 (1.83)	2.40 (1.82)	2.00 (1.73)	**2.26 (1.80)**	2.40 (1.83)	2.20 (1.77)	1.60 (1.60)	**2.06 (1.74)**
April	3.20 (2.03)	3.00 (2.00)	3.00 (1.99)	**3.06 (2.00)**	3.00 (1.99)	2.80 (1.94)	1.40 (1.51)	**2.40 (1.81)**
May	7.60 (2.92)	6.20 (2.67)	5.00 (2.44)	**6.26 (2.68)**	7.00 (2.81)	5.80 (2.59)	3.80 (2.16)	**5.53 (2.52)**
June	8.80 (3.12)	8.00 (2.99)	6.80 (2.79)	**7.86 (2.97)**	8.00 (2.99)	7.40 (2.89)	5.00 (2.42)	**6.80 (2.77)**
July	8.80 (3.12)	8.00 (3.00)	7.00 (2.82)	**7.93 (2.98)**	8.20 (3.02)	7.00 (2.81)	5.00 (2.43)	**6.73 (2.75)**
August	7.20 (2.85)	6.40 (2.70)	6.40 (2.71)	**6.66 (2.75)**	7.00 (2.81)	6.40 (2.71)	6.00 (2.64)	**6.46 (2.72)**
September	7.20 (2.85)	6.20 (2.68)	5.40 (2.52)	**6.26 (2.68)**	6.80 (2.78)	6.00 (2.63)	5.20 (2.48)	**6.00 (2.63)**
October	6.20 (2.67)	5.60 (2.56)	4.80 (2.40)	**5.53 (2.54)**	6.00 (2.63)	5.00 (2.42)	4.40 (2.32)	**5.13 (2.46)**
Mean	**5.38 (2.47)**	**4.81 (2.36)**	**4.13 (2.22)**	-	**5.10 (2.42)**	**4.45 (2.29)**	**3.40 (2.05)**	-
Factors		**C.D.**	**SE(d)**	**SE(m)**		**C.D.**	**SE(d)**	**SE(m)**
Month		0.66	0.33	0.23		0.78	0.39	0.28
Stages		0.33	0.16	0.11		0.39	0.19	0.14
Month × Stages		1.10	0.58	0.41		1.15	0.68	0.48

Each value represents mean of five observations
Figures in parentheses are √(n+1) transformed value

During both the years, mean population of all stages of wax moth started increasing from April and increased till July thereafter (from August), the population started declined till March. In year 2015-16, mean population of all stages of wax moth was found highest in July (7.93) followed by June (7.86), August (6.66), September (6.26) May (6.26), October (5.53), November (3.26), December (3.06), April (3.06) and January (2.80) while the lowest

population were recorded in the month of March (2.26) and February (2.33). In year 2016-17, mean population of wax moth was found highest in June (6.80) followed by July (6.73), August (6.46), September (6.00), May (5.53), October (5.13), November (3.06), December (2.80), January (2.60) and April (2.40) while the lowest population were recorded in the month of March (2.06) followed by February (2.20). Irrespective of the different month, larval population was found highest (5.38 and 5.10) followed by pupae (4.81 and 4.45) and adults (4.13 and 3.40), respectively in year 2015-16 and 2016-17.

4.1.4. Population of Greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 10-frame bees strength during 2015-16 and 2016-17

Population of Greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 10-frame bees strength during 2015-16 and 2016-17 are presented in the Table 4.4.

Table 4.4. Population of Greater wax moth (*G. mellonella*) in *A. mellifera* colonies with 10- frame bees strength during 2015-16 and 2016-17

Year / Month	2015-16				2016-17			
	Stages of wax moth				Stages of wax moth			
	No. of larvae	No. of pupae	No. of adults	Mean	No. of larvae	No. of pupae	No. of adults	Mean
November	2.40 (1.83)	2.00 (1.71)	0.80 (1.31)	**1.73 (1.61)**	2.20 (1.78)	1.80 (1.64)	0.60 (1.22)	**1.53 (1.55)**
December	2.20 (1.75)	1.80 (1.65)	0.60 (1.24)	**1.53 (1.55)**	2.00 (1.70)	1.60 (1.59)	0.40 (1.16)	**1.33 (1.48)**
January	0.60 (1.24)	1.60 (1.60)	0.40 (1.16)	**0.86 (1.34)**	0.40 (1.16)	1.40 (1.54)	0.40 (1.16)	**0.73 (1.29)**
February	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	**0.00 (1.00)**	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	**0.00 (1.00)**
March	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	**0.00 (1.00)**	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	**0.00 (1.00)**
April	1.20 (1.47)	1.00 (1.41)	0.80 (1.33)	**1.00 (1.40)**	1.00 (1.41)	0.80 (1.33)	0.60 (1.24)	**0.80 (1.33)**
May	1.80 (1.66)	1.20 (1.47)	1.00 (1.41)	**1.33 (1.52)**	1.60 (1.60)	1.00 (1.41)	1.00 (1.41)	**1.20 (1.47)**
June	3.20 (2.02)	1.60 (1.60)	1.20 (1.47)	**2.00 (1.70)**	3.00 (1.99)	1.40 (1.54)	1.00 (1.41)	**1.80 (1.65)**
July	4.20 (2.27)	3.00 (1.97)	1.80 (1.65)	**3.00 (1.97)**	4.00 (2.23)	2.80 (1.91)	1.60 (1.60)	**2.80 (1.91)**
August	3.60 (2.13)	2.80 (1.91)	1.60 (1.60)	**2.66 (1.88)**	3.20 (2.04)	2.60 (1.84)	1.40 (1.54)	**2.40 (1.81)**
September	3.20 (2.04)	2.40 (1.83)	1.40 (1.54)	**2.33 (1.80)**	3.00 (1.99)	2.20 (1.77)	1.20 (1.47)	**2.13 (1.74)**
October	3.00 (1.99)	2.20 (1.74)	1.20 (1.47)	**2.13 (1.74)**	2.80 (1.94)	2.00 (1.68)	1.00 (1.41)	**1.93 (1.68)**
Mean	**2.11 (1.70)**	**1.63 (1.57)**	**0.90 (1.35)**	-	**1.93 (1.65)**	**1.46 (1.52)**	**0.76 (1.30)**	-
Factors		**C.D.**	**SE(d)**	**SE(m)**		**C.D.**	**SE(d)**	**SE(m)**
Month		0.55	0.27	0.19		0.54	0.27	0.19
Stages		0.27	0.13	0.09		0.27	0.13	0.09
Month × Stages		0.95	0.48	0.34		0.93	0.47	0.33

Each value represents mean of five observations
Figures in parentheses are √(x+1) transformed value

Data in the Table 4.4 revealed that in 10- frames bees strength colonies, the population of wax moth (larval, pupal and adult) varied in different months 2015-16 and 2016-17. During both the years, population of greater wax moth (larval, pupal as well as adult) started increasing from April and increased till July; thereafter, (from August) the population started declining and declined till January. There was no population of wax moth (larval, pupal as well as adult) observed during February and March month of both years. During 2015-16 (table-4), the highest larval population (4.20) was recorded in the month of July followed by August (3.60), June (3.20), September (3.20), October (3.00), November (2.40), December (2.20), May (1.80) and April (1.20) while the lowest population of larvae was recorded in January (0.60). Highest number (3.00) of pupae were recorded in the month of July followed by August (2.80), September (2.40), October (2.20), November (2.00), December (1.80), January (1.60), May (1.20) and April (1.00) while the negligible population (0.00) was in February and March. (3.00). Highest (1.80) number of adults were recorded in the month of July followed by August (1.60), September (1.40), June and October (1.20) and May (1.00) which significantly differed from the lowest population February (0.00), March (0.00), January (0.40), December (0.60), April (0.80) and November (0.80).

Data in the Table 4.4 also revealed that during 2016-17, there was no population of wax moth observed during February and March. The highest larval population (4.00) was recorded in the month of July followed by August (3.20), June (3.00), September (3.00), October (2.80), November (2.20), December (2.00), and April (1.00) while the lowest population was recorded in January (0.40). Highest number (2.80) of pupae were recorded in the month of July followed by August (2.60), September (2.20), October (2.00) November (1.80), December (1.60), January (1.40), May (1.00) and April (0.80) while the negligible population (0.00) of pupa was in February and March. Maximum (1.60) number of adults were recorded in the month of July followed by August (1.40), September (1.20), May (1.00), June (1.00) October (1.00), April (0.60) and November (0.60) which significantly differed from minimum population of adults in February (0.00), March (0.00), December (0.40) and January (0.40).

In year 2015-16, mean population of all stages of wax moth was found highest in July (3.00) followed by August (2.66), September (2.33), October (2.13), June (2.00), November (1.73), December (1.53) and May (1.33) April (1.00) while the lowest population was recorded in the month of January (0.86). In year 2016-17, mean population of wax moth was found highest in July (2.80) followed by August (2.40), September (2.13), October (1.93), June (1.80), November (1.53), December (1.33) and May (1.20) April (0.80) while lowest population were recorded in the month of January (0.83). Irrespective of the different month, larval population was found highest (2.11 and 1.93) followed by pupae (1.63 and 1.46) and adults (0.90 and 0.76), respectively in year 2015-16 and 2016-17.

4.1.5. Correlation between weather parameters and Greater wax moth (*G. mellonella*) incidence in *A. mellifera* colonies with different bee frame strength during 2015-16

The correlation between greater wax moth and weather parameters are presented in table 4.5 revealed that in 4- frame bees strength colonies, the correlation between number of larvae and weather parameters were found positive and significant for minimum temperature (r= 0.338) and for maximum RH (r= 0.346), positive and highly significant for minimum RH (r= 0.501). Correlation did not exist between number of larvae and maximum temperature and of bright sunshine hours. The correlation between number of pupae and minimum RH was found positive and highly significant (r=0.372) but correlation did not exist between pupae population and weather parameters as maximum temperature, minimum temperature, maximum RH and of bright sunshine hours. The correlation between number of adults and weather parameters were found positive and significant for minimum temperature (r= 0.319) and positive and highly significant for minimum RH (r= 0.468), however, no correlation existed between number of adults and weather parameters as maximum temperature, maximum RH and bright sunshine hour. In 6- frame bees strength, the correlation between number of larvae and weather parameters were found positive and highly significant for minimum temperature (r= 0.400), for maximum RH (r= 0.375), for minimum RH (r= 0.548) and negative and significant for bright sunshine hours (r= -0.305), whereas correlation did not exist between larvae and maximum temperature. It was positive and highly significant for minimum temperature (r= 0.419), for maximum RH (r= 0.368), for minimum RH (r= 0.538) and negative and significant for bright sunshine hour (r= -0.346), whereas no correlation existed between pupae and maximum temperature.

The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature (r= 0.391), for minimum RH (r= 0.521), positive and significant for maximum RH (r= 0.346), whereas negative and significant for bright sunshine hour (r= - 0.278), however, correlation did not existed between adult and maximum temperature. In 8- frame bee strength, the correlation between number of larvae and weather parameters were found positive and highly significant for maximum temperature (r= 0.344), for minimum RH (r= 0.512), and positive and significant for maximum RH (r= 0.344) whereas no correlation existed between number of larvae and maximum temperature and bright sunshine hours. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH (r= 0.457) and positive and significant for minimum temperature (r= 0.312). Correlation did not exist between number of pupae and weather parameters such as maximum temperature, maximum RH and bright sunshine hours. The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature (r= 0.385) and for minimum RH (r=

0.429), whereas correlation did not exist between number of adults and weather parameters as maximum temperature, maximum RH and bright sunshine hours. In 10- frames bees strength, the correlation between number of larvae and weather parameters was found positive and highly significant for minimum RH (r= 0.377) but no correlation existed between larval population and weather parameters for maximum temperature, minimum temperature, maximum RH and of bright sunshine hour. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH (r= 0.467), whereas no correlation existed between number of pupae and maximum temperature, minimum temperature, maximum RH and bright sunshine hour.

The correlation between number of adults and weather parameters were found positive and significant for minimum RH (r= 0.331). Correlation also did not exist between adult and weather parameters as maximum temperature, minimum temperature, maximum RH and of bright sunshine hour. During the year 2015-16, the greater wax moth larva infested bee colonies throughout the year but population starts increasing from May and progressively to acquire peak in July in 4, 6, 8 and l0- frame bees strength. During July, averages of weather parameters were recorded as maximum temperature (35.10°C), minimum temperature (26.10°C), maximum RH (90%), minimum RH (72%) and number of bright sunshine hour (5.9 hours) were recorded. During March, the averages of different weather parameters were recorded as maximum temperature (29.90°C), minimum temperature (13.70°C), maximum RH (88%), minimum RH (46 %) and number of bright sunshine hours (8.10 hours).

4.1.5.2. Correlation between weather parameters and greater wax moth (*G. mellonella*) incidence in *A. mellifera* colonies with different frame strength during 2016-17

The correlation between greater wax moth incidence and weather parameters are also depicted in table 4.5 indicated that in 4-frame bees strength colonies, the correlation between the number of larvae and weather parameters were found positive and highly significant for minimum temperature (r= 0.368), for minimum RH (r= 0.433), positive and significant (r= 0.275) for max maximum RH whereas no correlation existed between the number of larvae for maximum temperature and bright sunshine hours. The correlation between number of pupae and weather parameters were also found positive and significant for minimum temperature (r= 0.295) and for minimum RH (r= 0.324) but correlation did not exists between the number of pupae and weather parameters as maximum temperature maximum RH and number of bright sunshine hours. The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature (r= 0.358) and for minimum RH (r= 0.374). No correlation existed between number of adult and weather parameters for maximum temperature, maximum RH and number of bright sunshine hours. In 6-frame bees strength, the correlation between number of larvae and weather parameters were, found positive and highly significant for minimum temperature (r= 0.358) and for

minimum RH (r= 0.374) whereas, no correlation existed between number of larvae and weather parameters for maximum temperature, maximum RH and number of bright sunshine hours. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH (r= 0.040) and positive and significant for minimum temperature (r= 0.337) whereas, no correlation existed between number of pupae and weather parameters such as maximum temperature, maximum RH and number of bright sunshine hours. The correlation between number of adults and weather parameters were found positive and highly significant (r= 0.361) for minimum temperature and for minimum RH (r= 0.389), however, no correlation existed between number of adults and weather parameters (as maximum temperature, maximum RH and number of bright sunshine hour). In 8-frame bees strength, the correlation between number of larvae and weather parameters were found positive and significant for minimum temperature (r= 0.306) and positive and highly significant for minimum RH (r= 0.361) whereas, no correlation existed between number of larvae and weather parameters such as maximum temperature, maximum RH and of bright sunshine hours. Correlation did not exist between number of pupae and weather parameters.

The correlation between number of adults and weather parameters were found to be positive and significant for minimum temperature (r= 0.282), whereas no correlation existed between number of adults and weather parameters (as maximum temperature, maximum RH and number of bright sunshine hours). In 10-frame bees strength, the correlation between number of larvae and weather parameters was found positive and significant for minimum RH (r= 0.337) but no correlation existed between number of larvae and weather parameters as maximum temperature, minimum temperature, maximum RH and of bright sunshine hours. The correlation between number of pupae and weather parameters was found positive and significant for minimum RH (r= 0.283), whereas no correlation existed between number of pupae and weather parameters for maximum temperature, minimum temperature, maximum RH and of bright sunshine hours. Correlation also did not exist between number of adults and weather parameters.

During the year 2016-17, the greater wax moth larvae starts infesting bee colonies throughout the year but population start increasing from May and progressively to acquire peak in July in 4, 6, 8 and l0- frame bees strength. The average of different weather parameters in July were recorded as maximum temperature (35.10°C), minimum temperature (27°C), maximum RH (88%), minimum RH (67%) and number of bright sunshine hour (6.8 hour).

Table 4.5. Correlation between weather parameters and Greater wax moth (*G. mellonella)* in *A. mellifera* colonies with different bee strength during 2015-16 and 2016-17

Bee strength / Weather parameters	Number of frames covered by bees during 2015-16											
	4 frame bees			6 frame bees			8 frame bees			10 frame bees		
	Larvae	Pupae	Adults	Larvae	Pupae	Adults	Larvae	Pupae	Adults	Larvae	Pupae	Adults
Max. temp. (°C)	0.202	0.147*	0.185	0.222	0.218	0.199	0.182	0.147	0.172	0.149*	0.151	0.082
Min. temp. (°C)	0.338*	0.207*	0.319*	0.400**	0.419**	0.391**	0.344**	0.312**	0.385**	0.231	0.259	0.188
Max. RH (%)	0.501**	0.372**	0.468**	0.548**	0.538*	0.521**	0.512**	0.457**	0.429**	0.377**	0.467**	0.331*
Min. RH (%)	0.346*	0.241	0.220	0.375**	0.368*	0.346*	0.344**	0.260	0.223	0.213	0.220	0.138*
Bright sunshine (hr)	-0.164	-0.018	-0.131	-0.305*	-0.346	-0.278*	-0.247	-0.218	-0.251	-0.121	-0.143	-0.096
Number of frames covered by bees during 2016-2017												
Max. temp. (°C)	0.181	0.142*	0.244	0.209*	0.156	0.189	0.155	0.175*	0.123	0.128	0.091*	0.154
Min. temp. (°C)	0.368**	0.297	0.462**	0.358*	0.337	0.361**	0.306*	0.262*	0.282*	0.272	0.218	0.243
Max. RH (%)	0.433**	0.324*	0.437**	0.374	0.401	0.389**	0.361**	0.226*	0.346*	0.337*	0.283*	0.197
Min. RH (%)	0.275*	0.150	0.169	0.191	0.174	0.167	0.255	0.136	0.226	0.236	0.189	0.105
Bright sunshine (hr)	**-0.139**	**-0.074**	**-0.093**	**-0.021**	**-0.148**	**-0.105**	**-0.025**	**-0.108**	**-0.223**	**-0.043**	**-0.032**	**-0.056**

* Significant at 5% level of significance
* * Significant at 1% level of significance

During this period, the weather conditions for the development of greater wax moth was very congenial and owing to the scarcity of bee flora and unfavorable weather conditions for bees, the colony population was at their lowest level leaving sufficient empty space on the combs for the spread of this pest. Lowest population of all stages of wax moth (larvae, pupae and adults) was found in March and the average of weather parameters were recorded as maximum temperature (29.90°C), minimum temperature (13.70°C), maximum RH (88%), minimum RH (46%) and number of bright sunshine hour (8.10 hours).

4.1.6. Comb area damaged by in *A. mellifera* colonies with different bee frame strength during different month of 2015-16 and 2016-17

Data on comb area damaged by *G. mellonella* in *A. mellifera* colonies with different bee frame strength during different month of year 2015-16 and 2016-17 are presented in Table 4.6. Data in Table 4.6 indicated that during 2015-16, the comb area damaged by *G. mellonella* in 4 frame bee strength colonies started increasing in April (212.85 cm^2) and increased till July (1376.00 cm^2). From August, the damaged area started decreasing in different month and it reached to lowest limit in March (86.00 cm^2). The maximum comb area damaged was recorded in July (1376.00 cm^2). In 6 frame bee strength colonies, the comb area damaged started increasing in April (150.50 cm^2) and increased till July (1268.50 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (70.95 cm^2). The maximum comb area damaged was recorded in July (1268.50 cm^2). In 8 frame bee strength colonies, the comb area damaged started increasing in April (118.25 cm^2) and increased till July (903.00 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (55.90 cm^2). The maximum comb area damaged was recorded in July (903.00 cm^2). In 10 frame bee strength colonies, the comb area damaged started increasing in April (101.05 cm^2) and increased till July (602.00 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (32.25 cm^2). The maximum comb area damaged was recorded in July (602.00 cm^2). Irrespective of the bee strength, the maximum comb area damaged (cm^2) was recorded in July (1037.38) whereas the minimum in March (61.28). The pattern of damaged area during different months was same in 4, 6, 8 and 10 frame bee strength colonies. However, the mean area damaged (cm^2) was lowest in 10 frame bee colonies (234.14) followed by 8 (352.97), 6 (500.09) and 4 frame bee colonies (577.99).

Comb area damaged during 2016-17 is also presented in Table 4.6. Data in Table 4.6 indicated that the comb area damaged by *G. mellonella* in 4 frame bee strength colonies started increasing in April (176.30 cm^2) and increased till July (1333.00 cm^2). From August, the damaged area started decreasing in different month and it reached to lowest limit in March (70.95 cm^2). The maximum comb area damaged was recorded in July (1333.00 cm^2).

Table 4.6. Comb area damaged by *G. mellonella* in *A. mellifera* colonies with different bee frame strength during different months of 2015-16 and 2016-17

Mean bee frame strength in different year / Month	Comb area damage in cm^2									
	2015-16					2016-17				
	Bee frame strength					Bee frame strength				
	4	6	8	10	Mean	4	6	8	10	Mean
November	559.00	462.25	359.05	242.95	**405.81**	548.25	359.05	301.00	275.20	**370.88**
December	232.20	152.65	103.35	70.95	**138.71**	189.20	137.60	73.10	70.95	**106.43**
January	111.80	101.50	86.00	66.65	**92.56**	101.05	86.00	70.95	30.10	**82.24**
February	101.05	86.00	70.95	32.25	**72.56**	101.05	70.95	70.95	25.80	**68.26**
March	86.00	70.95	55.90	32.25	**61.28**	70.95	70.95	55.90	21.50	**54.83**
April	212.85	150.50	118.25	101.05	**145.66**	176.30	122.55	118.25	86.00	**125.78**
May	548.25	425.70	202.10	163.40	**334.86**	473.00	361.20	172.00	150.50	**289.18**
June	599.85	488.05	326.80	219.39	**408.52**	520.30	447.20	236.50	187.05	**347.76**
July	1376.00	1268.50	903.00	602.00	**1037.38**	1333.00	1204.00	885.80	559.00	**995.45**
August	1182.50	1098.65	774.00	464.00	**879.79**	1019.10	935.25	526.75	376.25	**697.14**
September	1014.80	922.35	623.50	451.50	**753.03**	857.85	771.85	457.95	359.00	**611.66**
October	911.60	774.00	612.75	363.35	**657.92**	752.50	660.05	436.45	333.25	**545.56**
Mean	**577.99**	**500.09**	**352.97**	**234.14**		**511.87**	**435.55**	**283.8**	**206.21**	

Factors	C.D.	SE(d)	SE(m)		C.D.	SE(d)	SE(m)
Month	0.62	0.31	0.22		0.62	0.31	0.22
Bee strength	0.35	0.18	0.12		0.35	0.18	0.12
Month × Bee strength	1.24	0.62	0.44		1.24	0.62	0.44

Each value represents mean of five observations

In 6 frame bee strength colonies, the comb area damaged started increasing in April (122.55 cm^2) and increased till July (1204.00 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (70.95 cm^2). The maximum comb area damaged was recorded in July (1204.00 cm^2). In 8 frame bee strength colonies, the comb area damaged started increasing in April (118.25 cm^2) and increased till July (885.80 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (55.90 cm^2). The maximum comb area damaged was recorded in July (885.80 cm^2). In 10 frame bee strength colonies, the comb area damaged started increasing in April (86.00 cm^2) and increased till July (559.00 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (21.50 cm^2). The maximum comb area damaged was recorded in July (602.00 cm^2). Irrespective of the bee strength, the maximum comb area damaged (cm^2) was recorded in July (995.45) whereas the minimum in March (54.83). The pattern of damaged area during different months was same in 4, 6, 8 and 10 frame bee strength colonies. However, the mean area damaged (cm^2) was lowest in 10 frame bee colonies (206.21) followed by 8 (283.80), 6 (435.55) and 4 frame bee colonies (51.87).

4.1.7. Per cent comb area damaged by *G. mellonella* in *A. mellifera* colonies with different bee frame strength during different months of 2015-16 and 2016-17

Data on per cent comb area damaged by *G. mellonella* in *A. mellifera* colonies with different bee frame strength during different months of 2015-16 and 2016-17 are presented in Table 4.7. Data in Table 4.7 indicated that during 2015-16, the comb area damaged by *G. mellonella* in 4 frame bee strength colonies started increasing in April (13.30%) and increased till July (86%). From August, the damaged area started decreasing in different month and it reached to lowest limit in March (5.38%). The maximum comb area damaged was recorded in July (86.00%). In 6 frame bee strength colonies, the comb area damaged started increasing in April (9.41%) and increased till July (79.28%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (4.43%). The maximum comb area damaged was recorded in July (79.28%). In 8 frame bee strength colonies, the comb area damaged started increasing in April (7.39%) and increased till July (56.44%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (3.49%). The maximum comb area damaged was recorded in July (56.44%). In 10 frame bee strength colonies, the comb area damaged started increasing in April (6.32%) and increased till July (37.63%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (2.01%). The maximum comb area damaged was recorded in July (37.63%). Irrespective of the bee strength, the maximum comb area damaged (%) was recorded in July (64.84) whereas the minimum in March (3.83). The pattern of damaged area during different months was same in

4, 6, 8 and 10 frame bee strength colonies. However, the mean area damaged (%) was lowest in 10 frame bee colonies (14.63) followed by 8 (22.06), 6 (31.25) and 4 frame bee colonies (36.12).

Per cent comb area damaged during 2016-17 is also presented in Table 4.7. Data in Table 4.7 indicated that the per cent comb area damaged by *G. mellonella* in 4 frame bee strength colonies started increasing in April (11.02) and increased till July (83.31%). From August, the damaged area started decreasing in different month and it reached to lowest limit in March (4.44%). The maximum comb area damaged was recorded in July (83.31%). In 6 frame bee strength colonies, the comb area damaged started increasing in April (7.66%) and increased till July (75.25%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (4.43%). The maximum comb area damaged was recorded in July (75.25%). In 8 frame bee strength colonies, the comb area damaged started increasing in April (7.39%) and increased till July (3.49%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (3.49%). The maximum comb area damaged was recorded in July (3.49%). In 10 frame bee strength colonies, the comb area damaged started increasing in April (5.38%) and increased till July (34.94%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (1.34). The maximum comb area damaged was recorded in July (34.94). Irrespective of the bee strength, the maximum comb area damaged (%) was recorded in July (62.21) whereas the minimum in March (3.42%). The pattern of damaged area during different months was same in 4, 6, 8 and 10 frame bee strength colonies. However, the mean area damaged (%) was lowest in 10 frame bee colonies (12.89) followed by 8 (17.74), 6 (27.22) and 4 frame bee colonies (31.99).

Table 4.7. Per cent comb area damaged by *G. mellonella* in *A. mellifera* colonies of different bee frame strength during different months of 2015-16 and 2016-17

Mean bee frame strength in different year / Month	Comb area damage (%)									
	2015-16					2016-17				
	Bee frame strength					Bee frame strength				
	4	6	8	10	Mean	4	6	8	10	Mean
November	34.94 (36.12)	28.89 (32.33)	22.44 (28.17)	15.18 (23.01)	**25.36 (29.91)**	34.27 (35.83)	22.44 (28.17)	18.81 (25.55)	17.20 (24.32)	**23.17 (28.47)**
December	14.51 (22.14)	9.54 (17.39)	6.45 (14.89)	4.45 (12.45)	**8.73 (16.57)**	11.83 (19.81)	8.60 (16.73)	4.57 (12.27)	4.44 (12.14)	**7.35 (16.06)**
January	6.99 (15.31)	6.32 (14.56)	5.38 (13.26)	4.17 (11.89)	**5.79 (13.89)**	6.32 (14.56)	4.44 (12.14)	4.43 (12.14)	1.88 (7.33)	**4.50 (12.00)**
February	6.31 (14.56)	5.37 (15.33)	4.43 (12.14)	2.01 (7.94)	**4.53 (12.04)**	6.32 (14.50)	4.42 (12.12)	3.49 (10.85)	1.61 (7.33)	**4.19 (11.90)**
March	5.38 (12.90)	4.43 (12.14)	3.49 (10.85)	2.01 (7.94)	**3.83 (13.26)**	4.43 (12.14)	4.43 (12.14)	3.49 (10.85)	1.34 (6.53)	**3.42 (10.21)**
April	13.30 (21.38)	9.41 (17.68)	7.39 (15.69)	6.32 (14.50)	**9.10 (17.31)**	11.02 (19.27)	7.66 (15.93)	7.39 (15.69)	5.38 (13.33)	**7.86 (16.92)**
May	34.27 (35.83)	26.61 (31.05)	12.63 (20.83)	10.21 (18.71)	**20.92 (26.60)**	29.56 (32.97)	22.58 (28.39)	10.75 (19.00)	9.41 (17.77)	**18.08 (24.53)**
June	37.49 (37.63)	30.50 (33.36)	20.43 (26.79)	13.71 (21.66)	**25.53 (29.86)**	32.52 (34.83)	27.95 (31.70)	14.78 (22.50)	11.69 (19.96)	**21.74 (27.25)**
July	86.00 (68.31)	79.28 (63.17)	56.44 (48.62)	37.63 (37.84)	**64.84 (54.48)**	83.31 (66.17)	75.25 (60.26)	55.36 (48.04)	34.94 (36.05)	**62.21 (52.05)**
August	73.91 (58.65)	68.67 (56.17)	48.38 (44.02)	29.03 (32.56)	**55.00 (47.83)**	63.69 (52.96)	58.45 (49.80)	32.92 (35.04)	23.52 (29.09)	**44.64 (41.05)**
September	63.43 (52.95)	57.65 (49.40)	38.30 (38.23)	28.22 (32.13)	**47.06 (42.24)**	53.62 (47.08)	48.24 (44.02)	28.62 (32.35)	22.44 (28.38)	**38.22 37.41)**
October	56.98 (49.00)	48.38 (44.01)	38.97 (38.62)	22.71 (28.40)	**41.12 (40.94)**	47.03 (43.45)	41.24 (39.96	27.28 (31.50)	20.83 (27.02)	**34.09 (36.71**
Mean	**36.12 (36.92)**	**31.25 (33.97)**	**22.06 (28.00)**	**14.63 (22.47)**		**31.99 (34.43)**	**27.22 (31.43)**	**17.74 (24.90)**	**12.89 (12.03)**	

Factors	C.D.	SE(d)	SE(m)		C.D.	SE(d)	SE(m)
Month	1.26	0.63	0.45		1.02	0.51	0.36
Bee strength	2.19	1.10	0.78		1.77	0.89	0.63
Month × Bee strength	4.38	2.20	1.55		3.55	1.78	1.26

Each value represents mean of five observations

Figures in parentheses are angular root transformed value

4.1.8. Correlation between weather parameters and comb area damage by greater wax moth (*G. mellonella)* in *A. mellifera* colonies with different frames strength during 2015-16 and 2016-17

During 2015-16, the mean combs damage area in all frame strength (4, 6, 8 and 10) was recorded maximum in July (1037.38 cm^2), whereas it was found to be lowest comb damage in March (61.28 cm^2) while in year 2016-17, maximum damaged area (995.45cm^2) were recorded in July and minimum was in March (54.83 cm^2). During year 2015-16, average weather parameters of July were recorded as maximum temperature (35.10°C), minimum temperature (26.10°C), maximum RH (90%), minimum RH (72%) and number of bright sunshine hour (5.9 hour). Whereas, in March, maximum temperature (29.90°C), minimum temperature (13.70°C), maximum RH (88%), minimum RH (46%) and number of bright sunshine hour (8.10 hour) were recorded while in 2016-17, average of different weather parameters in July were recorded as maximum temperature (35.10°C), minimum temperature (27.00°C), maximum RH (88%), minimum RH (67%) and number of bright sunshine hour (6.8 hour) and in March, the average of weather parameters were recorded as maximum temperature (29.90°C), minimum temperature (13.70°C), maximum RH (88%), minimum RH (46%) and number of bright sunshine hour (8.10 hour).

The data in Table 4.8 indicated significant positive correlation exists between comb area damage with maximum temperature (r= 0.852 and r= 0.793), maximum humidity (r= 0.686 and r= 0.645) and negatively non-significant with minimum temperature (r= -0.697 and r= -0.635) and minimum RH (r= -0.699 and r= -0.641) respectively, in year 2015-16 and 2016-17 in 4- frame bee strength whereas no correlation existed between comb damage and sunshine hours. Significant positive correlation of comb area damage with maximum temperature in 6 and 8 frame bee strength (r= 0.772 and r= 0.792), maximum humidity (r= 0.645 and r= 0.940) and non significant with minimum temperature and minimum RH (r= -0.665 and r= -0.936), respectively in year 2015-16 while in year 2016-17, correlation of comb damage with maximum temperature in 6 and 8 frame (r= 0.789 and r= 0.830), maximum humidity (r= 0.694 and r= 0.835) and negatively non significant with minimum RH (r= -0.693 and r= -0.832) and positively non-significant with minimum temperature (r= 0.672 and r= 0.833), respectively.

There was a non significant correlation found between comb area damage by larvae in 10 frame bee strength with maximum temperature, minimum temperature, maximum RH, minimum RH and sunshine hours with (r= 0.450, r= 0.344, r= 0.382, r= 0.467 and r= 0.613) and (r= 0.228, r= 0.243, r= 0.322, r= 0.398 and r= 0.548) respectively, during 2015-16 and 2016-17.

Table 4.8. Correlation between weather parameters and comb area damage by Greater wax moth (*G. mellonella)* in *A. mellifera* colonies with different frames strength during 2015-16 and 2016-17

Weather parameters	Comb area damaged in colonies with different bee strength							
	2015-16				2016- 17			
	Number of bee frames covered by bee				Number of bee frames covered by bee			
	4	6	8	10	4	6	8	10
Max. temp. (°C)	0.852*	0.767**	0.792**	0.820**	0.793*	0.767**	0.786**	0.817**
Min. temp. (°C)	0.697	-0.635	-0.651	-0.688	-0.635	-0.565	-0.617	-0.659
Max. RH (%)	0.686**	0.222**	0.232**	0.162**	0.645**	0.191**	0.206**	0.144**
Min. RH (%)	-0.267	-0.251	-0.258	-0.240	-0.315	-0.302	-0.290	-0.267
Bright sunshine (hr)	0.130	0.043	0.006	0.023	0.134	0.036	0.003	-0.023

* Significant at 5% level of significance
**Significant at 1% level of significance

Significant correlation found between the comb area damage and maximum temperature in 4, 6 and 8 frame strength (r= 0.767, r= 0.786 and r= 0.817), maximum humidity (r= 0.191, r= 0.206 and r= 0.144) and negatively non significant with minimum RH (r= -3.02, r= -0.290 and r= -0.267), respectively. Correlation did not exist between comb area damage and sunshine hours in 4, 6, 8 and 10 frame bee strength with (r= 0.130, r= 0.043, r= 0.006 and r= 0.023) in year 2015- 16 and (r= 0.134, r= 0.036, r= 0.003 and r= -0.023), respectively in year 2016-17.

4.2.1. Seasonal incidence of Greater wax moth (*G. mellonella*) larvae during June to October in stored combs in 2016 and 2017

Seasonal incidence of greater wax moth (*G. mellonella*) larvae during June to October in stored combs in 2016 and 2017 are presented in the Table 4.9. Data in the table 4.9 indicated that during 2016, at the time of first observation during June, the number of larvae recorded per comb in case seven combs were stored (1.40). In the following observations, the number of larvae/comb increased till September (29.60 on 30th September). However, during October, the number decreased. During October, the number of larvae recorded per comb was 20.00 and 13.60 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of larvae recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation i.e. on 30th October, the number of larvae recorded per comb was highest (16.80) when ten combs were stored in a hive body followed by nine combs (16.60), eight comb (13.80) and seven comb (13.60).

Table 4.9. Seasonal incidence of Greater wax moth (*G. mellonella*) larvae during June to October in stored combs during 2016 and 2017

Number of combs in hive body	Cumulative number of larvae/comb during different months of 2016										Mean
	June		July		August		September		October		
	15.6.16	30.6.16	15.7.16	30.7.16	15.8.16	30.8.16	15.9.16	30.9.16	15.10.16	30.10.16	
Seven	1.40 (1.54)	3.00 (1.98)	5.60 (2.54)	12.20 (3.61)	19.40 (4.51)	24.00 (4.98)	27.20 (5.29)	29.60 (5.50)	20.00 (4.58)	13.60 (3.81)	**15.60 (3.83)**
Eight	1.80 (1.65)	3.80 (2.17)	6.20 (2.66)	15.00 (3.99)	20.40 (4.60)	25.20 (5.11)	28.40 (5.41)	31.00 (5.6)	24.40 (5.03)	13.80 (3.84)	**17.00 (4.01)**
Nine	2.40 (1.82)	4.00 (2.23)	7.60 (2.89)	16.60 (4.19)	23.00 (4.88)	26.60 (5.23)	33.20 (5.83)	35.40 (6.03)	24.80 (5.06)	16.60 (4.16)	**19.02 (4.23)**
Ten	2.80 (1.92)	4.60 (2.36)	9.80 (3.24)	18.20 (4.37)	25.80 (5.17)	29.00 (5.47)	32.80 (5.80)	36.40 (6.11)	25.60 (5.15)	16.80 (4.21)	**20.18 (4.38)**
Mean	**2.10 (1.73)**	**3.85 (2.19)**	**7.30 (2.83)**	**15.50 (4.04)**	**22.15 (4.79)**	**26.20 (5.20)**	**30.40 (5.58)**	**33.10 (5.82)**	**23.70 (4.95)**	**15.20 (4.01)**	-
Factors			**C.D.**				**SE(d)**		**SE(m)**		
Month			0.11				0.05		0.04		
Combs			0.18				0.09		0.06		
Month × Combs			0.36				0.18		0.12		
	Cumulative number of larvae/comb during different months of 2017										**Mean**
Seven	1.80 (1.66)	3.20 (2.04)	6.00 (2.61)	12.60 (3.66)	19.80 (4.55)	25.00 (5.08)	28.20 (5.38)	30.20 (5.55)	22.60 (4.48)	14.40 (3.91)	**16.38 (3.93)**
Eight	2.00 (1.72)	4.00 (2.32)	6.40 (2.70)	15.80 (4.09)	21.80 (4.75)	26.80 (5.26)	28.80 (5.44)	31.20 (5.66)	25.40 (5.13)	15.00 (3.99)	**17.72 (4.10)**
Nine	2.80 (1.92)	4.20 (2.27)	7.80 (2.93)	17.00 (4.23)	23.80 (4.97)	27.60 (5.33)	31.60 (5.69)	34.80 (5.98)	26.40 (5.22)	16.80 (4.21)	**19.28 (4.28)**
Ten	3.00 (1.96)	4.80 (2.40)	10.20 (3.30)	20.20 (4.59)	26.80 (5.26)	30.20 (5.58)	32.20 (5.75)	35.60 (6.04)	27.60 (5.33)	17.20 (4.26)	**20.78 (4.45)**
Mean	**2.40 (1.82)**	**4.05 (2.37)**	**7.60 (2.89)**	**16.40 (4.14)**	**23.05 (4.88)**	**27.40 (5.31)**	**30.20 (5.57)**	**32.95 (5.81)**	**25.50 (5.13)**	**15.85 (4.09)**	-
Factors			**C.D.**				**SE(d)**		**SE(m)**		
Month			0.11				0.05		0.04		
Combs			0.18				0.09		0.06		
Month × Combs			0.36				0.18		0.12		

Each value represents mean of five observations
Figures in parentheses are √(n+1) transformed value

Data in the Table 4.9 also indicated that during 2017, at the time of first observation during June, the number of larvae recorded per comb in case seven combs were stored (1.80). In the following observations, the number of larvae/comb increased till September (30.20 on 30th September). However, during October, the number decreased. During October, the number of larvae recorded per comb was 22.60 and 14.40 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of larvae recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation i.e. on 30th October, the number of larvae recorded per comb was highest (17.20) when ten combs were stored in a hive body followed by nine combs (16.80), eight comb (15.00) and seven comb (14.40).

4.2.2. Pupal population of Greater wax moth (*G. mellonella*) during June to October in stored combs in 2016 and 2017

Seasonal incidence of greater wax moth (*G. mellonella*) pupae during June to October in stored combs in 2016 and 2017 are presented in the Table 4.10. Data in the table 4.10 indicated that during 2016, at the time of first observation during June, the number of pupae recorded per comb in case seven combs were stored (0.20). In the following observations, the number of pupae/comb increased till September (26.80 on 30th September). However, during October, the number decreased. During October, the number of pupae recorded per comb was 19.60 and 19.40 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of pupae recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation i.e. on 30th October, the number of pupae recorded per comb was highest (12.80) when ten combs were stored in a hive body followed by nine combs (10.80), eight comb (10.40) and seven comb (9.40).

Data in the Table 4.10 also indicated that during 2017, at the time of first observation during June, the number of pupae recorded per comb in case seven combs were stored (1.80). In the following observations, the number of pupae/comb increased till September (30.20 on 30th September). However, during October, the number decreased. During October, the number of pupae recorded per comb was 22.60 and 14.40 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of pupae recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body.

Table 4.10. Pupal population of Greater wax moth (*G. mellonella*) during June to October in stored combs during 2016 and 2017

Number of combs in hive body	Cumulative number of pupae/comb during different months of 2016										Mean
	June		July		August		September		October		
	15.6.16	30.6.16	15.7.16	30.7.16	15.8.16	30.8.16	15.9.16	30.9.16	15.10.16	30.10.16	
Seven	0.20 (1.08)	1.40 (1.54)	2.80 (1.93)	8.20 (3.02)	12.80 (3.70)	21.40 (4.68)	25.80 (5.15)	26.80 (5.25)	19.60 (4.52)	9.40 (3.21)	**12.86 (3.41)**
Eight	0.40 (1.14)	2.20 (1.76)	3.00 (1.99)	12.00 (3.59)	19.20 (4.46)	23.40 (4.92)	26.60 (5.25)	27.40 (5.32)	20.00 (4.57)	10.40 (3.36)	**14.44 (3.63)**
Nine	1.00 (1.34)	3.80 (2.18)	4.60 (2.36)	14.60 (3.94)	20.80 (4.66)	24.40 (5.03)	30.60 (5.60)	33.00 (5.82)	22.80 (4.87)	10.80 (3.42)	**16.64 (3.92)**
Ten	1.40 (1.54)	4.80 (2.39)	6.00 (2.64)	15.20 (4.01)	23.00 (4.89)	27.40 (5.32)	32.20 (5.75)	34.80 (5.98)	23.80 (4.97)	12.80 (3.71)	**18.14 (4.12)**
Mean	**0.75 (1.27)**	**3.05 (1.97)**	**4.10 (2.23)**	**12.50 (3.64)**	**18.95 (4.43)**	**24.15 (4.99)**	**28.20 (5.44)**	**30.50 (5.59)**	**21.55 (4.73)**	**10.85 (3.43)**	-
Factors			**C.D.**			**SE(d)**			**SE(m)**		
Month			0.12			0.06			0.04		
Combs			0.20			0.10			0.07		
Month × Combs			0.40			0.20			0.14		
	Cumulative number of pupae/comb during different months of 2017										**Mean**
Seven	0.60 (1.22)	1.80 (1.65)	3.00 (1.97)	8.80 (3.11)	13.60 (3.80)	21.00 (5.64)	26.20 (5.20)	27.60 (5.32)	20.00 (4.56)	10.40 (3.36)	**13.30 (3.48)**
Eight	1.00 (1.41)	2.00 (1.70)	3.40 (2.08)	12.80 (3.70)	19.80 (4.52)	24.80 (5.06)	27.00 (5.28)	28.40 (5.41)	21.20 (4.71)	11.20 (3.49)	**15.16 (3.74)**
Nine	1.20 (1.39)	4.00 (2.23)	4.80 (2.40)	15.00 (3.99)	21.60 (4.75)	25.60 (5.15)	30.20 (5.57)	33.20 (5.84)	23.80 (4.97)	12.40 (3.65)	**17.18 (3.99)**
Ten	1.40 (1.47)	5.00 (2.44)	6.40 (2.71)	17.20 (4.25)	25.00 (5.09)	27.20 (5.30)	32.60 (5.79)	34.40 (5.94)	24.40 (5.03)	13.60 (3.81)	**18.72 (4.18)**
Mean	**1.05 (1.37)**	**3.20 (2.01)**	**4.40 (2.29)**	**13.45 (3.76)**	**20.00 (4.54)**	**24.65 (5.04)**	**29.00 (5.46)**	**30.90 (5.63)**	**22.35 (4.82)**	**11.90 (3.58)**	-
Factors			**C.D.**			**SE(d)**			**SE(m)**		
Month			0.13			0.06			0.04		
Combs			0.20			0.10			0.07		
Month × Combs			0.41			0.20			0.14		

Each value represent mean of five observations
Figures in parentheses are √(n+1) transformed value

At the time of last observation i.e. on 30th October, the number of pupae recorded per comb was highest (17.20) when ten combs were stored in a hive body followed by nine combs (16.80), eight comb (15.00) and seven comb (14.40).

4.2.3. Seasonal incidence of Greater wax moth (*G. mellonella*) adult during June to October in stored combs in 2016 and 2017

Seasonal incidence of greater wax moth (*G. mellonella)* adult during June to October in stored combs in 2016 and 2017 are presented in the Table 4.11. Data in the Table 4.11 indicated that during 2016, at the time of first observation during June, the number of adult recorded per comb in case seven combs were stored (0.00). In the following observations, the number of adults increased till September (26.00 on 30th September). However, during October, the number decreased. During October, the number of adult recorded per comb was 15.20 and 8.20 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of adult recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation i.e. on 30th October, the number of adult recorded per comb was highest (10.40) when ten combs were stored in a hive body followed by nine combs (9.80), eight comb (8.80) and seven comb (8.20).

Data in the Table 4.11 also indicated that during 2017, at the time of first observation during June, the number of adult recorded per comb in case seven combs were stored (0.00). In the following observations, the number of adult/comb increased till September (27.00 on 30th September). However, during October, the number decreased. During October, the number of adult recorded per comb was 16.80 and 9.00 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of adult recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation i.e. on 30th October, the number of adult recorded per comb was highest (11.00) when ten combs were stored in a hive body followed by nine combs (10.80), eight comb (9.20) and seven comb (9.00).

Table 4.11. Seasonal incidence of Greater wax moth (*G. mellonella*) adult during June to October in stored combs during 2016 and 2017

Number of combs in hive body	Cumulative number of adults/comb during different months of 2016										Mean
	June		July		August		September		October		
	15.6.16	30.6.16	15.7.16	30.7.16	15.8.16	30.8.16	15.9.16	30.9.16	15.10.16	30.10.16	
Seven	0.00 (1.00)	1.00 (1.37)	1.40 (1.53)	6.00 (2.63)	11.60 (3.53)	17.60 (4.29)	23.40 (4.93)	26.00 (5.18)	15.20 (4.01)	8.20 (3.02)	**11.04 (3.15)**
Eight	0.40 (1.16)	1.40 (1.54)	2.80 (1.94)	9.40 (3.21)	16.80 (4.21)	20.40 (4.62)	24.00 (4.99)	27.00 (5.27)	16.60 (4.18)	8.80 (3.12)	**12.76 (3.42)**
Nine	0.80 (1.29)	3.00 (1.98)	4.00 (2.23)	11.80 (3.56)	18.80 (4.44)	22.80 (4.87)	25.20 (5.11)	30.20 (5.56)	19.40 (4.50)	9.80 (3.28)	**14.58 (4.68)**
Ten	1.20 (1.47)	3.20 (2.03)	4.40 (2.31)	14.60 (3.94)	19.80 (4.55)	23.20 (4.91)	27.80 (5.36)	32.40 (5.77)	19.60 (4.51)	10.40 (3.37)	**15.66 (3.82)**
Mean	**0.60 (1.23)**	**2.15 (1.73)**	**3.15 (2.00)**	**10.45 (3.34)**	**16.75 (4.18)**	**21.00 (4.67)**	**25.10 (5.09)**	**28.90 (5.45)**	**17.70 (4.30)**	**9.30 (3.20)**	-
Factors			**C.D.**			**SE(d)**			**SE(m)**		
Month			0.11			0.06			0.04		
Combs			0.18			0.09			0.06		
Month × Combs			0.36			0.18			0.13		
		Cumulative number of adults/comb during different months of 2017									**Mean**
Seven	0.00 (1.00)	1.60 (1.61)	2.00 (1.71)	6.40 (2.71)	12.60 (3.68)	18.80 (4.42)	25.00 (5.09)	27.00 (5.27)	16.80 (4.19)	9.00 (3.14)	**11.92 (3.28)**
Eight	0.60 (1.24)	1.80 (1.65)	2.60 (1.89)	9.60 (3.24)	17.80 (4.31)	20.80 (4.66)	25.40 (5.13)	27.80 (5.35)	17.40 (4.27)	9.20 (3.19)	**13.30 (3.49)**
Nine	1.00 (1.34)	3.40 (2.09)	4.20 (2.27)	12.20 (3.62)	20.40 (4.62)	23.80 (4.97)	26.00 (5.18)	31.60 (5.70)	20.80 (4.65)	10.80 (3.42)	**15.42 (3.79)**
Ten	1.00 (1.39)	4.20 (2.26)	4.80 (2.40)	15.80 (4.08)	21.40 (4.73)	24.00 (4.99)	28.40 (5.41)	32.40 (5.77)	20.80 (4.64)	11.00 (3.45)	**16.38 (3.91)**
Mean	**0.65 (1.24)**	**2.75 (1.90)**	**3.40 (2.07)**	**11.00 (3.41)**	**18.05 (4.33)**	**21.85 (3.76)**	**26.20 (5.20)**	**29.70 (5.52)**	**18.95 (4.44)**	**10.00 (3.30)**	-
Factors			**C.D.**			**SE(d)**			**SE(m)**		
Month			0.12			0.06			0.04		
Combs			0.19			0.10			0.07		
Month × Combs			0.39			0.20			0.14		

Each value represent mean of five observations
Figures in parentheses are √(n+1) transformed value

4.2.4.1. Correlation between weather parameters and Greater wax moth (*G. mellonella*) incidence in stored comb with different strength during June to October of year 2016

During 2016, the greater wax moth larvae starts infesting combs from first fortnight of June and progressively to acquire peak in September in 7, 8, 9 and 10 combs/hive. During September, average of weather parameters were recorded as maximum temperature (35.23°C), minimum temperature (24.22°C), maximum RH (86.43%), minimum RH (54.20%) and number of bright sunshine hour (8.17 hour). During this period, the weather condition for the development of the greater wax moth was very congenial. In June, the average of different weather parameters were recorded as maximum temperature (41.1°C), minimum temperature (26.70°C), maximum RH (65%), minimum RH (35.9%) and number of bright sunshine hour (8.4 hour).

The correlation between wax moth population and weather parameters are presented in table 4.12 indicated that in 7 comb stored in hive body, correlation between number of larvae and weather parameters were found positive and significant for minimum temperature (r= 0.232) and for maximum RH (r= 0.376), positive and highly significant for minimum RH (r= 0.212). Correlation did not exist between number of larvae and maximum temperature and bright sunshine hours. The correlation between number of pupae and minimum RH was found positive and highly significant (r= 0.225). Correlation did not exist between pupal population and weather parameters such as maximum temperature, minimum temperature, maximum RH and bright sunshine hours. The correlation between number of adults and weather parameters were found to be positive and significant for minimum temperature (r= 0.190) and positive and highly significant for maximum RH (r= 0.332), whereas no correlation existed between number of adults and weather parameters as maximum temperature, minimum RH and bright sunshine hour.

In 8 combs stored per hive, the correlation between number of larvae and weather parameters were found positive and highly significant for minimum temperature (r= 0.345), for maximum RH (r= 0.513), for minimum RH (r= 0.346) and negative and significant (r= -0.248) for bright sunshine hours. Correlation did not exist between larvae and maximum temperature. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum temperature (r= 0.315), maximum RH (r= 0.459), for minimum RH (r= 0.263) and negative and significant for bright sunshine hour (r= -0.219). Correlation did not exist between number of pupae and maximum temperature. The correlation between number of adults and weather parameters were found to be positive and highly significant for minimum temperature (r= 0.392), for minimum RH (r= 0.522), positive and significant for maximum RH, whereas negative and significant (r= -0.276) for bright sunshine hour. No correlation existed between adult and maximum temperature.

In 9 comb stored per hive, the correlation between number of larvae and weather parameters were found positive and highly significant for maximum temperature (r= 0.220),

for minimum RH (r= 0.376) and positive and significant for maximum RH (r= 0.549). Significant correlation did not exist between number of larvae and maximum temperature (r=0.220) and bright sunshine hours (r= 0.306). The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH (r= 0.365) and positive and significant for minimum temperature (r= 0.420). No correlation existed between number of pupae and weather parameters for maximum temperature, maximum RH and bright sunshine hours. The correlation between number of adults and weather parameters were found to be positive and highly significant for minimum temperature (r= 0.384) and for minimum RH (r= 0.224) but no correlation existed between number of adults and weather parameters such as maximum temperature, maximum RH and bright sunshine hours.

In 10 frame stored in hive body, the correlation between number of larvae and weather parameters was found positive and highly significant for minimum RH (r= 0.347) but no correlation existed between larval and weather parameters as maximum temperature, minimum temperature, maximum RH and bright sunshine hour. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH (r= 0.240). No correlation existed between number of pupae and maximum temperature, minimum temperature, maximum RH and bright sunshine hour. The correlation between number of adults and weather parameters were found to be positive and significant for minimum RH (r= 0.222). Correlation also did not exist between adult and weather parameters such as maximum temperature, minimum temperature, RH and number of bright sunshine hour.

4.2.4.2. Correlation between weather parameters and greater wax moth *Galleria mellonella* in stored comb (without bees) with different strength during June to October 2017

During 2017, the greater wax moth larval infestation showed an increasing trend from starting of June and reaching its peak in September (late rainy season) in 7, 8, 9 and 10 combs stored in hive body. In this month, the ranges of maximum temperature (34.92°C), minimum temperature (23.05°C), maximum RH (87.2%), minimum RH (49.50%) and number of bright sunshine hour (6.8 hour) were recorded. During June, the average of different weather parameters were recorded as maximum temperature (39.30°C), minimum temperature (25.7°C), maximum RH (67.9%), minimum RH (34.7%) and number of bright sunshine hour (7.9 hour).

Seven frame strength, the correlation between greater wax moth and weather parameters are also depicted in table 4.12 indicated that correlation between the number of larvae and weather parameters were found positive and highly significant for minimum temperature (r = 0.273) for minimum RH (r= 0.235), positive and significant for maximum RH (r= 0.360), whereas no correlation existed between the number of larvae for maximum temperature and bright sunshine hours. The correlation between number of pupae and weather

parameters were also found positive and significant for minimum temperature (r= 0.215) and for minimum RH (r= 0.190) but correlation did not exist between the number of pupae and weather parameters as maximum temperature, maximum RH and number bright sunshine hours. The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature (r = 0.245) and for minimum RH (r= 0.106), however, no correlation existed between number of adults and weather parameters for maximum temperature, maximum RH and number of bright sunshine hours.

In 8 comb stored per hive body, the correlation between number of larvae and weather parameters were found positive and highly significant for minimum temperature (r= 0.309) and for minimum RH (r= 0.256), whereas, no correlation existed between number of larvae and weather parameters for maximum temperature, maximum RH and number of bright sunshine hours. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH (r= 0.137). It was positive and significant for minimum temperature (r= 0.264), whereas no correlation existed between number of pupae and weather parameters such as maximum temperature, maximum RH and number of bright sunshine hours. The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature (r= 0.362) and for minimum RH (r= 0.166), however, no correlation existed between number of adult and weather parameters (maximum temperature, maximum RH and bright sunshine hour).

In 9 combs stored in hive body, the correlation between number of larvae and weather parameters were found positive and significant for minimum temperature (r= 0.359) and positive and highly significant for minimum RH (r= 0.193), whereas, no correlation existed between number of larvae and weather parameters as maximum temperature, maximum RH and of bright sunshine hours. Correlation did not exist between number of pupae and weather parameters. The correlation between number of adult and weather parameters were found to be positive and significant (r= 0.280) for minimum temperature whereas no correlation existed between number of adult and weather parameters (such as maximum temperature, maximum RH and number of bright sunshine hours).

In 10 combs stored in hive body, the correlation between number of larvae and weather parameters was found positive and significant for maximum RH (r= 0.435) but no correlation existed between number of larvae and weather parameters as maximum temperature, minimum temperature, minimum RH and hours of bright sunshine. The correlation between number of pupae and weather parameters was found positive and significant for minimum RH (r = 0.152), whereas no correlation existed between number of pupae and weather parameters for maximum temperature, mininimum temperature, maximum RH and hours of bright sunshine. Correlation also did not exist between number of adults and weather parameters.

Table 4.12. Correlation between weather parameters and Greater wax moth, *Galleria mellonella* in stored comb (without bees) with different strength during June to October of year 2016 and 2017

Combs group in hive body during different years / Weather parameters	Number of empty combs group/ hive body/ chamber during 2016											
	7 frame			8 frame			9 frame			10 frame		
	Larvae	Pupae	Adults	Larvae	Pupae	Adults	Larvae	Pupae	Adults	Larvae	Pupae	Adults
Max. temp. (°C)	0.148*	0.152	0.083	0.182	0.149	0.199	0.220	0.218	0.170	0.203	0.146*	0.186
Min. temp. (°C)	0.232	0.260	0.190	0.345**	0.315**	0.392**	0.402**	0.420**	0.384**	0.336*	0.206*	0.318*
Max. RH (%)	0.376**	0.465**	0.332*	0.513**	0.459**	0.522**	0.549**	0.536*	0.428**	0.502**	0.375**	0.466**
Min. RH (%)	0.212	0.225	0.136*	0.346**	0.263	0.348*	0.376**	0.365*	0.224	0.347*	0.240	0.222
Bright sunshine (hr)	-0.122	-0.145	-0.095	-0.248	-0.219	-0.276*	-0.306*	-0.347	-0.250	-0.162	-0.017	-0.132
	Number of empty combs group/ hive body/ chamber during 2017											
Max. temp. (°C)	0.128	0.092*	0.155	0.158	0.176*	0.190	0.208*	0.155	0.122	0.181	0.140*	0.242
Min. temp. (°C)	0.273	0.215	0.245	0.309*	0.264*	0.362**	0.359*	0.336	0.280*	0.370**	0.296	0.460**
Max. RH (%)	0.336*	0.282*	0.198	0.363**	0.228*	0.388**	0.375	0.402	0.345*	0.435**	0.325*	0.436**
Min. RH (%)	0.235	0.190	0.106	0.256	0.137	0.166	0.193	0.176	0.225	0.275*	0.152	0.166
Bright sunshine (hr)	-0.045	-0.035	-0.057	-0.028	-0.109	-0.103	-0.022	-0.149	-0.222	-0.136	-0.075	-0.092

* Significant at 5% level of significance
* * Significant at 1% level of significance

4.2.5. Effects of storing different number of combs on damage by *G. mellonella* during June to October 2016 and 2017

Data on comb area damaged by *G. mellonella* by storing different number of combs during June to October in two consecutive years are presented in Table 4.13. During 2016 data in Table 4.13 indicated that in case 7 combs were stored, the area damaged per comb (cm^2) was minimum at the time of first observation in mid June (8.60). In the following observations, the cumulative area damaged per frame increased till the end of September (169.85). In October, area damaged did not increased and was almost same as in the end of September. The area damaged per comb (cm^2) was 170.28 and 170.32 in mid October and end October, respectively. The pattern of damage during different months was same when 8, 9 and 10 combs were stored. At the time of first observation (mid June), the area damaged per comb (cm^2) was significantly higher when 10 combs were stored (19.35) than 9 (12.90), 8 (10.75) and 7 combs (8.60). At the time of last observation on 30th October, the cumulative area damaged (cm^2) was maximum (219.52) when 10 combs were stored followed by 9 (202.31) combs, 8 (190.00) and 7 combs (170.32). During all the observation from June to October, the area damaged per comb (cm^2) was maximum in case 10 combs were stored followed by 9, 8 and 7 comb storage.

During 2017, data in Table 4.13 also indicated that in case 7 combs were stored, the area damaged per comb (cm^2) was minimum at the time of first observation in mid June (9.68). In the following observations, the cumulative area damaged per frame increased till the end of September (174.15). In October, area damaged did not increased and was almost same as in the end of September. The area damaged per comb (cm^2) was 174.36 and 174.40 in mid October and end October, respectively. The pattern of damage during different months was same when 8, 9 and 10 combs were stored. At the time of first observation (mid June), the area damaged per comb (cm^2) was significantly higher when 10 combs were stored (20.43) than 9 (15.05), 8 (9.57) and 7 combs (9.68). At the time of last observation on 30th October, the cumulative area damaged (cm^2) was maximum (223.89) when 10 combs were stored followed by 9 (204.50) combs, 8 (200.16) and 7 combs (174.40). During all the observation from June to October, the area damaged per comb (cm^2) was maximum in case 10 combs were stored followed by 9, 8 and 7 comb storage.

Table 4.13. Comb area damaged by *G. mellonella* by storing different number of combs during June to October during 2016 and 2017

Number of combs stored	Cumulative comb area damaged per frame (cm^2) in 2016										Mean
	June		July		August		September		October		
	15.6.16	30.6.16	15.7.16	30.7.16	15.8.16	30.8.16	15.9.16	30.9.16	15.10.16	30.10.16	
7	8.60	12.90	20.43	40.85	96.75	107.50	144.05	169.85	170.28	170.32	**94.14**
8	10.75	19.35	25.80	58.05	101.05	122.55	169.85	189.20	189.41	190.00	**107.54**
9	12.90	21.50	32.25	79.55	118.25	141.90	180.60	202.10	202.31	202.31	**119.36**
10	19.35	23.65	38.70	133.30	139.75	161.25	193.50	219.30	219.51	219.52	**136.78**
Mean	**12.90**	**19.35**	**29.32**	**77.94**	**113.95**	**133.30**	**172.00**	**195.11**	**195.38**	**195.58**	**-**
Factors			**C.D.**			**SE(d)**			**SE(m)**		
Month			0.18			0.09			0.06		
Comb number			0.29			0.14			0.10		
Month × Comb number			0.59			0.29			0.20		
	Cumulative comb area damaged per frame (cm^2) in 2017										
7 Frame	9.68	13.98	21.50	43.00	101.05	109.65	148.35	174.15	174.36	174.40	**97.00**
8 Frame	9.57	19.89	27.95	60.20	105.35	126.85	172.00	199.95	200.16	200.16	**112.20**
9 Frame	15.05	22.58	33.33	81.70	122.55	146.20	182.75	204.25	204.46	204.50	**121.73**
10 Frame	20.43	24.73	39.78	135.45	141.90	167.70	197.80	223.60	223.81	223.89	**139.90**
Mean	**13.68**	**20.30**	**30.64**	**80.09**	**117.71**	**137.60**	**175.23**	**200.49**	**200.70**	**200.73**	**-**
Factors			**C.D.**			**SE(d)**			**SE(m)**		
Month			0.17			0.09			0.06		
Comb number			0.28			0.14			0.10		
Month × Comb number			0.57			0.28			0.20		

Each value represents mean of five observation

4.2.6. Correlation of weather parameters with comb area damaged by *G. mellonella by* storing different number of combs during June to October in the year 2016 and 2017

The damage caused by *G. mellonella* in the stored combs of different frames strength (4, 6, 8 and 10 frames) was recorded from June to October 2016 and 2017 in Table 4.14 indicated that the mean comb area damaged in all frame was recorded maximum in 30th September (195.11 cm^2 and 200.49 cm^2), whereas it was found to be comparatively lowest during first fortnight of June (12.90 cm^2 and 13.68 cm^2), respectively during the year 2016 and 2017. During 30th September (2nd fortnight of September), averages of weather parameters were recorded as maximum temperature (35.7°C), minimum temperature (24.60°C), maximum RH (87.10 %) minimum RH (51.30%) and number of bright sunshine hour (8.4 hour) and in first fortnight of June (15th June), average maximum temperature (41.10°C), minimum temperature (26.70°C), maximum RH (65.00%) minimum RH (35.90%) and number of bright sunshine hour (8.4 hour) recorded in year 2016 while in year 2017, during 2nd fortnight of September (30th September), average of weather parameters were as maximum temperature (35.41°C), minimum temperature (22.4°C), maximum RH (84.40%), minimum RH (36.5%) and number of bright sunshine hours (6.7 hour) and on first fortnight of June (15th June), average maximum temperature, minimum temperature, maximum RH, minimum RH and number of bright sunshine hour, *i.e.,* (39.90°C), (25.70°C), (67.92%), (34.71%) and (7.90), respectively.

The correlation study indicated significant positive correlation of comb area damage with maximum temperature (r = 0.703 and r = 0.704), maximum humidity (r= 0.227 and r= 0.222) and negatively non-significant with minimum temperature (r= -0.512 and r= -0.475) and minimum RH (r = -0.267 and r = -0.315), respectively in the year 2016 and 2017. Significant positive correlation were found in comb damage with maximum temperature in 8, 9 and 10 frame (r= 0.767, r= 0.792 and r= 0.820), maximum humidity (r= 0.222, r= 0.232 and r= 0.162) and negatively non significant with and minimum RH (r= -0.251, r= -0.258 and r = -0.240), respectively in year 2016 while in 2017, maximum temperature in 8, 9 and 10 frame (r = 0.767, r = 0.786 and r = 0.817), maximum humidity (r= 0.191, r= 206 and r= 0.144) and negatively non significant with minimum RH (r= -0.302, r= -0.290 and r= -0.267), respectively. There was no significant relation found with the comb damage and sunshine hours during both the year in 7, 8, 9 and 10 frame with (r= 0.130, r = 0.043, r = 0.006 and r= 0.023) and in year 2016 and (r= 0.134, r= 0.036, r= 0.003 and r= -0.023) in year 2017.

Table 4.14. Correlation of weather parameters with comb area damaged by *G. mellonella* by storing different number of combs during June to October 2016 and 2017

Number of combs stored in different years / Weather parameters	Number of combs stored/ hive body							
	2016				2017			
	7	8	9	10	7	8	9	10
Max. temp. (°C)	0.703*	0.767**	0.792**	0.820**	0.704*	0.767**	0.786**	0.817**
Min. temp. (°C)	-0.512	-0.604	-0.651	-0.688	-0.475	-0.565	-0.617	-0.659
Max. RH (%)	0.227**	0.222**	0.232**	0.162**	0.222**	0.191**	0.206**	0.144**
Min. RH (%)	-0.267	-0.251	-0.258	-0.240	-0.315	-0.302	-0.290	-0.267
Bright sunshine (hr)	0.130	0.043	0.006	0.023	0.134	0.036	0.003	-0.023

* Significant at 5% level of significance
** Significant at 1% level of significance

4.3. Effectiveness of different plant extracts against *Galleria mellonella* L. larvae.

Efficacy of 13 plants extracts belonging to nine families were tested in laboratory against *G. mellonella* used in this experiment (Table 4.15) to examine their effects on the larval, pupal mortality and emergence of adult wax moth, the details of which are given in Table 4.15.

Table 4.15. List of different plant extracts tested against *G. mellonella* in laboratory

Sr. No.	Common name	Scientific name	Family	Plant part used as extract
1.	**Isabgol**	*Plantago psyllium*	Plantaginaceae	Isabgol husk
2.	**Urad**	*Vigna mungo*	Leguminoceae	Leaves and Stem
3.	**Moong**	*Vigna radiata*	Leguminoceae	Leaves and Stem
4.	**Til**	*Sesamum indicum*	Pedaliaceae	Leaves and Stem
5.	**Alsi**	*Linum usitatissimum*	Linaceae	Leaves and Seed
6.	**Barley**	*Hordeum sativum*	Gramineae	Leaves and Stem
7.	**Pea**	*Pisum sativum*	Fabaceae	Leaves and Stem
8.	**Chickpea**	*Cicer arietinum*	Fabaceae	Leaves and Stem
9.	**Garden vetch**	*Vicia sativa*	Fabaceae	Leaves and Stem
10.	**Pumpkin**	*Cucurbita moschata*	Cucurbitaceae	Leaves and Seed
11.	**Mustard**	*Brassica juncea*	Brassicaceae	Leaves and Stem
12.	**Raddish**	*Raphanus sativus*	Brassicaceae	Leaves and Root
13.	**French bean**	*Phaseolus vulgaris*	Fabaceae	Leaves and Stem

4.3. Effectiveness of different plant extracts against *G. mellonella*

Data on effectiveness of different plant extracts against *G. mellonella* in laboratory are given in Table 4.16. Data in Table 4.16 revealed that maximum larval mortality (%) was recorded in case of *Plantago psyllium* husk (93.33) followed by *Hordeum sativum* leaves and

Raphanus sativus stem (80.00), *H. sativum* stem and *Raphanus sativus* leaves (73.33), *Linum usitatissimum* seed (66.66), *Cucurbita moschata* seed (60.00), *L. usitatissimum* leaves (53.33), *Vicia sativa* leaves and *C. moschata* leaves (46.66) and *L. usitatissimum* seed (66.66) *Vicia sativa* stem (40.00). Among 25 different extracts, 14 could not cause any larval mortality i.e. were not effective against larvae (0.00% mortality) and were at par with control (0.00% mortality). Among the plant extracts, which could result mortality in larval stages are *P. psyllium* husk, *L. usitatissimum* leaves, *L. usitatissimum* seed, *H. sativum* leaves, *H. sativum* stem, *V. sativa* leaves, *V. sativa* stem, *C. moschata* leaves, *C. moschata* seed, *R. sativus* leaves, *R. sativus* stem. No larval mortality (0.00%) was recorded in *Vigna radiata* leaves, *V. radiata* stem, *V. mungo* leaves, *V. mungo* stem, *S. indicum* leaves, *S. indicum* stem *Pisum sativum* leaves and *P. sativum* stem, *C. arietinum* leaves, *C. arietinum* stem, *P. vulgaris* leaves and *P. vulgaris* stem. The larval mortality in case of extract of *L. usitatissimum* leaves, *V. sativa* leaves, *V. sativa* stem, *C. moschata* leaves and *C. moschata* seed was at par but significantly higher than control.

Data on pupal mortality (%) in Table 4.16 revealed that out of 25 extract, 19 could not cause any mortality in pupal stage (0.00) and were at par with control (0.00). Among the plant extract which could cause pupal mortality; the pupal mortality (%) was observed due to *C. arietinum* leaves (46.66) followed by *C. arietinum* stem (26.66), *V. sativa* leaves (20.00), *L. usitatissimum* seed (13.33), *H. sativum* leaves (6.66) and *P. vulgaris* (6.66). Pupal mortality was significanly higher in case of *C. arietinum* leaves, *C. arietinum* stem, *Vicia sativa* leaves and L. *usitatissimum* seed extract as compare to control. However, pupal mortality in case of *H. sativum* leaves and *P. vulgaris* leaves was at par with control.

Data on adult emergence (%) in Table 4.16 indicated that out of 25 extracts, 11 extracts were not effective i.e. there was 100% adult emergence in those extracts and emergence was at par with control (100%). *P. psyllium* husk extract was most effective resulting in only 6.66 per cent adult emergence followed by *H. sativum* leaves (13.33%), *L. usitatissimum* seed and *R. sativus* stem (20.00%), *H. sativum* stem and *R. sativus* leaves (26.66%), *V. sativa* leaves (33.33%), *C. moschata* seed (40.00%), *L. usitatissimum* leaves (46.66%), *C. arietinum* leaves and *C. moschata* leaves (53.33%), *V. sativa* stem (60.00%), *C. arietinum* stem (73.33%), *V. sativa* leaves and *P.vulgaris* leaves (93.33%).

On the whole data in table 4.16, this can be concluded that 11 plant extract resulted in significantly higher larval mortality than control; six plant extract could cause pupal mortality but only 4 could cause significantly higher pupal mortality than control. Considering all the three parameters collectively (larval mortality, pupal mortality and adult emergence), it could be concluded that 11 plant extracts namely, *V. radiata* leaves, *V. radiata* stem, *V. mungo* leaves, *V. mungo* stem, *S. indicum* leaves, *S. indicum* stem, *P. sativum* leaves, *S. indicum* stem, *B. juncea* leaves, *B. juncea* stem and *P. vulgaris* stem were not effective against *G.*

mellonella. Among the 14 effective extract, *P. psyllium* husk extract was most effective followed by *H. sativum* leaves*, L. usitatissimum* seed and *R. sativus* stem, *H. sativum* stem and *R. sativus* leaves, *V. sativa* leaves, *C. moschata* seed, *L. usitatissimum* leaves*, C. arietinum* leaves, *C. moschata* leaves, *V. sativa* stem, *C. arietinum* stem and *P. vulgaris* leaves (least effective).

Table 4.16. Effectiveness of different plant extracts against *G. mellonella* in laboratory conditions.

Sr. No.	Plant extract	Larval mortality (%)	Pupal mortality (%)	Adult emergence (%)
1	*Plantago psyllium*	93.33 (81.13)	0.00 (0.00)	6.66 (8.85)
2	*Vigna radiata* leaves	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
3	*Vigna radiata* stem	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
4	*Vigna mungo* leaves	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
5	*Vigna mungo* stem	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
6	*Sesamum indicum* leaves	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
7	*Sesamum indicum* stem	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
8	*Linum usitatissimum* leaves	53.33 (46.90)	0.00 (0.00)	46.66 (43.06)
9	*Linum usitatissimum* seed	66.66 (54.96)	13.33 (17.70)	20.00 (26.55)
10	*Hordeum sativum* leaves	80.00 (68.05)	6.66 (8.85)	13.33 (13.07)
11	*Hordeum sativum* stem	73.33 (59.18)	0.00 (0.00)	26.66 (30.77)
12	*Pisum sativum* leaves	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
13	*Pisum sativum* stem	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
14	*Cicer arietinum* leaves	0.00 (0.00)	46.66 (43.06)	53.33 (46.90)
15	*Cicer arietinum* stem	0.00 (0.00)	26.66 (30.77)	73.33 (59.18)
16	*Vicia sativa* leaves	46.66 (43.06)	20.00 (26.55)	33.33 (34.61)
17	*Vicia sativa* stem	40.00 (39.21)	0.00 (0.00)	60.00 (50.74)
18	*Cucurbita moschata* leaves	46.66 (43.06)	0.00 (0.00)	53.33 (46.90)
19	*Cucurbita moschata* seed	60 (51.12)	0.00 (0.00)	40.00 (38.83)
20	*Brassica juncea* leaves	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
21	*Brassica juncea* stem	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
22	*Raphanus sativus* leaves	73.33 (59.18)	0.00 (0.00)	26.66 (30.77)
23	*Raphanus sativus* stem	80.00 (68.05)	0.00 (0.00)	20.00 (26.55)
24	*Phaseolus vulgaris* leaves	0.00 (0.00)	6.66 (8.85)	93.33 (81.13)
25	*Phaseolus vulgaris* stem	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
26	Control	0.00 (0.00)	0.00 (0.00)	100.00 (90.00)
C.D.		13.61	12.86	15.25
SE(m)		4.78	4.51	5.35
SE(d)		6.76	6.38	7.57
C.V.		35.08	103.84	15.06

Each value represents mean of three observations
Figures in parentheses are angular root transformed value

4.4. Effectiveness of different chemical and non-chemical treatments against *G. mellonella* in stored combs

Effectiveness of different treatments against *G. mellonella* in raised stored combs and per cent infested comb area was studied for two years 2016 and 2017 during June to October. The treatment details are given below in Table 4.17.

Table 4.17. Chemical and non chemical treatment details for management of *G. mellonella* in stored combs

Sr. No.	Treatment	Concentration
T_1	Acetic acid spray	80%
T_2	Formic acid spray	85%
T_3	Aluminium phosphide fumigation	1 tablet (3g)
T_4	Low temperature treatment	0, -5°C, -10°C and -15°C
T_5	Hive chambers separation with newspaper	One newspaper
T_6	Separation of combs with newspapers	One frame covered in each newspaper
T_7	Neem oil spray	3%
T_8	Broadcasting neem leaves powder	40g
T_9	NSKE spray	5%
$T1_0$	*Bt var. kurstaki* spray	5%
T_{11}	Control	No spray

4.4.1. Effect of different treatments on *G. mellonella* infestation in raised combs under storage conditions during June to October, 2016

Data on the effect of different treatments on *G. mellonella* infestation in raised combs under storage conditions during June to October, 2016 are presented in Table 4.18. Data in table 4.18 indicated that at the time of first observation (15 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 169.85 in control. The most effective treatment was low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage(cm^2) was 0.00, 0.52, 6.45, 9.68, 21.50, 32.25, 49.45, 58.05, 70.95, 79.55 and 111.80, respectively. At this time, the comb area damaged was 169.85 cm^2 in control. At the time of second observation (30 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 365.50 in control. The most effective treatment was low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, acetic acid spray, formic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was

0.00, 0.75, 6.99, 9.68, 33.33, 40.85, 45.15, 55.90, 59.13, 94.60, 103.20 and 208.55, respectively. At this time, the comb area damaged was 365.50 cm^2 in control. At the time of third observation (45 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 989.00 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, formic acid spray, NSKE spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.45, 0.75, 7.53, 10.75, 64.50, 77.40,79.55, 86.00, 94.60, 129.00, 210.70 and 763.25, respectively. At this time, the comb area damaged was 989.00 cm^2 in control. At the time of fourth observation (60 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 1290.00 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, formic acid spray, NSKE spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.53, 0.88, 8.06, 11.28, 94.60, 129.00, 131.15, 132.23, 144.05, 646.08, 935.25 and 1139.50, respectively. At this time, the comb area damaged was 1290.00 cm^2 in control. At the time of fifth observation (75 DAT), the average area damaged per comb (cm^2) ranged from 0.21 in low temperature treatment (-15°C) to 1472.75 in control.

The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.21, 0.53, 1.01, 8.60, 12.90, 133.30, 137.60,154.80, 173.07, 187.05, 741.75, 1085.75 and 1247.00, respectively. At this time, the comb area damaged was 1472.75 cm^2 in control. At the time of sixth observation (90 DAT), the average area damaged per comb (cm^2) ranged from 0.32 in low temperature treatment (-15°C) to 1526.50 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.32, 0.54, 1.07, 10.75, 13.97, 139.75,154.80,161.25, 182.75, 199.95, 864.65, 1154.55 and 1552.30, respectively. At this time, the comb area damaged was 1526.50 cm^2 in control.

Table 4.18. Effect of different treatments on *Galleria mellonella* infestation in raised combs under storage conditions during June to October, 2016

Sr. No.	Treatments	Average area infested per comb (cm^2)										Mean
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT	135 DAT	150 DAT	
T_1	**Acetic acid spray**	49.45	55.90	94.60	144.05	187.05	199.95	219.30	247.25	337.55	369.80	**190.49**
T_2	**Formic acid spray**	58.05	59.13	79.55	131.15	173.07	182.75	197.80	225.75	322.50	346.15	**177.59**
T_3	**Aluminium phosphide fumigation**	9.68	9.68	10.75	11.28	12.90	13.97	17.20	18.28	19.35	23.65	**14.67**
T_4	**Low temperature treatment 0°C**	6.45	6.99	7.53	8.06	8.60	10.75	10.75	11.82	11.83	12.90	**9.57**
	Low temperature treatment -5°C	0.52	0.75	0.79	0.88	1.01	1.07	1.61	2.15	3.23	4.30	**1.63**
	Low temperature treatment -10°C	0.00	0.00	0.45	0.53	0.53	0.54	0.75	1.07	1.61	1.61	**0.71**
	Low temperature treatment -15°C	0.00	0.00	0.00	0.00	0.21	0.32	0.32	0.54	1.07	1.08	**0.35**
T_5	**Hive chambers Separation with newspaper**	79.55	94.60	129.00	935.25	1085.75	1154.55	1231.95	1290.00	1502.85	1599.60	**910.31**
T_6	**Separation of combs with newspapers**	32.25	45.15	64.50	94.60	137.60	154.80	180.60	187.05	197.80	208.55	**130.29**
T_7	**Neem oil spray**	70.95	103.20	210.70	646.08	741.75	864.25	1285.70	1343.75	1464.15	1586.70	**831.72**
T_8	**Broadcasting neem leaves powder**	111.80	208.55	763.25	1139.50	1247.00	1552.30	1599.60	1599.60	1599.60	1599.62	**1142.09**
T_9	**NSKE spray**	38.70	40.85	86.00	132.23	154.80	161.25	169.85	176.30	223.60	240.80	**142.44**
T_{10}	***Bt var. kurstaki* spray**	21.50	33.33	77.40	129.00	133.30	139.75	154.80	167.70	180.60	197.80	**123.52**
T_{11}	**Control**	169.85	365.50	989.00	1290.00	1472.75	1526.50	1599.60	1599.60	1599.60	1599.60	**1221.21**
	Mean	**46.34**	**73.12**	**179.54**	**333.04**	**382.59**	**425.91**	**476.42**	**490.78**	**533.24**	**556.24**	
	Factor	**CD**				**SE(d)**				**SE(m)**		
	Treatment	5.20				2.64				1.86		
	Time	4.40				2.23				1.58		
	Treatment × Time	16.45				8.40				5.91		

Each value represents mean of three observations

* DAT= Days after first treatment

At the time of seventh observation (105 DAT), the average area damaged per comb (cm^2) ranged from 0.32 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.32, 0.75, 1.61,10.75, 17.20, 154.80, 169.85, 180.60, 197.80, 219.30, 1285.70 and1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of eighth observation (120 DAT), the average area damaged per comb (cm^2) ranged from 0.54 in low temperature treatment (-15°C) to 1599.60 in control.

The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.54, 1.07, 2.15, 11.82, 19.35, 167.70, 176.30,187.05, 1290.00 and1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of ninth observation (135 DAT), the average area damaged per comb (cm^2) ranged from 1.07 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 1.07, 1.61, 3.23, 11.83, 19.35, 180.60, 197.80, 322.50, 377.55, 1502.85 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of last observation (150 DAT) i.e. end of the experiment, the average area damaged per comb (cm^2) ranged from 1.08 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 1.08, 1.61, 4.30,12.90, 23.65, 197.80, 208.55, 240.80, 346.15, 369.80 1586.70, 1599.60 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. From the above observations, it can be concluded that the order of effectiveness of treatment

was the low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder.

4.4.2. Per cent area infestation in raised combs in different treatments against *G. mellonella* under storage conditions during June to October, 2016

Per cent area infestations in raised combs in different treatments against *G. mellonella* under storage conditions during June to October, 2016 are presented in Table 4.19. Data in table 4.19 indicated that at the time of first observation (15 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 10.61 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, Separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb infested area (%) was 0.00, 0.01, 0.40, 0.60, 1.34, 2.01, 2.41, 3.09, 3.62,4.43, 4.97 and 6.98, respectively. At this time, the comb area infestation (%) was highest (10.61) in control. At the time of second observation (30 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 22.84 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, acetic acid spray, formic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb infested area (%) was 0.00, 0.03, 0.43, 2.08, 2.55, 2.82, 3.49, 3.69, 5.91, 6.45 and 13, respectively. At this time, the comb area infestation (%) was highest (22.84) in control.

At the time of third observation (45 DAT), the per cent area infestation per comb (%) ranged from 0.00 low temperature treatment (-15°C) to16.81 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, formic acid spray, NSKE spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.00, 0.02, 0.04, 0.47, 0.67, 4.03, 4.84, 4.97, 5.57, 5.91, 8.06 and 13.17, respectively. At this time, the comb area infestation (%) was highest (16.81) in control. At the time of fourth observation (60 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C) to 80.62 in control.

Table 4.19. Per cent area infestation in raised combs in different treatments against *G. mellonella* under storage conditions during June to October, 2016

Sr. No.	Treatments	Area infested per comb (%)										Mean
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT	135 DAT	150 DAT	
T_1	**Acetic acid spray**	3.09	3.49	5.91	9.00	11.69	12.49	13.70	15.45	21.09	23.11	**11.90**
T_2	**Formic acid spray**	3.62	3.69	4.97	8.19	10.81	11.42	12.36	14.10	20.15	21.63	**11.09**
T_3	**Aluminium phosphide fumigation**	0.60	0.60	0.67	0.70	0.80	0.87	1.08	1.14	1.20	1.47	**0.91**
T_4	**Low temperature treatment 0 °C**	0.40	0.43	0.47	0.50	0.53	0.67	0.67	0.73	0.73	0.80	**0.59**
	Low temperature treatment -5°C	0.01	0.03	0.04	0.04	0.05	0.06	0.06	0.13	0.20	0.26	**0.09**
	Low temperature treatment -10°C	0.00	0.00	0.02	0.03	0.03	0.03	0.04	0.06	0.10	0.10	**0.04**
	Low temperature treatment -15°C	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.06	0.06	**0.02**
T_5	**Hive chambers Separation with newspaper**	4.97	5.91	8.06	58.45	67.85	72.15	76.99	80.62	93.92	99.97	**56.89**
T_6	**Separation of combs with newspapers**	2.01	2.82	4.03	5.91	8.60	9.67	11.28	11.69	12.36	13.03	**8.14**
T_7	**Neem oil spray**	4.43	6.45	13.17	40.38	46.35	54.01	80.35	83.98	91.50	99.16	**51.98**
T_8	**Broadcasting neem leaves powder**	6.98	13.03	47.70	71.21	77.93	97.01	99.97	99.97	99.97	99.97	**71.37**
T_9	**NSKE spray**	2.41	2.55	5.57	8.26	9.76	10.07	10.61	11.01	13.97	15.05	**8.93**
T_{10}	***Bt var. kurstaki* spray**	1.34	2.08	4.84	8.06	8.33	8.73	9.67	10.48	11.28	12.36	**7.72**
T_{11}	**Control**	10.61	22.84	61.81	80.62	92.04	95.40	99.97	99.97	99.97	99.97	**76.32**
Mean		**2.89**	**4.56**	**11.23**	**20.81**	**23.91**	**26.61**	**29.76**	**30.66**	**33.32**	**34.78**	

Each value represents mean of three observations

The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, formic acid spray, NSKE spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.00, 0.03, 0.04, 0.50, 0.70, 5.91, 8.06, 8.19, 8.26, 9.00, 40.38, 58.45 and 71.21, respectively. At this time, the comb area infestation (%) was highest (80.62) in control. At the time of fifth observation (75 DAT), the per cent area infestation per comb (%) ranged from 0.01 in low temperature treatment (-15°C) to 92.04 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.01, 0.03, 0.05, 0.53, 0.80, 8.33, 8.60, 9.76, 10.81, 11.69, 46.35, 67.85 and 77.93, respectively. At this time, the comb area infestation (%) was highest (80.62) in control. At the time of sixth observation (90 DAT), the per cent area infestation per comb (%) ranged from 0.02 in low temperature treatment (-15°C) to 95.40 in control.

The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.02, 0.03, 0.06, 0.67, 0.87, 8.73, 9.67, 10.07,11.42,12.49 and 97.01, respectively. At this time, the comb area infestation (%) was highest (95.40) in control. At the time of seventh observation (105 DAT), the per cent area infestation per comb (%) ranged from 0.02 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.02, 0.04, 0.06, 0.67, 1.08, 9.67, 10.61, 11.28, 12.36, 13.70, 76.99, 80.35 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of eighth observation (120 DAT), the per cent area infestation per comb (%) ranged from 0.54 in low temperature treatment

(-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.03, 0.06, 0.13, 0.73, 1.14, 10.48, 11.01, 11.69, 14.10, 15.45, 80.62, 83.98 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of ninth observation (135 DAT), the per cent area infestation per comb (%) ranged from 0.06 in low temperature treatment (-15°C) to 99.97 in control.

The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.06, 0.10, 0.20, 0.73, 1.20, 11.28, 12.36, 13.97, 20.15, 21.09, 91.50, 93.92 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of last observation (150 DAT) i.e. end of the experiment, the per cent area infestation per comb (%) ranged from 0.06 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of was low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.06, 0.10, 0.26, 0.80, 1.47, 12.36, 13.03, 15.05, 21.63, 23.11, 99.16, 99.97 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. From the above observations, it can be concluded that the order of per cent infested area in raised combs was the low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder.

4.4.3. Effect of different treatments on *G. mellonella* infestation in raised combs under storage conditions during June to October, 2017

Data on the effect of different treatments on *G. mellonella* infestation in raised combs under storage conditions during June to October, 2017 are presented in Table 4.20. Data in table 4.20 indicated that at the time of first observation (15 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 170.38 in control. The most effective treatment was low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, Separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.51, 6.45, 8.60, 22.03, 32.78, 39.77, 51.60, 59.66, 72.02, 80.62 and 170.38, respectively. At this time, the comb area damaged was 170.38 cm^2 in control. At the time of second observation (30 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 371.95 in control.

The most effective treatment was low temperature treatment (-15°C), followed by low temperature treatment (-10°C), low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, Acetic acid spray, formic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.43, 0.52, 6.99, 9.14, 38.16, 51.68, 52.68, 56.98, 60.74, 96.75, 108.58 and 218.76, respectively. At this time, the comb area damaged was 371.95 cm^2 in control. At the time of third observation (45 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 1010.50 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, formic acid spray, *Bt* spray, NSKE spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.43, 0.75, 7.53, 10.21, 65.04, 81.70, 87.61, 89.69, 95.14, 131.15, 217.15 and 786.90, respectively. At this time, the comb area damaged was 1010.50 cm^2 in control. At the time of fourth observation (60 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 1294.30 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting

Table 4.20. Effect of different treatments on *Galleria mellonella* infestation in raised combs under storage conditions during June to October, 2017

Sr. No	Treatments	Average area infested per comb (cm^2)										Mean
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT	135 DAT	150 DAT	
T_1	**Acetic acid spray**	51.60	56.98	95.14	146.20	191.35	234.35	258.00	267.35	402.05	449.35	**215.37**
T_2	**Formic acid spray**	59.66	60.74	81.70	141.90	178.45	189.20	202.12	227.90	339.70	354.75	**183.61**
T_3	**Aluminium phosphide fumigation**	8.60	9.14	10.21	10.96	12.90	13.43	17.73	18.81	19.89	23.11	**14.47**
T_4	**Low temperature treatment 0°C**	6.45	6.99	7.53	8.06	9.13	10.75	10.75	11.29	11.82	11.83	**9.46**
	Low temperature treatment -5°C	0.51	0.52	0.75	0.86	0.96	1.03	1.55	2.04	3.16	3.76	**1.51**
	Low temperature treatment -10°C	0.00	0.43	0.43	0.43	0.43	0.43	0.52	1.07	1.51	1.61	**0.68**
	Low temperature treatment -15°C	0.00	0.00	0.00	0.00	0.32	0.32	0.54	0.54	0.86	1.08	**0.36**
T_5	**Hive chambers Separation with newspaper**	80.62	96.75	131.15	956.75	1107.25	1176.05	1244.85	1298.60	1524.35	1599.60	**921.59**
T_6	**Separation of combs with newspapers**	32.78	51.60	65.04	95.68	141.90	156.95	182.75	191.35	219.30	236.50	**137.38**
T_7	**Neem oil spray**	72.02	108.58	217.15	685.85	789.05	894.40	1296.45	1353.35	1472.75	1595.30	**848.49**
T_8	**Broadcasting neem leaves powder**	126.85	218.76	786.90	1143.80	1272.80	1566.60	1599.60	1599.60	1599.60	1599.60	**1151.41**
T_9	**NSKE spray**	39.77	52.68	89.69	134.38	163.40	169.85	180.60	225.75	237.62	238.65	**153.23**
T_{10}	***Bt var. kurstaki* spray**	22.03	38.16	87.61	126.85	135.45	144.05	153.72	160.17	172.00	198.88	**123.89**
T_{11}	**Control**	170.38	371.95	1010.50	1294.30	1599.60	1599.60	1599.60	1599.60	1599.62	1599.60	**1244.47**
Mean		**47.94**	**76.66**	**184.55**	**339.00**	**400.21**	**439.78**	**482.05**	**496.95**	**543.15**	**565.25**	

Factor	CD	SE(d)	SE(m)
Treatment	4.21	2.14	1.51
Time	3.55	1.81	1.28
Treatment × Time	13.31	6.77	4.78

Each value represents mean of three observations

* DAT= Days after first treatment

neem leaves powder where the comb area damage (cm^2) was 0.00, 0.43, 0.86, 8.06, 10.96, 95.68, 126.85, 134.38, 141.90, 146.20, 685.85, 956.75 and 1143.80, respectively. At this time, the comb area damaged was 1294.30 cm^2 in control. At the time of fifth observation (75 DAT), the average area damaged per comb (cm^2) ranged from 0.21 in low temperature treatment (-15°C) to 1472.75 in control. The most effective treatment was low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.32, 0.43, 0.96, 9.13, 12.90, 135.45, 141.90, 163.40, 178.45, 191.35, 789.05, 1107.25 and 1272.80, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of sixth observation (90 DAT), the average area damaged per comb (cm^2) ranged from 0.32 in low temperature treatment (-15°C) to 1599.60 in control.

The most effective treatment was in low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.32, 0.43, 1.03, 10.75, 13.43, 144.05, 156.95, 169.85, 189.20, 234.35, 894.40, 1176.05 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of seventh observation (105 DAT), the average area damaged per comb (cm^2) ranged from 0.52 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray, and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.52, 0.52, 1.55, 10.75, 17.73, 153.72, 180.60, 182.75, 201.12, 258.00, 1244.85, 1296.45 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of eighth observation (120 DAT), the average area damaged per comb (cm^2) ranged from 0.54 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area

damage (cm^2) was 0.54, 1.07, 2.04, 11.29, 18.81, 160.17, 191.35, 225.75, 227.90, 267.35, 1298.60, 1353.35 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control.

At the time of ninth observation (135 DAT), the average area damaged per comb (cm^2) ranged from 0.86 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.86, 1.51,3.16,11.82, 19.89, 172.00, 219.30, 237.62, 339.70, 402.05, 1472.75, 1524.35 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of last observation (150 DAT) i.e. end of the experiment, the average area damaged per comb (cm^2) ranged from 1.08 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 1.08, 1.61, 3.76, 11.83, 23.11, 198.88, 236.50, 238.65, 354.75, 449.35, 1595.30, 1599.60 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. From the above observations, it can be concluded that the order of effectiveness of treatment was the low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder.

4.4.4. Per cent area infestation in raised combs in different treatments against *G. mellonella* under storage conditions during June to October, 2017

Per cent area infestations in raised combs in different treatments against *G. mellonella* under storage conditions during June to October, 2017 are presented in Table 4.21. Data in table 4.21 indicated that at the time of first observation (15 DAT), the per cent area infestation per comb (%) ranged from 0.00 low temperature treatment (-15°C, -10°C) to 10.64 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, Separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, neem oil spray, hive chamber separation

with newspaper and broadcasting neem leaves powder where the comb infested area (%) was 0.00, 0.03, 0.40, 0.53, 1.37, 2.01, 2.04, 2.48, 3.22, 3.72, 4.50, 5.03, 7.92, respectively. At this time, the comb area infestation (%) was highest (10.64) in control. At the time of second observation (30 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C) to 23.24 in control.

The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C), low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.00, 0.02, 0.03, 0.43, 0.57, 2.38, 3.22, 3.29, 3.56, 3.79, 6.04, 6.78 and 13.67, respectively. At this time, the comb area infestation (%) was highest (23.24) in control. At the time of third observation (45 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C) to 63.15 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, formic acid spray, *Bt* spray, NSKE spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the the comb area damage (%) was 0.00, 0.02, 0.04, 0.47, 0.63, 4.06, 5.10, 5.47, 5.60, 5.94, 8.19, 13.57 and 49.18, respectively. At this time, the comb area infestation (%) was highest (23.24) in control.

At the time of fourth observation (60 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C) to 80.89 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.00, 0.02, 0.05, 0.50, 0.68, 5.98, 7.92, 8.39, 8.86, 9.13, 42.86, 59.79 and 71.48 respectively. At this time, the comb area infestation (%) was highest (80.89) in control. At the time of fifth observation (75 DAT), the per cent area infestation per comb (%) ranged from 0.02 in low temperature treatment (-15°C) to 99.97 in control.

The lowest comb area infestation (%) was observed in case of low temperature treatment (15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide

Table 4.21. Per cent area infestation in raised combs in different treatments against *G. mellonella* under storage conditions during June to October, 2017

Sr. No.	Treatments	Area infested per comb (%)										Mean
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT	135 DAT	150 DAT	
T_1	**Acetic acid spray**	3.22	3.56	5.94	9.13	11.95	14.64	16.12	16.70	25.12	28.08	**13.45**
T_2	**Formic acid spray**	3.72	3.79	5.10	8.86	11.15	11.82	12.63	14.24	21.23	22.17	**11.47**
T_3	**Aluminium phosphide fumigation**	0.53	0.57	0.63	0.68	0.80	0.83	1.10	1.17	1.24	1.44	**0.90**
T_4	**Low temperature treatment 0°C**	0.40	0.43	0.47	0.50	0.57	0.66	0.67	0.70	0.70	0.73	**0.58**
	Low temperature treatment -5°C	0.03	0.03	0.04	0.05	0.06	0.06	0.09	0.12	0.19	0.23	**0.09**
	Low temperature treatment -10°C	0.00	0.02	0.02	0.02	0.02	0.02	0.03	0.06	0.09	0.10	**0.04**
	Low temperature treatment -15°C	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.03	0.05	0.06	**0.02**
T_5	**hive chambers Separation with newspapers**	5.03	6.04	8.19	59.79	69.20	73.50	77.80	81.16	95.27	99.97	**57.60**
T_6	**Separation of combs with newspapers**	2.04	3.22	4.06	5.98	8.86	9.80	11.42	11.95	13.70	14.48	**8.55**
T_7	**Neem oil spray**	4.50	6.78	13.57	42.86	49.31	55.90	81.02	84.58	92.04	99.70	**53.03**
T_8	**Broadcasting neem leaves powder**	7.92	13.67	49.18	71.48	79.55	97.91	99.97	99.97	99.97	99.97	**71.96**
T_9	**NSKE spray**	2.48	3.29	5.60	8.39	10.21	10.61	11.28	14.10	14.85	14.91	**9.57**
T_{10}	***Bt var. kurstaki* spray**	1.37	2.38	5.47	7.92	8.46	9.00	9.60	10.01	10.75	12.43	**7.74**
T_{11}	**Control**	10.64	23.24	63.15	80.89	99.97	99.97	99.97	99.97	99.97	99.97	**77.77**
	Mean	**2.99**	**4.78**	**11.53**	**21.18**	**25.00**	**27.48**	**30.12**	**31.05**	**33.94**	**35.30**	

Each value represents mean of three observations

fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.02, 0.02, 0.06, 0.66, 0.80, 8.46, 8.86,10.21, 11.15,11.95, 49.31, 69.20 and 79.55, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of sixth observation (90 DAT), the per cent area infestation per comb (%) ranged from 0.02 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.02, 0.02, 0.06, 0.66, 0.83, 9.00, 9.80, 10.61, 11.82, 14.64, 55.90, 73.50 and 97.91, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of seventh observation (105 DAT), the per cent area infestation per comb (%) ranged from 0.03 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment(-1 5°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray, and broadcasting neem leaves powder where the comb area damage (%) was 0.03, 0.03, 0.09, 0.67, 1.10, 9.60,11.28, 11.42, 12.63, 16.12, 77.80, 81.02 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of eighth observation (120 DAT), the per cent area infestation per comb (%) ranged from 0.04 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.04, 0.06, 0.12, 0.70, 1.17, 10.01, 11.95, 14.10, 14.24, 16.70, 81.16, 84.58 and 99.97 respectively. At this time, the comb area infestation (%) was highest (99.97) in control.

At the time of ninth observation (135 DAT), the per cent area infestation per comb (%) ranged from 0.05 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray,

separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the the comb area damage (%) was 0.05, 0.09, 0.19, 0.70, 1.24, 10.75, 13.70, 14.85, 21.23, 25.12, 92.04, 95.27 and 99.97 respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of last observation (150 DAT) i.e. end of the experiment, the per cent area infestation per comb (%) ranged from 0.06 in low temperature treatment (-15°C) to 99.97 in control.

The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the the comb area damage (cm^2) was 0.06, 0.10, 0.23, 0.73, 1.44,14.48, 14.91, 22.17, 28.08, 99.70, 99.97 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. From the above observations, it can be concluded that the order of per cent infested area in raised comb was the low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder.

CHAPTER- V

DISCUSSION

The results of the present investigation entitled "Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs" are discussed under the following headings:

5.1.1. Seasonal incidence of greater wax moth, *G. mellonella* in *A. mellifera* colonies with different bees strength during year 2015-16 and 2016-17

5.1.2. Correlation between weather parameters and Greater wax moth, *G. mellonella* incidence in *A. mellifera* colonies

5.1.3. Comb area damaged by *G. Mellonella* larvae

5.1.4. Correlation between weather parameters and comb area damage

5.2.1. Seasonal incidence of greater wax moth, *G. mellonella* in stored combs during June to October 2016 and 2017

5.2.2. Correlation between weather parameters and Greater wax moth (*G. mellonella*) incidence in stored comb

5.2.3. Effects of different comb frame strength on comb area damaged by *G. mellonella*

5.2.4. Correlation of weather parameters with comb area damaged in stored combs

5.3. Effectiveness of different plant extracts against *G. mellonella* L. larvae

5.4. Effectiveness of different chemical and non-chemical treatments against *G. mellonella* in stored combs

5.1.1.1. Population of Greater wax moth, *G. mellonella* in *A. mellifera* colonies with 4-frame bees strength during 2015-16 and 2016-17

Data revealed that in 4- frames bees strength colonies, the population of wax moth (larval, pupal as well as adult) varied during different months during 2015-16 and 2016-17. During both the years, population of greater wax moth (larval, pupal as well as adult) started increasing from April and increased till July, thereafter (from August) the population started declining and declined till March. During 2015-16, the highest larval population (13.60) was recorded in the month of July followed by June (13.00), August (12.40), September (11.20), May (9.60), October (9.00), November (7.00), December (6.60), January (5.80) and April (4.00) while the lowest population of larvae was in March (3.00) and February (3.20). The highest (10.60) number of pupae were recorded in the month of July followed by June (10.00), August (9.80), September (8.80), May (7.40), October (7.40), November (5.40), December (5.20), January (5.00) and April (3.80) while lowest number of pupae were in March (2.80) and February (3.00). Highest number of adults (8.60) were recorded in the month of June followed by July (8.00), August (7.60), September and May (6.60), October (6.00), November (4.00),

December (3.60), April (3.60) and January (3.40) which significantly differed from the lowest population of adult in March (2.60) and February (2.80).

During 2016-17, the maximum larval population (13.40) was recorded in the month of July followed by June (12.60), August (11.80), September (11.00), May (9.00), October (8.80), November (6.60), December (6.00), January (5.60) and April (3.80) while the minimum population of larvae were recorded in the month of March (2.80) which was at par with the population in February (3.00). The maximum number of pupae (10.60) were recorded in the month of July followed by June (10.00), August (9.80), September (8.60), October (7.40), May (7.20), November (5.20), December (5.00), January (4.60) and April (3.60) while minimum number of pupae were recorded in the month of March (2.40) which was at par with the population in February (3.00). Maximum (8.00) number of adult were recorded in the month of July followed by June (7.80), August (7.20), September (6.20), May (6.00), October (5.60), November (3.60), December and April (3.40) and January (3.20) while minimum population of adult was in March (2.40) and in February (2.60). Our data on the seasonal abundance of moth larvae were comparable to those of other studies conducted in India, indicating that a maximum infestation occurred during July to October, May to October and March to December respectively (Sharma *et al.*, 2011). Sohali *et al.* (2017) studied the seasonal abundance (No. moth larvae/hive) of *G. mellonella* larvae in hives of honey bees located in district Sargodha, Punjab, Pakistan and reported that the maximum moth abundance occurred during the regional dearth period, *i.e.,* May-November. The peak abundance (14.8 ± 3.9 moth larvae/hive) occurred in August. Earlier investigators reported that moth infestations occur in almost all times of the year due to overlapping generations of the wax moth (Garg and Kashyap, 1998; Hood *et al*., 2003). Usually, weak colonies succumb to moth damage first. The active period of this pest have been showed to occur from March to October in India (Garg and Kashyap, 1998) and can remain sustained in November (Brar *et al.,* 1985). In our study, maximum moth abundance occurred in July, August and September, likely owing to higher ambient temperatures during those months.

5.1.1.2. Population of Greater wax moth, *G. mellonella* in *A. mellifera* colonies with 6-frame bees strength during 2015-16 and 2016-17

During 2015-16, the highest larval population (12.40) was recorded in the month of July followed by August (12.00), June (11.80), September (10.00), May (8.20), October (8.00), November (6.00), December (5.80), January (5.40) and April (3.40) while the lowest population of larvae was recorded in the month of March (2.60) which was at par with the population in February (3.00). Highest number of pupae (8.80) were recorded in the month of July followed by June (8.40), August (8.00), September (7.40), May (6.80), October (6.60), November (4.60), December (4.40), January (4.00) and April (3.20) while lowest number of pupae were recorded in the month of March (2.40) which are at par with the population in

February (3.00). Highest number of adults (7.40) were recorded in the month of June and July followed by August (7.00), September (6.00), May (5.60), October (5.40), November (3.40), December and April (3.00) which significantly differed from the lowest population of adult in March (2.40), February (2.60) and January (2.80).

During 2016-17, the maximum larval population (12.20) was recorded in the month of July followed by August (11.60), June (11.40), September (9.60), May (8.00), October (7.60), November (5.80), December (5.60), January (5.20) and April (3.40) while the minimum population of larvae were in March (2.40) and February (2.80). The maximum number of pupae (8.40) were recorded in the month of July followed by June (8.20), August (7.60), September (7.20), October (6.60), May (6.60), November (4.40), December (4.20), January (3.80) and April (3.20) while the minimum number of pupae were recorded in the month of March (2.20) which was at par with the population in February (2.80). Maximum (7.20) number of adult were recorded in the month of July followed by June (7.00), August (6.80), September (5.60), May and October (5.20), April and November (3.20) which significantly differed from the minimum population of adult in March (2.00), February (2.40), January (2.60) and December (2.80). Mandal and Vishwakarma (2016) reported that the GWM egg clusters, larvae, pupae and adults per hive were 34.6, 86.00, 89.67 and 30.67 respectively, observed in the month of September, which is quite more than the other months of observations. The peak month observed as September, which lonely contributes about 32.00%, 37.28%, 37.78% and 22.01% out of total egg clusters, larvae, pupae and adults population observed during the experimental period, respectively. According to overall pupal population, the month September lonely contributed 37.78% population, while 5.62, 8.43, 17.70, 16.29, 8.29 and 5.90 per cent population were attained during the month of June, July, August, October, November and December, respectively. The mean number of GWM pupae in different months varied as June < July < August < September > October > November > December irrespective of the standard week and months both. According to the Viraktamath (1989), the overall prevalence of wax moth in modern bee hive was found to be 27.4%. The nature of severity was differentiated and categorized into three groups as 35%, 47% and 2% as light, moderate and severely affected respectively.

5.1.1.3. Population of Greater wax moth, *G. mellonella* in *A. mellifera* colonies with 8-frame bees strength during 2015-16 and 2016-17

During 2015-16 , the highest and similar larval population (8.80) was recorded in the month of June and July followed by May (7.60), August (7.20), September (7.20), October (6.20), November (3.80), December (3.60), January (3.20) and April (3.20) while the lowest population of larvae was recorded in the month of March (2.40) which was at par with the population in February (2.60). Highest and similar (8.00) number of pupae were recorded in the month of June and July followed by August (6.40), May (6.20), September (6.20),

October (5.60), November (3.40), December (3.20), January (3.00) and April (3.00) while lowest number of pupae were recorded in the February and March (3.00). Highest number of adults (7.00) were recorded in the month of July followed by June (6.80), August (6.40), September (5.40), May (5.00), October (4.80), April (3.00), November (2.60), December (2.40) and January (2.20) which significantly differed from the lowest and similar population of adult in March (2.00) and February (2.00).

During year 2016-17, the maximum larval population (8.20) was recorded in the month of July followed by June (8.00), May (7.00), August (7.00), September (6.80), October (6.00), November (3.80), December (3.40), January (3.20) and April (3.00) while the minimum and similar population of larvae were recorded in February and March (2.40). The maximum number of pupae (7.40) were recorded in the month of June followed by June (7.00), August (6.40), September (6.00), May (5.80), October (5.00) and November (3.00), December (2.80) and April (2.80) while the minimum number of pupae were recorded in March (2.20), February (2.40) and January (2.60) respectively. Maximum (6.00) number of adult were recorded in the month of August followed by September (5.20), June (5.00), July (5.00), October (4.40), May (3.80), November (2.40) December (2.20) and January (2.00) which significantly differed from the minimum population of adult in April (1.40), March (1.60) and February (1.80). Raghunandan and Basavarajappa (2014) reported that the normal colonies with a weak population were more prone to *G. mellonella* infestation and it was more in the semi-arid region during summer (30.8%) followed by a rainy season (23.4%). However, the infestation was less 11.0 and 6.6% during the summer and winter seasons respectively in malnad. The prevalence of *G. mellonella infestation* is common, however, the intensity was depended on colony strength and prevailing ecological conditions during various seasons at different region of South-Western Karnataka. The peak infestation was observed during July to September in the brood frames (Gupta, 1987).

5.1.1.4. Population of Greater wax moth *G. mellonella* in *A. mellifera* colonies with 10-frame bees strength during 2015-16 and 2016-17

During 2015-16, the highest larval population (4.20) was recorded in the month of July followed by August (3.60), June (3.20), September (3.20), October (3.00), November (2.40), December (2.20), May (1.80) and April (1.20) while the lowest population of larvae was recorded in January (0.60). Highest number (3.00) of pupae were recorded in the month of July followed by August (2.80), September (2.40), October (2.20), November (2.00), December (1.80), January (1.60), May (1.20) and April (1.00) while the negligible population (0.00) was in February and March. (3.00). Highest (1.80) number of adults were recorded in the month of July followed by August (1.60), September (1.40), June and October (1.20) and May (1.00) which significantly differed from the lowest population February (0.00), March (0.00), January (0.40), December (0.60), April (0.80) and November (0.80). There was no

population of wax moth (larval, pupal as well as adult) observed during February and March month of both years

During 2016-17, there was no population of wax moth observed during February and March. The highest larval population (4.00) was recorded in the month of July followed by August (3.20), June (3.00), September (3.00), October (2.80), November (2.20), December (2.00), and April (1.00) while the lowest population was recorded in January (0.40). Highest number (2.80) of pupae were recorded in the month of July followed by August (2.60), September (2.20), October (2.00) November (1.80), December (1.60), January (1.40), May (1.00) and April (0.80) while the negligible population (0.00) of pupa was in February and March. Maximum (1.60) number of adults were recorded in the month of July followed by August (1.40), September (1.20), May (1.00), June (1.00) October (1.00), April (0.60) and November (0.60) while minimum population of adults was in February (0.00), March (0.00), December (0.40) and January (0.40). Swamy (2008) reported that the incidence of *Galleria mellonella* was maximum in March (47.37%), followed by February (42.10%) and April (41.18%). Whereas it was found to be comparatively lower in July (11.76%) followed by June (15.38%) and August (16.67%). They also reported that the rate of infestation of greater wax moth was higher in the weaker colonies as compared to the stronger colonies. The strong colonies were completely free of the greater wax moth during October, June and July. However, the infestation was observed throughout the year in weaker colonies. These findings are in conformity with the explanation made by Earp (1925). Grout (1946) and Warren and Huddleston (1962) reported that the infestation of greater wax moth were observed throughout the year in the weaker colonies. Kumari and Jha (2013) observed the pest infestation in the hive as well as storage of raised combs and reported that the maximum area of infestation were found in the month of September (40.74, 42.93%) while the lowest in the month of June (3.42, 4.41 %) respectively in two years of 2011 and 2012. It might be due to the high temperature and humidity in the environment. Full covered frames with bee recorded least infestation. It might be due to the self-defence behaviour of worker bees.

5.1.2.1. Correlation between weather parameters and Greater wax moth, *G. mellonella* incidence in *A. mellifera* colonies with different bee frame strength during 2015-16

The correlation between greater wax moth and weather parameters revealed that in 4-frame bees strength colonies, the correlation between number of larvae and weather parameters were found positive and significant for minimum temperature and for maximum RH, positive and highly significant for minimum RH. Correlation did not exist between number of larvae and maximum temperature and of bright sunshine hours. The correlation between number of pupae and minimum RH was found positive and highly significant but correlation did not exist between pupae population and weather parameters as maximum

temperature, minimum temperature, maximum RH and of bright sunshine hours. The correlation between number of adults and weather parameters were found positive and significant for minimum temperature and positive and highly significant for minimum RH, however, no correlation existed between number of adults and weather parameters as maximum temperature, maximum RH and bright sunshine hour. In 6- frame bees strength, the correlation between number of larvae and weather parameters were found positive and highly significant for minimum temperature, for maximum RH, for minimum RH and negative and significant for bright sunshine hours, whereas correlation did not exist between larvae and maximum temperature. It was positive and highly significant for minimum temperature, maximum RH, minimum RH and negative and significant for bright sunshine hour, whereas no correlation existed between pupae and maximum temperature.

The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature, minimum RH, positive and significant maximum RH, whereas negative and significant for bright sunshine hour, however, correlation did not existed between adult and maximum temperature. In 8- frame bee strength, the correlation between number of larvae and weather parameters were found positive and highly significant for maximum temperature, for minimum RH and positive and significant for maximum RH whereas no correlation existed between number of larvae and maximum temperature and bright sunshine hours. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum and positive and significant for minimum temperature. Correlation did not exist between number of pupae and weather parameters such as maximum temperature, maximum RH and bright sunshine hours. The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature and for minimum RH, whereas correlation did not exist between number of adults and weather parameters as maximum temperature, maximum RH and bright sunshine hours. In 10- frames bees strength, the correlation between number of larvae and weather parameters was found positive and highly significant for minimum RH but no correlation existed between larval population and weather parameters for maximum temperature, minimum temperature, maximum RH and of bright sunshine hour. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH, whereas no correlation existed between number of pupae and maximum temperature, minimum temperature, maximum RH and bright sunshine hour. The correlation between number of adults and weather parameters were found positive and significant for minimum RH. Correlation also did not exist between adult and weather parameters as maximum temperature, minimum temperature, maximum RH and of bright sunshine hour. During the year 2015-16, the greater wax moth larva infested bee colonies throughout the year but population starts increasing from May and progressively to acquire

peak in July in 4, 6, 8 and l0- frame bees strength. During July, averages of weather parameters were recorded as maximum temperature (35.10°C), minimum temperature (26.10°C), maximum RH (90%), minimum RH (72%) and number of bright sunshine hour (5.9 hours) were recorded. During March, the averages of different weather parameters were recorded as maximum temperature (29.90°C), minimum temperature (13.70°C), maximum RH (88%), minimum RH (46 %) and number of bright sunshine hours (8.10 hours). Deosi *et al*. (2014) reported that wax moth occurrence remained in the colony through the year but its intensity increased in monsoon month and reached a peak during autumn season. When the colony strength decreases, wax moth infestation increased in the colony. Therefore, the bee Keeper should start regular pest management practice in the monsoon itself to prevent the infestation for further decrease. Weather may influence the physiology and behavior of an insect directly, leading to any number of phenotypical and population changes, or indirectly by influencing, for example, populations of natural enemies (Mendesil and Tesfaye, 2009; Kautz *et al.,* 2011).

Most insect populations are extremely sensitive to temperature fluctuations, with the rate of insect metabolism often doubling with every 10 °C increase in temperature (Gillooly *et al*., 2001; Clarke and Fraser, 2004). This would not be the case for wax moths, though, as they live in hives where honey bees tightly control the minimum/maximum hive temperature, especially in the brood nest area. Instead, weather may influence host (bee) biology such that ambient temperatures produce conditions in the hives that favor the moth abundance. Swamy (2008) reported that the rate of infestation of greater wax moth was higher in the weaker colonies as compared to the stronger ones. The strong colonies were completely free from the greater wax moth during October, June and July. However, the infestation was observed throughout the year in weaker colonies. These findings are in conformity with the observations made by Earp (1925); Grout (1946) and Warren and Huddleston (1962) where they reported that the infestation of greater wax moth was observed throughout the year in the weaker colonies.

5.1.2.2. Correlation coefficient between weather parameters and greater wax moth (*G. mellonella*) incidence in *A. mellifera* colonies with different frame strength during the year 2016-17

The correlation coefficients worked out between greater wax moth incidence and weather parameters indicated that in 4-frame bees strength colonies. The correlation between the number of larvae and weather parameters were found positive and highly significant for minimum temperature, minimum RH, positive and significant for maximum RH, whereas no correlation existed between the number of larvae for maximum temperature and bright sunshine hours. The correlation between number of pupae and weather parameters were also found positive and significant for minimum temperature and minimum RH but correlation did

not exists between the number of pupae and weather parameters such as maximum temperature maximum RH and number of bright sunshine hours. The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature and minimum RH. No correlation existed between number of adult and weather parameters for maximum temperature, maximum RH and number of bright sunshine hours. In 6-frame bees strength, the correlation between number of larvae and weather parameters were found to be positive and highly significant for minimum temperature and for minimum RH whereas, no correlation existed between number of larvae and weather parameters for maximum temperature, maximum RH and number of bright sunshine hours. The correlation between number of pupae and weather parameters were found to be positive and highly significant for minimum RH and positive and significant for minimum temperature whereas, no correlation existed between number of pupae and weather parameters such as maximum temperature, maximum RH and number of bright sunshine hours.

The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature and minimum RH, however, no correlation existed between number of adults and weather parameters (as maximum temperature, maximum RH and number of bright sunshine hour). In 8-frame bees strength, the correlation between number of larvae and weather parameters were found positive and significant for minimum temperature and positive and highly significant for minimum RH whereas, no correlation existed between number of larvae and weather parameters such as maximum temperature, maximum RH and of bright sunshine hours. Correlation did not exist between number of pupae and weather parameters. The correlation between number of adults and weather parameters were found to be positive and significant for minimum temperature, whereas no correlation existed between number of adults and weather parameters (as maximum temperature, maximum RH and number of bright sunshine hours). In 10-frame bees strength colonies, the correlation between number of larvae and weather parameters was found positive and significant for minimum RH but no correlation existed between number of larvae and weather parameters (as maximum temperature, minimum temperature, maximum RH and of bright sunshine hours). The correlation between number of pupae and weather parameters was found positive and significant for minimum RH, whereas no correlation existed between number of pupae and weather parameters for maximum temperature, minimum temperature, maximum RH and of bright sunshine hours. Correlation also did not exist between number of adults and weather parameters. Mandal and Vishwakarma (2016) reported that the maximum temperature, minimum temperature and minimum relative humidity were positive significantly correlated with the larval population of GWM per hive, whereas the negative non-significant correlation with the maximum relative humidity and

positive non-significant correlation with rainfall. Deosi *et al*. (2014) observed that pest incidence was more in autumn season that may be due to weather conditions favourable for honey bees and also scarcity of bee flora was more during that season which might have provided condition conductive for attack of wax moth on weakened bee colonies.With an increase in the temperature and relative humidity regimes there was a corresponding decrease in the total duration of greater wax moth. However, the hatching increased with increase in temperature and relative humidity as reported by Swamy (2013). Swamy *et al.* (2013) also observed that the adult longevity and fecundity decreased with a decrease in relative humidity and their relative humidity combination prolonged all the developmental periods and reduced the fecundity. However, 30°C temperature was found to be more favorable for all the developmental stages. Our results get support from Huang (1984) who also agreed that with the optimum temperature for larval development of *G. mellonella* and *A. grisella* was 28 -29ºC.

5.1.3.1. Comb area damaged in *A. mellifera* colonies with different bee strength during different month of 2015-16 and 2016-17

During 2015-16, data indicated that during 2015-16, the comb area damaged by *G. mellonella* in 4 frame bee strength colonies started increasing in April (212.85 cm^2) and increased till July (1376.00 cm^2). From August, the damaged area started decreasing in different month and it reached to lowest limit in March (86.00 cm^2). In 6 frame bee strength colonies, the comb area damaged started increasing in April (150.50 cm^2) and increased till July (1268.50 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (70.95 cm^2). In 8 frame bee strength colonies, the comb area damaged started increasing in April (118.25 cm^2) and increased till July (903.00 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (55.90 cm^2). In 10 frame bee strength colonies, the comb area damaged started increasing in April (101.05 cm^2) and increased till July (602.00 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (32.25 cm^2). Irrespective of bee strength, the maximum comb area damaged (cm^2) was recorded in July (1037.38), whereas the minimum in March (61.28). However, the mean area damaged (cm^2) was lowest in 10 frame bee colonies (234.14) followed by 8 (352.97), 6 (500.09) and 4 frame bee colonies (577.99).

During 2016-17, comb area damaged by *G. mellonella* in 4 frame bee strength colonies started increasing in April (176.30 cm^2) and increased till July (1333.00 cm^2). From August, the damaged area started decreasing in different month and it reached to lowest limit in March (70.95 cm^2). In 6 frame bee strength colonies, the comb area damaged started increasing in April (122.55 cm^2) and increased till July (1204.00 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (70.95 cm^2). In 8 frame bee strength colonies, the comb area damaged started increasing in

April (118.25 cm^2) and increased till July (885.80 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (55.90 cm^2). In 10 frame bee strength colonies, the comb area damaged started increasing in April (86.00 cm^2) and increased till July (559.00 cm^2). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (21.50 cm^2). However, the mean area damaged (cm^2) was lowest in 10 frame bee colonies (206.21) followed by 8 (283.80), 6 (435.55) and 4 frame bee colonies (51.87). Vikramath (2000) observed that a single wax moth larva per comb caused damage of 7.67 cm^2 while 10 larvae per comb caused 66.67 cm^2 after 7 days of release.

The trend remained same on 14th, 21st and 28th day of release. After 35th day, a single larva per comb caused 91.67 cm^2 of damage while 10 larvae per comb caused 818.33 cm^2, which amounted to 0.11 and 1.02 combs of *A. mellifera.* The results showed that 10 larvae per comb were needed to completely damage a comb of *A. mellifera.* Present findings are in close agreement with the report of Paddock (1930) who recorded 6-7 larvae damaging the comb of *A. mellifera* making it unfit for the use by honey bees. Present results also endorse the findings of Oh-Haewoon *et al.* (1995) who reported that a single larva of *G. mellonella* destroyed an average of 100 cells of the comb of *A. mellifera,* which equals to the damage of 39cm^2 in terms of area. Raghunandan and Basavarajappa (2014) reported that the normal colonies with weak population were more prone to *G. mellonella* infestation and it was further in semi-arid region during summer (30.8%) followed by rainy season (23.4%). However, the infestation was less 11.0 and 6.6% during summer and winter seasons respectively in Malnad.

5.1.3.2. Per cent comb area damaged by *G. mellonella* in *A. mellifera* colonies with different bee strength during different month during 2015-16 and 2016-17

Data indicated that during 2015-16, the comb area damaged by *G. mellonella* in 4 frame bee strength colonies started increasing in April (13.30%) and increased till July (86%). From August, the damaged area started decreasing in different month and it reached to lowest limit in March (5.38%). In 6 frame bee strength colonies, comb area damaged started increasing in April (9.41%) and increased till July (79.28%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (4.43%). In 8 frame bee strength colonies, the comb area damaged started increasing in April (7.39%) and increased till July (56.44%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (3.49%). In 10 frame bee strength colonies, the comb area damaged started increasing in April (6.32%) and increased till July (37.63%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (2.01%). However, the mean area damaged (%) was lowest in 10 frame bee colonies (14.63) followed by 8 (22.06), 6 (31.25) and 4 frame bee colonies (36.12).

During 2016-17, the per cent comb area damaged by *G. mellonella* in 4 frame bee strength colonies started increasing in April (11.02) and increased till July (83.31%). From August, the damaged area started decreasing in different month and it reached to lowest limit in March (4.44%). In 6 frame bee strength colonies, the comb area damaged started increasing in April (7.66%) and increased till July (75.25%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (4.43%). In 8 frame bee strength colonies, the comb area damaged started increasing in April (7.39%) and increased till July (3.49%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (3.49%). In 10 frame bee strength colonies, the comb area damaged started increasing in April (5.38%) and increased till July (34.94%). From August, the damaged area started decreasing in different months and it reached to lowest limit in March (1.34). Irrespective of the bee strength, the maximum comb area damaged (%) was recorded in July (62.21) whereas the minimum in March (3.42%). Swamy (2008) conclude that the incidence of greater wax moth was recorded in both strong and weak colonies of *Apis cerana.* The incidence was maximum in March (47.37%), followed by February (42.10%) and April (41.18%). Whereas it was found to be comparatively lower in July (11.76%) followed by June (15.38%) and August (16.67%). Shylesha (1987) quantified the rate of desertion of *A. cerana* colonies in Bangalore as 2.20 per cent in December and 42.85 per cent in August. In Bangalore, Kuberappa *et al*. (1994) reported the desertion of *A. cerana* colonies from 7.69 to 20.00 per cent in monsoon and 8.00 to 12.00 per cent in honey flow season. Of the 33 colonies they observed, the mean desertion was 42.90 per cent in the infested and 26.48 per cent in the uninfected colonies. In Raichur (North-Karnataka) 26.09 per cent of the infested colonies of *A. cerana* deserted during monsoon (Viraktamath, 1989). Jyothi *et al*. (1990) viewed that a high rate of infestation (up to 100.0%) during July-August in the colonies of *A. dorsata* would induce premature desertion in Bangalore.The nature of severity was differentiated and categorized in to three groups by Kebede *et al*. (2015) as 35%, 47% and 2% combs infestation *viz*., light, moderate and severely affected, respectively.

5.1.4. Correlation between weather parameters and comb area damage by greater wax moth (*G. mellonella*) in *A. mellifera* colonies with different bee strength during 2015-16 and 2016-17

Results indicated significant positive correlation exists between comb area damage with maximum temperature, maximum humidity and negatively non-significant with minimum temperature and minimum RH respectively, in year 2015-16 and 2016-17 in 4-frame bee strength whereas no correlation existed between comb damage and sunshine hours. Significant positive correlation of comb area damage with maximum temperature in 6 and 8 frame bee strength, maximum humidity and non significant with minimum temperature and minimum RH, respectively in year 2015-16 while in year 2016-17, correlation of combs

damage with maximum temperature in 6 and 8 frame maximum humidity and negatively non significant with minimum RH and positively non significant with minimum temperature, respectively. There was a non significant correlation found between comb area damage by larvae in 10 frame bee strength with maximum temperature, minimum temp, maximum RH, minimum RH and sunshine hours during the years 2015-16 and 2016-17. Significant correlation found between the comb area damage and maximum temperature in 4, 6 and 8 frame strength, maximum humidity and negatively non significant with minimum RH, respectively. Correlation did not exist between comb area damage and sunshine hours in 4, 6, 8 and 10 frame bee strength in year 2015- 16 and 2016-17. In study of Sohali (2017), the minimum and maximum temperatures were found strongly correlated with wax moth abundance and consequently, the % of hives with moth damaged combs. When high abundances are found, moth infected combs need to be removed from the hive and treated separately to reduce infestations. Collectively, these efforts may further help the development of integrated pest management (IPM) strategies, targeting greater wax moths. Swati and Verma (2016) reported that the incidence of wax moth larvae was not correlated with the weather parameter except for minimum temperature.

5.2.1.1. Seasonal incidence of Greater wax moth, *G. mellonella* larvae during June to October in stored combs in 2016 and 2017

During 2016, at the time of first observation during June, the number of larvae recorded per comb in case seven combs were stored was (1.40). In the following observations, the number of larvae/comb increased till September (29.60 on 30th September). However, during October, the number decreased. During October, the number of larvae recorded per comb was 20.00 and 13.60 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded from June to October, the number of larvae recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation *i.e*., on 30th October, the number of larvae recorded per comb was highest (16.80) when ten combs were stored in a hive body followed by nine combs (16.60), eight comb (13.80) and seven comb (13.60).

During 2017, at the time of first observation during June, the number of larvae recorded per comb in case seven combs were stored (1.80). In the following observations, the number of larvae/comb increased till September (30.20 on 30th September). However, during October, the number decreased. During October, the number of larvae recorded per comb was 22.60 and 14.40 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of larvae recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a

hive body. At the time of last observation i.e. on 30th October, the number of larvae recorded per comb was highest (17.20) when ten combs were stored in a hive body followed by nine combs (16.80), eight comb (15.00) and seven comb (14.40). This may be due to more darkness in the hive body by storing 10 combs as compared to storage of 9, 8 and 7 frames. Another reason may be availability of more food in 10 combs storage as compared to 9, 8 and 7 frames. The results are agreement with the Mandal and Vishwakarma (2016). They reported that highest number of egg clusters (9.00) and larvae (26.33) of *G. mellonella* infesting *A. mellifera* combs was observed during 37th and 38th standard week in changing environmental conditions during storage. The highest number of GWM egg clusters and larvae per hive were 34.60 and 86.00, respectively, observed in the month of September, which is quite more than the other months of observations.

5.2.1.2. Pupal population of Greater wax moth, *G. mellonella* during June to October in stored combs in 2016 and 2017

During 2016, at the time of first observation during June, the number of pupae recorded per comb in case seven combs were stored (0.20). In the following observations, the number of pupae/comb increased till September (26.80 on 30th September). However, during October, the number decreased. During October, the number of pupae recorded per comb was 19.60 and 19.40 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of pupae recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation *i.e.,* on 30th October, the number of pupae recorded per comb was highest (12.80) when ten combs were stored in a hive body followed by nine combs (10.80), eight comb (10.40) and seven comb (9.40).

During 2017, at the time of first observation during June, the number of pupae recorded per comb in case seven combs were stored (1.80). In the following observations, the number of pupae/comb increased till September (30.20 on 30th September). However, during October, the number decreased. During October, the number of pupae recorded per comb was 22.60 and 14.40 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of pupae recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation *i.e.,* on 30th October, the number of pupae recorded per comb was highest (17.20) when ten combs were stored in a hive body followed by nine combs (16.80), eight comb (15.00) and seven comb (14.40). Mandal and Vishwakarma (2016) indicated that the highest number of pupae (23.67) of *G. mellonella* infesting *A. mellifera* combs was observed during 37th and 38th standard week in changing environmental

conditions. The highest number of GWM pupae (89.67) was observed in the month of September, which is quite more than the other months of observations.

5.2.1.3. Seasonal incidence of Greater wax moth, *G. mellonella* adult during June to October in stored combs in 2016 and 2017

During 2016, at the time of first observation during June, the number of adult recorded per comb in case seven combs were stored (0.00). In the following observations, the number of adults increased till September (26.00 on 30th September). However, during October, the number decreased. During October, the number of adult recorded per comb was 15.20 and 8.20 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of adult recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation *i.e.,* on 30th October, the number of adult recorded per comb was highest (10.40) when ten combs were stored in a hive body followed by nine combs (9.80), eight comb (8.80) and seven comb (8.20).

During 2017, at the time of first observation during June, the number of adult recorded per comb in case seven combs were stored (0.00). In the following observations, the number of adult/comb increased till September (27.00 on 30th September). However, during October, the number decreased. During October, the number of adult recorded per comb was 16.80 and 9.00 on 15th and 30th October, respectively. This pattern of seasonal incidence was same when eight, nine and ten combs were stored in a hive body (chamber). During all the observations recorded during June to October, the number of adult recorded per comb was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs in a hive body. At the time of last observation i.e. on 30th October, the number of adult recorded per comb was highest (11.00) when ten combs were stored in a hive body followed by nine combs (10.80), eight comb (9.20) and seven comb (9.00). Mandal and Vishwakarma (2016) indicated that the highest number of adult (8.00) of *G. mellonella* infesting *A. mellifera* combs was observed during 37th and 38th standard week during storage. The highest number (30.67) of GWM adults were observed in the month of September, which is higher than the observations of another month. The peak month as September shares about 22.01% of total population of the adults.

5.2.2.1. Correlation between weather parameters and Greater wax moth, *G. mellonella* incidence in stored empty comb with different number of comb groups during June to October in year 2016

During year 2016, the greater wax moth larvae starts infesting combs from first fortnight of June and progressively to acquire peak in September in 7, 8, 9 and 10 combs/hive. During September, average of weather parameters were recorded as maximum temperature

(35.23°C), minimum temperature (24.22°C), maximum RH (86.43%), minimum RH (54.20%) and number of bright sunshine hour (8.17 hour). During this period, the weather condition for the development of the greater wax moth was very congenial. In June, the average of different weather parameters were recorded as maximum temperature (41.1°C), minimum temperature (26.70°C), maximum RH (65%), minimum RH (35.9%) and duration of bright sunshine (8.4 hour).

The correlation coefficients between wax moth population and weather parameters are indicated that in 7 combs stored in hive body, correlation between number of larvae and weather parameters were found positive and significant for minimum temperature and maximum RH, positive and highly significant for minimum RH. Correlation did not exist between number of larvae and maximum temperature and bright sunshine hours. The correlation between number of pupae and minimum RH was found positive and highly significant. Correlation did not exist between pupal population and weather parameters such as maximum temperature, minimum temperature, maximum RH and bright sunshine hours. The correlation between number of adults and weather parameters were found to be positive and significant for minimum temperature and positive and highly significant for maximumm RH, whereas no correlation existed between number of adults and weather parameters such as maximum temperature, minimum RH and bright sunshine hour.

In 8 combs stored per hive body, the correlation between number of larvae and weather parameters were found positive and highly significant for minimum temperature (r= 0.345), for maximum RH, for minimum RH and negative and significant for bright sunshine hours. Correlation did not exist between larvae and maximum temperature. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum temperature, maximum RH, for minimum RH and negative and significant for bright sunshine hours. Correlation did not exist between number of pupae and maximum temperature. The correlation between number of adults and weather parameters were found to be positive and highly significant for minimum temperature, minimum RH, positive and significant for maximum RH, whereas negative and significant for bright sunshine hours. No correlation existed between adult and maximum temperature.

In 9 comb stored per hive, the correlation between number of larvae and weather parameters were found positive and highly significant for maximum temperature, for minimum RH and positive and significant for maximum RH. Significant correlation did not exist between number of larvae and maximum temperature and bright sunshine hours. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH and positive and significant for minimum temperature. No correlation existed between number of pupae and weather parameters for maximum temperature, maximum RH and bright sunshine hours. The correlation between number of

adults and weather parameters were found to be positive and highly significant for minimum temperature and for minimum RH but no correlation existed between number of adults and weather parameters such as maximum temperature, maximum RH and bright sunshine hours.

In 10 comb stored hive body, the correlation between number of larvae and weather parameters was found positive and highly significant for minimum RH but no correlation existed between larval population and weather parameters as maximum temperature, minimum temperature, maximum RH and bright sunshine hours. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH. No correlation existed between number of pupae and maximum temperature, minimum temperature, maximum RH and bright sunshine hour. The correlation between number of adults and weather parameters were found to be positive and significant for minimum RH. Correlation also did not exist between adult and weather parameters such as maximum temperature, minimum temperature, RH and number of bright sunshine hour. Mandal and Vishwakarma (2016) reported that the maximum temperature, minimum temperature and minimum relative humidity were positive significantly correlated with the larval population of GWM per hive, whereas the negative non-significant correlation with the maximum relative humidity and positive non-significant correlation with rainfall. Therefore, it is concluded that the GWM population were positively correlated with temperature and minimum relative humidity.

5.2.1.2. Correlation between weather parameters and greater wax moth, *Galleria mellonella* in stored comb (without bees) with different number of comb groups during June to October in year 2017

During year 2017, the greater wax moth larval infestation showed an increasing trend from starting of June and reaching to its peak in September (late rainy season) in 7, 8, 9 and l0 combs stored in hive body. In this month, the ranges of maximum temperature (34.92°C), minimum temperature (23.05°C), maximum RH (87.2%), minimum RH (49.50%) and number of bright sunshine hours (6.8 hour) were recorded. During June, the average of different weather parameters were recorded as maximum temperature (39.30°C), minimum temperature (25.7°C), maximum RH (67.9%), minimum RH (34.7%) and duration of bright sunshine (7.9 hours).

In 7 combs stored per hive body, the correlation coefficients between greater wax moth and weather parameters indicated that correlation between the number of larvae and weather parameters were found positive and highly significant for minimum temperature, minimum RH, positive and significant for maximum RH, whereas no correlation existed between the number of larvae for maximum temperature and bright sunshine hours. The correlation between number of pupae and weather parameters were also found positive and significant for minimum temperature and minimum RH but correlation did not exist between

the number of pupae and weather parameters as maximum temperature, maximum RH and number bright sunshine hours. The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature and for minimum RH, however, no correlation existed between number of adults and weather parameters for maximum temperature, maximum RH and number of bright sunshine hours.

In 8 comb stored per hive body, the correlation between number of larvae and weather parameters were found positive and highly significant for minimum temperature and for minimum RH, whereas no correlation existed between number of larvae and weather parameters for maximum temperature, maximum RH and number of bright sunshine hours. The correlation between number of pupae and weather parameters were found positive and highly significant for minimum RH. It was positive and significant for minimum temperature, whereas no correlation existed between number of pupae and weather parameters such as maximum temperature, maximum RH and number of bright sunshine hours. The correlation between number of adults and weather parameters were found positive and highly significant for minimum temperature and minimum RH, however, no correlation existed between number of adult and weather parameters (maximum temperature, maximum RH and bright sunshine hour).

In 9 combs stored in hive body, the correlation between number of larvae and weather parameters were found positive and significant for minimum temperature and positive and highly significant for minimum RH, whereas, no correlation existed between number of larvae and weather parameters such as maximum temperature, maximum RH and of bright sunshine hours. Correlation did not exist between number of pupae and weather parameters. The correlation between number of adult and weather parameters were found to be positive and significant for minimum temperature whereas no correlation existed between number of adult and weather parameters (such as maximum temperature, maximum RH and number of bright sunshine hours).

In 10 combs stored in hive body, the correlation between number of larvae and weather parameters was found positive and significant for maximum RH but no correlation existed between number of larvae and weather parameters such as maximum temperature, minimum temperature, minimum RH and hours of bright sunshine. The correlation between number of pupae and weather parameters was found positive and significant for minimum RH, whereas no correlation existed between number of pupae and weather parameters for maximum temperature, minimum temperature, maximum RH and hours of bright sunshine. Correlation also did not exist between number of adults and weather parameters.

5.2.3. Effects of storing different number of combs per hive body on comb damage by *G. mellonella* during June to October in two years

During 2016, in case 7 combs were stored, the area damaged per comb (cm^2) was minimum at the time of first observation in mid June (8.60). In the following observations, the cumulative area damaged per frame increased till the end of September (169.85). In October, area damaged did not increased and was almost same as in the end of September. The area damaged per comb (cm^2) was 170.28 and 170.32 in mid October and end October, respectively. The pattern of comb damage during different months was same when 8, 9 and 10 combs were stored. At the time of first observation (mid June), the area damaged per comb (cm^2) was significantly higher when 10 combs were stored (19.35) than 9 (12.90), 8 (10.75) and 7 combs (8.60). At the time of last observation on 30th October, the cumulative area damaged (cm^2) was maximum (219.52) when 10 combs were stored followed by 9 (202.31) combs, 8 (190.00) and 7 combs (170.32). During all the observation from June to October, the area damaged per comb (cm^2) was maximum in case 10 combs were stored followed by 9, 8 and 7 comb storage.

During 2017, in case 7 combs were stored, the area damaged per comb (cm^2) was minimum at the time of first observation in mid June (9.68). In the following observations, the cumulative area damaged per frame increased till the end of September (174.15). In October, area damaged did not increased and was almost same as in the end of September. The area damaged per comb (cm^2) was 174.36 and 174.40 in mid October and end October, respectively. The pattern of damage during different months was same when 8, 9 and 10 combs were stored. At the time of first observation (mid June), the area damaged per comb (cm^2) was significantly higher when 10 combs were stored (20.43) than 9 (15.05), 8 (9.57) and 7 combs (9.68). At the time of last observation on 30th October, the cumulative area damaged (cm^2) was maximum (223.89) when 10 combs were stored followed by 9 (204.50) combs, 8 (200.16) and 7 combs (174.40). During all the observation from June to October, the area damaged per comb (cm^2) was maximum in case 10 combs were stored followed by 9, 8 and 7 comb storage.

5.2.4. Correlation of weather parameters with comb area damage by *G. mellonella by* storing different number of empty combs during June to October in the year 2016 and 2017

The correlation studies indicated significant positive correlation of comb area damage with maximum temperature, maximum humidity, negatively non-significant with minimum temperature and minimum RH, respectively in both the year (2016 and 2017). Significant positive correlation were found in comb damage with maximum temperature in 8, 9 and 10 empty stored comb frames, maximum humidity and negatively non significant minimum RH, respectively, in year 2016 while in 2017, maximum temperature in 8, 9 and 10 stored comb

frames, maximum humidity and negatively non significant with minimum RH, respectively. There was no significant relation found with the comb damage and sunshine hours in 7, 8, 9 and 10 frame during both the year.

5.3. Effectiveness of different plant extracts against *G. mellonella*

Data revealed that maximum larval mortality (%) was recorded in case of *Plantago psyllium* husk (93.33%) followed by *Hordeum sativum* leaves and *Raphanus sativus* stem (80.00%), *H. sativum* stem and *R. sativus* leaves (73.33), *Linum usitatissimum* seed (66.66%), *Cucurbita moschata* seed (60.00%), *L. usitatissimum* leaves (53.33%), *Vicia sativa* leaves and *C. moschata* leaves (46.66%) and *L. usitatissimum* seed (66.66%) *V. sativa* stem (40.00%). Among 25 different extract, 14 could not cause any larval mortality *i.e*., were not effective against larvae (0.00% mortality) and were at par with control (0.00% mortality). No larval mortality (0.00%) was recorded in *V. radiata* leaves*, V. radiata* stem, *V. mungo* leaves, *V. mungo* stem, *Sesamum indicum* leaves, *S. indicum* stem, *Pisum sativum* leaves and *P. sativum* stem, *C. arietinum* leaves, *C. arietinum* stem, *B. juncea* leaves *B. juncea* stem, *P. vulgaris* leaves and *P. vulgaris* stem. Data on pupal mortality (%) revealed that out of 25 extract, 19 could not cause any mortality in pupal stage (0.00) and were at par with control (0.00). Among the plant extract which could cause pupal mortality; the highest pupal mortality (%) was observed due to *C. arietinum* leaves (46.66) followed by *C. arietinum* stem (26.66), *V. sativa l*eaves (20.00), *L. usitatissimum* seed (13.33), *H. sativum* leaves (6.66) and *P. vulgaris* (6.66).

Data on adult emergence (%) indicated that out of 25extracts, 11 extracts were not effective *i.e.,* there was 100 per cent adult emergence in those extracts and emergence was at par with control (100%). *P. psyllium* husk extract was most effective resulting in only 6.66 per cent adult emergence followed by *H. sativum* leaves (13.33%), *L. usitatissimum* seed and *R. sativus* stem (20.00%), *H. sativum* stem and *R. sativus* leaves (26.66), *V. sativa* leaves (33.33%), *C. moschata* seed (40.00), *L. usitatissimum* leaves (46.66%), *C. arietinum* leaves and *C. moschata* leaves (53.33%)*, V. Sativa* stem (60.00%), *C. arietinum* stem (73.33), *V. sativa* leaves and *P.vulgaris* leaves (93.33). Sanad and Mohanny (2015) conclude related studies and revealed that the highest mortality per cent of wax moth larvae (70%), three days after application was recorded at the treatment of Mint followed by Chinese propolish and cinnamon extracts (60%) while clove and Egyptian propolis treatment gave only 50 and 40 per cent reduction, respectively. The toxicity of the crude twig and leaf extract of the medicinal plant *Aglalia odorata* to the larvae of greater wax moth, *G. mellonella* indicated that the crude twig and leaf extract were more efficient as a stomach poison than the crude leaf extract (Piyapong *et al.,* 1997). Pitan *et al*. (2015) evaluated the effectiveness of methanol, N-hexane and aqueous leaf extracts of *Ocimum gratissimum, Carica papaya, Tithonia diversifolia, Ageratum conyzoides* and *Azadirachta indica* in the management of greater wax moth (*Galleria mellonella*) in the laboratory. Methanol and N-hexane prepared

extracts of all the plants caused 100% and 90% and 100% mortality, respectively of the test insects within 6 hour. Ahmad *et al.* (2014) reported that the wax moth mortality was observed highest (13.99) in Neem Seed Extract (NSE), followed by (11.74) in Neem Leafs Extract (NLE), 4.06 in NSE+NLE, 15.83 in Phenyl Ball and 44.08 in Control. Izhar-ul-Haq *et al*. (2008) reported effective control of *G. mellonella* by the use of neem extracts. Eldin *et al*. (2012) studied the toxicological effects of three plant extracts in controlling *G. mellonella* and indicated that the mortality percentages of pupae were 100% and 93.3%, 96.6% and 100%, respectively with treatment at the three *Chenopodium* and *Camphor* concentrations (0.2, 0.3 and 0.4%) while it was only 16.6 % in the control treatment.

5.4.1. Effect of different chemical and non-chemical treatments on *G. mellonella* infestation in raised combs under storage conditions during June to October, 2016

During 2016, data indicated that at the time of first observation (15 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 169.85 in control. The most effective treatment was low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage(cm^2) was 0.00, 0.52, 6.45, 9.68, 21.50, 32.25, 49.45, 58.05, 70.95, 79.55 and 111.80, respectively. At this time, the comb area damaged was 169.85 cm^2 in control. At the time of second observation (30 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 365.50 in control. The most effective treatment was low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, acetic acid spray, formic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.75, 6.99, 9.68, 33.33, 40.85, 45.15, 55.90, 59.13, 94.60, 103.20 and 208.55, respectively. At this time, the comb area damaged was 365.50 cm^2 in control. At the time of third observation (45 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 989.00 in control. The most effective treatment was low temperature treatment -15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, formic acid spray, NSKE spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.45, 0.75, 7.53, 10.75, 64.50, 77.40, 79.55, 86.00, 94.60, 129.00, 210.70 and 763.25,

respectively. At this time, the comb area damaged was 989.00 cm^2 in control. At the time of fourth observation (60 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 1290.00 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, formic acid spray, NSKE spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.53, 0.88, 8.06, 11.28, 94.60, 129.00, 131.15, 132.23, 144.05, 646.08, 935.25 and 1139.50, respectively. At this time, the comb area damaged was 1290.00 cm^2 in control. At the time of fifth observation (75 DAT), the average area damaged per comb (cm^2) ranged from 0.21 in low temperature treatment (-15°C) to 1472.75 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.21, 0.53, 1.01, 8.60, 12.90, 133.30, 137.60,154.80, 173.07, 187.05, 741.75, 1085.75 and 1247.00, respectively. At this time, the comb area damaged was 1472.75 cm^2 in control. At the time of sixth observation (90 DAT), the average area damaged per comb (cm^2) ranged from 0.32 in low temperature treatment (-15°C) to 1526.50 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the the comb area damage (cm^2) was 0.32, 0.54, 1.07, 10.75, 13.97, 139.75,154.80,161.25, 182.75, 199.95, 864.65, 1154.55 and 1552.30, respectively. At this time, the comb area damaged was 1526.50 cm^2 in control. At the time of seventh observation (105 DAT), the average area damaged per comb (cm^2) ranged from 0.32 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.32, 0.75, 1.61,10.75, 17.20, 154.80, 169.85, 180.60, 197.80, 219.30, 1285.70 and1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of eighth observation (120

DAT), the average area damaged per comb (cm^2) ranged from 0.54 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.54, 1.07, 2.15, 11.82, 19.35, 167.70, 176.30,187.05, 1290.00 and1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of ninth observation (135 DAT), the average area damaged per comb (cm^2) ranged from 1.07 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 1.07, 1.61, 3.23, 11.83, 19.35, 180.60, 197.80, 322.50, 377.55, 1502.85 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of last observation (150 DAT) i.e. end of the experiment, the average area damaged per comb (cm^2) ranged from 1.08 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 1.08, 1.61, 4.30,12.90, 23.65, 197.80, 208.55, 240.80, 346.15, 369.80 1586.70, 1599.60 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. From the above observations, it can be concluded that the order of effectiveness of treatment was the low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder. Babarinde *et al.* (2013) reported that treatment containing aluminium phosphide tablet (3g) was incorporated as chemical method of control and the treated honeycomb samples were stored for two month. Of all the treatments used, the hermetic storage and aluminium phosphide had the best result in that the comb retained their freshness post two

months storage. Munshimbwe *et al*. (2011) suggested that an 80% solution of acetic acid could be used to control wax moths in stored frames on top-bars.

Kumari and Jha (2013) examined the effectiveness of different storage methods and observed that maximum comb area infestation (7800 cm^2 and 7830 cm^2) occurred in empty combs frames stored in chambers kept in store without fumigation, whereas minimum infestation (160.60 cm^2 and 210.30 cm^2) was in case when the frames were stored in the polythene sheet with fumigation. Frame stored in polythene sprayed with 3 per cent neem oil after drying in shade proved its superiority as the next best treatment in minimizing the per cent infestation. Zhou (2016) determined the optimal cryopreservation method for eradication of the Greater wax moth from honey bee comb. This study showed that all larvae, pupae and adults died after they were treated for one hour at either -15 to -20°C temperature.

5.4.2. Per cent area infestation in stored empty raised combs in different treatments against *G. mellonella* under storage conditions during June to October, 2016

Data indicated that at the time of first observation (15 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 10.61 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, Separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the the comb infested area (%) was 0.00, 0.01, 0.40, 0.60, 1.34, 2.01, 2.41, 3.09, 3.62,4.43, 4.97 and 6.98, respectively. At this time, the comb area infestation (%) was highest (10.61) in control. At the time of second observation (30 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 22.84 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, acetic acid spray, formic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb infested area (%) was 0.00, 0.03, 0.43, 2.08, 2.55, 2.82, 3.49, 3.69, 5.91, 6.45 and 13, respectively. At this time, the comb area infestation (%) was highest (22.84) in control. At the time of third observation (45 DAT), the per cent area infestation per comb (%) ranged from 0.00 low temperature treatment (-15°C) to16.81 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, formic acid spray, NSKE spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting

neem leaves powder where the comb area damage (%) was 0.00, 0.02, 0.04, 0.47, 0.67, 4.03, 4.84, 4.97, 5.57, 5.91, 8.06 and 13.17, respectively. At this time, the comb area infestation (%) was highest (16.81) in control. At the time of fourth observation (60 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C) to 80.62 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, formic acid spray, NSKE spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.00, 0.03, 0.04, 0.50, 0.70, 5.91, 8.06, 8.19, 8.26, 9.00, 40.38, 58.45 and 71.21, respectively. At this time, the comb area infestation (%) was highest (80.62) in control. At the time of fifth observation (75 DAT), the per cent area infestation per comb (%) ranged from 0.01 in low temperature treatment (-15°C) to 92.04 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.01, 0.03, 0.05, 0.53, 0.80, 8.33, 8.60, 9.76, 10.81, 11.69, 46.35, 67.85 and 77.93, respectively. At this time, the comb area infestation (%) was highest (80.62) in control. At the time of sixth observation (90 DAT), the per cent area infestation per comb (%) ranged from 0.02 in low temperature treatment (-15°C) to 95.40 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.02, 0.03, 0.06, 0.67, 0.87, 8.73, 9.67, 10.07,11.42,12.49 and 97.01, respectively. At this time, the comb area infestation (%) was highest (95.40) in control. At the time of seventh observation (105 DAT), the per cent area infestation per comb (%) ranged from 0.02 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.02, 0.04, 0.06, 0.67, 1.08, 9.67,

10.61, 11.28, 12.36, 13.70, 76.99, 80.35 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of eighth observation (120 DAT), the per cent area infestation per comb (%) ranged from 0.54 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.03, 0.06, 0.13, 0.73, 1.14, 10.48, 11.01, 11.69, 14.10, 15.45, 80.62, 83.98 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of ninth observation (135 DAT), the per cent area infestation per comb (%) ranged from 0.06 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.06, 0.10, 0.20, 0.73, 1.20, 11.28, 12.36, 13.97, 20.15, 21.09, 91.50, 93.92 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of last observation (150 DAT) *i.e.,* end of the experiment, the per cent area infestation per comb (%) ranged from 0.06 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of was low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.06, 0.10, 0.26, 0.80, 1.47, 12.36, 13.03, 15.05, 21.63, 23.11, 99.16, 99.97 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. From the above observations, it can be concluded that the order of per cent infested area in raised combs was the low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder. These findings are in agreement with the Bhopale *et al*., (2013) Among the products, minimum cell damage was observed in *Bt* kurstaki (Halt) which was on par with

that of Pongamia oil followed by *Bt* local strain-1 and neem oil (12 to 20 per cent cell damage). Dried neem leaf and *Bt* local strain-2 performed poorly with 32.22 to 37 per cent cell damage respectively. The comb damage in control was 90 per cent, which was significantly higher than the damage recorded in all other treatments Charriere and Imdorf (2004). The results are also in close propinquity with the Swamy (2000). None of the treatments could protect comb sufficiently except refrigerated condition.

5.4.3. Effect of different treatments on *G. mellonella* infestation in raised combs under storage conditions during June to October, 2017

Data indicated that at the time of first observation (15 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C, -10°C) to 170.38 in control. The most effective treatment was low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, Separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.51, 6.45, 8.60, 22.03, 32.78, 39.77, 51.60, 59.66, 72.02, 80.62 and 170.38, respectively. At this time, the comb area damaged was 170.38 cm^2 in control. At the time of second observation (30 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 371.95 in control. The most effective treatment was low temperature treatment (-15°C), followed by low temperature treatment (-10°C), low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.43, 0.52, 6.99, 9.14, 38.16, 51.68, 52.68, 56.98, 60.74, 96.75, 108.58 and 218.76, respectively. At this time, the comb area damaged was 371.95 cm^2 in control. At the time of third observation (45 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 1010.50 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, formic acid spray, *Bt* spray, NSKE spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.43, 0.75, 7.53, 10.21, 65.04, 81.70, 87.61, 89.69, 95.14, 131.15, 217.15 and 786.90, respectively. At this time, the comb area damaged was 1010.50 cm^2 in control. At the time of fourth observation (60 DAT), the average area damaged per comb (cm^2) ranged from 0.00 in low temperature treatment (-15°C) to 1294.30 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature

treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.00, 0.43, 0.86, 8.06, 10.96, 95.68, 126.85, 134.38, 141.90, 146.20, 685.85, 956.75 and 1143.80, respectively. At this time, the comb area damaged was 1294.30 cm^2 in control. At the time of fifth observation (75 DAT), the average area damaged per comb (cm^2) ranged from 0.21 in low temperature treatment (-15°C) to 1472.75 in control. The most effective treatment was low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.32, 0.43, 0.96, 9.13, 12.90, 135.45, 141.90, 163.40, 178.45, 191.35, 789.05, 1107.25 and 1272.80, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of sixth observation (90 DAT), the average area damaged per comb (cm^2) ranged from 0.32 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was in low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.32, 0.43, 1.03, 10.75, 13.43, 144.05, 156.95, 169.85, 189.20, 234.35, 894.40, 1176.05 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of seventh observation (105 DAT), the average area damaged per comb (cm^2) ranged from 0.52 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray, and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.52, 0.52, 1.55, 10.75, 17.73, 153.72, 180.60, 182.75, 201.12, 258.00, 1244.85, 1296.45 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of eighth observation (120 DAT), the average area damaged per comb (cm^2) ranged from 0.54 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment

(0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.54, 1.07, 2.04, 11.29, 18.81, 160.17, 191.35, 225.75, 227.90, 267.35, 1298.60, 1353.35 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of ninth observation (135 DAT), the average area damaged per comb (cm^2) ranged from 0.86 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 0.86, 1.51,3.16,11.82, 19.89, 172.00, 219.30, 237.62, 339.70, 402.05, 1472.75, 1524.35 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. At the time of last observation (150 DAT) i.e. end of the experiment, the average area damaged per comb (cm^2) ranged from 1.08 in low temperature treatment (-15°C) to 1599.60 in control. The most effective treatment was low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (cm^2) was 1.08, 1.61, 3.76, 11.83, 23.11, 198.88, 236.50, 238.65, 354.75, 449.35, 1595.30, 1599.60 and 1599.60, respectively. At this time, the comb area damaged was 1599.60 cm^2 in control. From the above observations, it can be concluded that the order of effectiveness of treatment was the low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder. Yadav *et al*. (2012) reported the effective treatment for wax moth under comb storage was fumigation with aluminium phosphide which, 90 days after the first treatment, resulted in the least comb damage area (19.55 cm^2) followed by combs placed in deep freezer, sulphur fumigation and NSKE spray with mean damage area of 44.95, 69.67 and 102.8 cm^2 per comb, respectively. The present findings are also in line with that of Williams (1997) who reported that phosphine controlled wax moth in empty combs. Atwal and Sharma (1967) and Verma *et al*. (1997) reported that the use of sulphur and cleaning of beehives assisted in reducing wax moth population. Kwadha *et al*. (2017) infested combs could also be exposed to cold rooms or

refrigerator equipment such as home freezers set at -7°C to -15 °C for 2-4.5 hours. These techniques are advantageous, since growth and development of GWM is dependent on environmental factors such as temperature. Almost complete loss (1599.60 cm^2) of stored combs was reported 90 days after first treatment, indicating total ineffectiveness of spreading dried out neem leaves powder (Yadav *et al*., 2012). Effectiveness of sulphur fumigation on *G. mellonella* collobrated the finding of Ahmed *et al*. (1993) and Calderone (2000) who advocated that observed that sulfur fumigation could be used for controlling wax moth.

5.4.4. Per cent area infestation in stored empty raised combs in different treatments against *G. mellonella* under storage conditions during June to October, 2017

Data indicated that at the time of first observation (15 DAT), the per cent area infestation per comb (%) ranged from 0.00 low temperature treatment (-15°C, -10°C) to 10.64 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, Separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb infested area (%) was 0.00, 0.03, 0.40, 0.53, 1.37, 2.01, 2.04, 2.48, 3.22, 3.72, 4.50, 5.03, 7.92, respectively. At this time, the comb area infestation (%) was highest (10.64) in control. At the time of second observation (30 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C) to 23.24 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C), low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, acetic acid spray, formic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.00, 0.02, 0.03, 0.43, 0.57, 2.38, 3.22, 3.29, 3.56, 3.79, 6.04, 6.78 and 13.67, respectively. At this time, the comb area infestation (%) was highest (23.24) in control. At the time of third observation (45 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature treatment (-15°C) to 63.15 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, formic acid spray, *Bt* spray, NSKE spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.00, 0.02, 0.04, 0.47, 0.63, 4.06, 5.10, 5.47, 5.60, 5.94, 8.19, 13.57 and 49.18, respectively. At this time, the comb area infestation (%) was highest (23.24) in control. At the time of fourth observation (60 DAT), the per cent area infestation per comb (%) ranged from 0.00 in low temperature

treatment (-15°C) to 80.89 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, separation of combs with newspapers, *Bt* spray, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.00, 0.02, 0.05, 0.50, 0.68, 5.98, 7.92, 8.39, 8.86, 9.13, 42.86, 59.79 and 71.48 respectively. At this time, the comb area infestation (%) was highest (80.89) in control. At the time of fifth observation (75 DAT), the per cent area infestation per comb (%) ranged from 0.02 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.02, 0.02, 0.06, 0.66, 0.80, 8.46, 8.86,10.21, 11.15,11.95, 49.31, 69.20 and 79.55, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of sixth observation (90 DAT), the per cent area infestation per comb (%) ranged from 0.02 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the comb area damage (%) was 0.02, 0.02, 0.06, 0.66, 0.83, 9.00, 9.80, 10.61, 11.82, 14.64, 55.90, 73.50 and 97.91, respectively. At this time, the comb area infestation (%) was highest (99.97) ^{in} control. At the time of seventh observation (105 DAT), the per cent area infestation per comb (%) ranged from 0.03 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, NSKE spray, separation of combs with newspapers, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray, and broadcasting neem leaves powder where the comb area damage (%) was 0.03, 0.03, 0.09, 0.67, 1.10, 9.60,11.28, 11.42, 12.63, 16.12, 77.80, 81.02 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) ^{in} control. At the time of eighth observation (120 DAT), the per cent area infestation per comb (%) ranged from 0.04 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area

infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder where the comb area damage (%) was 0.04, 0.06, 0.12, 0.70, 1.17, 10.01, 11.95, 14.10, 14.24, 16.70, 81.16, 84.58 and 99.97 respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of ninth observation (135 DAT), the per cent area infestation per comb (%) ranged from 0.05 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the the comb area damage (%) was 0.05, 0.09, 0.19, 0.70, 1.24, 10.75, 13.70, 14.85, 21.23, 25.12, 92.04, 95.27 and 99.97 respectively. At this time, the comb area infestation (%) was highest (99.97) in control. At the time of last observation (150 DAT) i.e. end of the experiment, the per cent area infestation per comb (%) ranged from 0.06 in low temperature treatment (-15°C) to 99.97 in control. The lowest comb area infestation (%) was observed in case of low temperature treatment (-15°C), followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder where the the comb area damage (cm^2) was 0.06, 0.10, 0.23, 0.73, 1.44,14.48, 14.91, 22.17, 28.08, 99.70, 99.97 and 99.97, respectively. At this time, the comb area infestation (%) was highest (99.97) in control. From the above observations, it can be concluded that the order of per cent infested area in raised comb was the low temperature treatment (-15°C) followed by low temperature treatment (-10°C) followed by low temperature treatment (-5°C), low temperature treatment (0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaves powder. These results are in line with those reported earlier by Cantwell and Shieh (1981) that Certan, a *Bacillus thuringiensis* preparation provided excellent wax moth control on stored combs. Vishwas and Gowda (2006) also reported that 500ppm of *Bacillus thuringiensis kurstaki* UAS strains (Dipel and Halt) resulted in 80, 63.33 and 63.33 per cent mortality of 3rd instar larvae of *G. mellonella*. They also reported that Neem oil spray resulted in significantly higher overall mean damage to stored

combs (625.31 cm^2) as compared with karanj oil spray (473.2 cm^2). It was thus clear from the present findings that wax moth infestation could be managed effectively in the month of September and special care should be taken as the activity of wax moth was found at its peak. Furthermore, the findings on the effectiveness of different storage treatment of raised combs on wax moth infestation revealed that raised combs when stored in polythene sheet with fumigation would be less prone to wax moth damage. Application of non-chemical method was, however, considered by far the cheapest and safest method.

CHAPTER- VI

SUMMARY AND CONCLUSION

The present investigation entitled "Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs" was carried out at Research farm, Apiary and Apiculture Laboratory of the Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar for two years. The results of different objective of investigations are summarised as below.

The population of wax moth (larval, pupal as well as adult) varied during different months during 2015-16 and 2016-17. During both the years, population of greater wax moth (larval, pupal as well as adult) started increasing from April and increased till July; thereafter (from August) the population started declining and declined till March. In 4- frames bees colonies, the mean population during both the years was highest in the month of July and lowest in March. This trends of highest and lowest mean population was also observed in 6, 8 and 10 frame bee colonies. In 4 frame bee colonies, the mean population during 2015-16 and 2016-17 was highest *i.e*., 10.73 and 10.66, respectively in the month of July whereas lowest *i.e.,* 2.80 and 2.53, respectively in the month of March. In 6 frames bees colonies, the mean population during 2015-16 and 2016-17 was maximum *i.e.,* 9.53 and 9.26, respectively in the month of July whereas, lowest *i.e.,* 2.46 and 2.20, respectively in the month of March. In 8 frames bees colonies, the mean population during 2015-16 and 2016-17 was maximum *i.e.,* 7.93 and 6.73, respectively in July whereas, minimum *i.e.,* 2.26 and 2.06, respectively in March. In 10 frames bees colonies, the mean population during 2015-16 and 2016-17 was maximum *i.e.,* 3.00 and 2.80, respectively in July whereas, minimum *i.e.,* 0.00 and 0.00, respectively in March. The mean population was more in weak colonies *i.e.,* 4 frame bee colonies followed by 6, 8 and 10 frame bee colonies. Hence this can be concluded that in colonies with different bee strength, the maximum population of greater wax moth was noticed in July whereas, minimum in March. Colonies with 4-frame bee strength had more population followed by 6, 8 and 10 frame bee colonies. Hence, stronger colonies had low population as compare to weak colonies.

Correlation studies between number of greater wax moth larvae, pupae and adults with the weather parameters showed significant positive correlation with maximum temperature and maximum RH, whereas no correlation existed with minimum temperature, minimum RH and number of bright sunshine hours during both the years 2015-16 and 2016-17.

The comb area damaged by Greater wax moth varied during different months during 2015-16 and 2016-17. During both the years, comb area damaged by *G. mellonella* in

different bee strength colonies started increasing in April and increased till July. From August, the damaged area started decreasing in different months and it reached to lowest limit in March. The maximum comb area damaged was recorded in July. In 4-frame bee colonies, the comb area damaged during 2015-16 and 2016-17 was maximum in July *i.e.* 1376.00 and 1333.00 cm^2, respectively, whereas minimum in March i.e. 86.00 and 70.95, respectively. This trend of highest and lowest damaged area was also noticed in 6, 8 and 10 frame bee colonies. During 2015-16, the mean comb area damaged was 577.99, 500.09, 352.97 and 234.14 in 4, 6, 8 and 10 frame bee colonies, respectively. During 2016-17, the mean comb area damaged was 511.87, 435.55, 283.80 and 206.21 cm^2 in 4, 6, 8 and 10 frame bee colonies, respectively. Hence, in both the years, the mean comb area damaged was lower in stronger colonies as compared to weak colonies

Correlation studies between comb area damaged by larvae in 4, 6 and 8 frame strength and weather parameters showed significant positive correlation with maximum temperature and maximum RH, whereas significant negative correlation existed with minimum temperature and minimum RH and number of bright sunshine hours during both the years 2015-16 and 2016-17. No correlation existed with maximum temperature and number of bright sunshine hours in 10-frame bee strength. Wax moth abundance and the per cent of hives with moth damaged were directly proportional to one other.

During both the years, larval, pupal and adult population in stored combs increased with the passage of time from June to September. However, in the month of October, the cumulative number of larvae, pupae and adults decreased. Larval, pupal and adult population was highest when ten combs were stored followed by 9, 8 and 7 combs when the number of different stages recorded was minimum.

Correlation studies between number of greater wax moth population (larvae, pupae and adults) in stored combs related to different frame strength with the different weather parameters showed significant positive correlation with maximum RH and maximum temperature, whereas no significant correlation existed with minimum temperature, minimum RH and number of bright sunshine hours during both the years 2016 and 2017.

During both the year, cumulative comb area damaged per frame increased with the passage of time from June to October. The comb area damaged at the time of two observations during October was almost same. At the end of the experiment *i.e.,* in October, the cumulative comb area damaged per frame was maximum when ten combs were stored in a hive body followed by 9, 8 and 7 combs where the area damaged was minimum.

The correlation study indicated significant positive correlation between extent of comb area damaged by wax moth larvae and maximum temperature, maximum humidity and non-significant with minimum temperature and minimum RH in both the years 2016 and

2017. No significant correlation found with the extent of comb damage and sunshine hours during both the years.

Among 25 different extracts, 14 could not cause any larval mortality *i.e.* were not effective against larvae (0.00% mortality) and were at par with control (0.00% mortality). Among the plant extracts which could cause mortality in larval stage are *Plantago psyllium* husk, *Linum usitatissimum* leaves, *L. usitatissimum* seed*, Hordeum sativum* leaves, *H. sativum* stem, *Vicia sativa* leaves, *V. sativa* stem, *Cucurbita moschata* leaves, *C. moschata* seed, *Raphanus sativus* leaves and *R. sativus* stem. Maximum larval mortality was recorded in case of *Plantago psyllium* husk (93.33%). Out of 25 plant extracts, 19 could not cause any mortality in pupal stage (0.00%) and were at par with control (0.00%). The highest pupal mortality was observed due to *Cicer arietinum* leaves (46.66%). From the data on adult emergence, it can be summarised that out of 25 extracts 11 extracts were not effective *i.e.,* there was 100 per cent adult emergence. *P. psyllium* husk extract was most effective resulting in only 6.66 per cent adult emergence. Considering all the three parameters collectively (larval mortality, pupal mortality and adult emergence), it can be concluded that out of 25 extracts, 11 plant extract namely, *V. radiata* leaves, *V. radiata* stem, *V. mungo* leaves*, V. mungo* stem*, Sesamum indicum* leaves, *S. indicum* stem, *Pisum sativum* leaves, *P. sativum* stem, *Brassica juncea* leaves, *B. juncea stem* and *P. vulgaris* stem were not effective against *G. mellonella*. Among the 14 effective extracts, *Plantago psyllium* husk extract was most effective followed by *H. sativum* leaves, *L. usitatissimum* seed *R. sativus* stem, *H. sativum* stem, *R. sativus* leaves, *V. sativa* leaves, *C. moschata* seed, *L. usitatissimum* leaves, *C. arietinum* leaves, *C. moschata* leaves*, V. sativa* stem, *C. arietinum* stem, *V. sativa* leaves and *P.vulgaris* leaves (least effective).

Different chemical and non-chemical measures were evaluated for the management of *G. mellonella* in stored combs. Combs were stored from June to October in both the years *i.e.,* 2016 and 2017. It is concluded that the most effective treatment was low temperature treatment (-15°C, -10°C) followed by low temperature treatment (-5°C and 0°C), Aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, Acetic acid spray, neem oil spray, hive chamber separation with newspaper and broadcasting neem leaf powder.

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Appendix-1

Average (Mean) monthly meteorological data during 2015-16

Weather parameter / Month	Temperature		Relative Humidity %		Sunshine
	Maximum	Minimum	Maximum	Minimum	hours
November	29.8	11.6	91.8	47.5	5.9
December	24.1	7.3	97.6	56.4	6.2
January	19.61	7.12	94.90	64.55	4.05
February	23.97	7.39	92.17	48.97	7.21
March	29.91	13.75	88.48	46.42	8.11
April	37.93	18.42	60.70	25.37	8.64
May	41.04	24.83	62.77	35.26	8.09
June	39.55	27.55	70.97	44.23	7.80
July	35.06	26.12	90.39	71.87	5.89
August	34.05	25.60	89.65	69.23	5.99
September	35.23	24.22	86.43	54.20	8.77
October	34.57	18.42	84.39	41.84	7.77

Average (Mean) monthly meteorological data during 2016-17

Weather parameter / Month	Temperature		Relative Humidity %		Sunshine
	Maximum	Minimum	Maximum	Minimum	hours
November	29.3	10.6	91.4	46.8	5.8
December	24.2	7.5	97.5	57.2	6.1
January	18.6	6.9	98.5	71.5	4.1
February	24.3	7.8	91.9	45.9	7.7
March	29.0	11.3	89.6	38.0	8.6
April	38.6	18.9	57.0	21.7	8.7
May	37.2	25.6	77.1	49.6	7.3
June	35.1	27.0	88.3	66.9	6.8
July	34.7	26.3	89.7	69.3	6.3
August	34.9	23.5	87.2	49.5	6.8
September	33.6	18.4	84.4	41.8	7.8
October	29.3	10.6	91.4	46.8	5.8

Appendix-II

Average (Mean) fortnighly meteorological data during June to October 2016

Weather parameter / Month	Temperature		Relative Humidity %		Sunshine
	Maximum	Minimum	Maximum	Minimum	Hours
15 June	41.1	26.7	65.0	35.9	8.4
30 June	38.2	28.3	76.2	51.6	7.3
15 July	35.8	26.8	88.7	72.3	6.4
30 july	34.4	25.4	91.9	71.5	5.4
15 August	34.1	25.6	90.1	70.7	5.8
30 August	34.0	25.6	89.3	67.8	6.2
15 September	34.8	23.8	85.8	57.1	9.2
30 September	35.7	24.6	87.1	51.3	8.4
15 October	35.1	21.5	86.3	45.0	7.3
30 October	34.0	15.5	82.6	38.9	8.3

Average (Mean) fortnighly meteorological data during June to October 2016

Weather parameter / Month	Temperature		Relative Humidity %		Sunshine
	Maximum	Minimum	Maximum	Minimum	hours
15 June	39.3	25.7	67.9	34.7	7.9
30 June	35.0	25.5	86.3	64.5	6.7
15 July	35.98	27.3	84.7	60.0	7.0
30 July	34.4	26.7	91.7	73.3	6.5
15 August	34.4	26.7	91.7	73.3	6.5
30 August	34.8	26.0	91.3	72.5	7.2
15 September	34.4	24.9	90.0	62.6	6.9
30 September	35.4	22.0	84.4	36.5	6.7
15 October	35.8	22.5	86.3	45.0	7.3
30 October	34.8	16.5	83.6	38.8	8.4

ABSTRACT

Title of thesis	**:**	**"Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs"**
Full name of the degree holder	**:**	**Lalita Panwar**
Admission No.	**:**	2014A19D
Title of degree	**:**	Ph.D. (Entomology)
Name and address of major advisor	**:**	**Dr. Yogesh Kumar** Professor and Head, Department of Entomology, CCS Haryana Agricultural University, Hisar, Haryana.
Degree awarding University/ Institute	**:**	CCS Haryana Agricultural University, Hisar, Haryana (India)
Year of award of degree	**:**	2018
Major subject	**:**	Entomology
Total number of page in thesis	**:**	108 + viii+ II
Number of words in the abstract	**:**	403

Keywords: *Galleria mellonella, Apis mellifera*, colonies, stored combs, plants extract

The investigation entitled "Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs" was carried out at Research farm, Apiary and Apiculture Laboratory of the Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana (India). The population of wax moth (larval, pupal as well as adult) varied during different months during two years study. During both the years, population started increasing from April and increased till July; thereafter (from August) the population started declining and declined till March. In colonies with 4, 6, 8 and 10 frame bee strength, the maximum incidence was noticed in July. Colonies with frame bee strength had more number of larvae, pupae and adult followed by 6, 8 and 10 frame bee colonies. During both the years (2015-16 and 2016-17), the comb area damaged by *G. Mellonella* in different bee strength colonies started increasing in April and increased till July. From August, the damaged area started decreasing and reached to lowest in March. Maximum comb damage was recorded in July.

The cumulative comb area damaged per frame in stored combs increased with the passege of storage time from June to October. Cumulative comb area damaged per frame was maximum when ten combs were stored in a hive body followed by 9, 8 and 7 combs. Larval, pupal and adult populaion in stored combs increase with the passege of storage time from June to October. Larval, pupal and adult populaion was highest when ten combs were stored in a hive body followed by 9, 8 and 7 combs.

Among the 25 plant extracts tested against *Galleria mellonella* in laboratory; 14 were found effective. Among the 14 effective extract, *Plantago psyllium* husk extract was most effective followed by *Hordeum sativum* leaves*, Linum usitatissimum* seed and *Raphanus sativus* stem, *H. sativum* stem and *R. sativus* leaves, *Vicia sativa* leaves, *Cucurbita moschata* seed, *L. usitatissimum* leaves*, Cicer arietinum* leaves, *C. moschata* leaves, *V. sativa* stem, *C. arietinum* stem and *Phaseolus vulgaris* leaves (least effective).

Among the different chemical and non chemical measures tested for management of greater wax moth in stored combs; the most effective was the low temperature treatment (-15°C, -10°C) followe by low temperature treatment (-5°C and 0°C), aluminium phosphide fumigation, *Bt* spray, separation of combs with newspapers, NSKE spray, formic acid spray, acetic acid spray, hive chamber separation with newspaper, neem oil spray and broadcasting neem leaves powder.

MAJOR ADVISOR **SIGNATURE OF STUDENT**

HEAD OF DEPARTMENT

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B.Sc. (Hons.) Agriculture	CCS HAU, Hisar	2012	67.8%	All Agriculture Subjects
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- Actively participated in NSS programmes and Inter-agricultural college sports and athletics meet
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List of Publications:

Total abstract publications are 10 in different conference and 2 popular article published in Modern Kheti.

- Lalita, Kumar, Y. and Yadav, S. 2018. Seasonal incidence of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* colonies in ecological condition of Hisar. *Journal of Entomology and Zoology Studies,* **6**(1): 790-795.
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(Lalita Panwar)

UNDERTAKING OF THE COPYRIGHT

I, **Lalita Panwar,** Admission No. **2014A19D,** undertake that I give copyright to the CCS HAU, Hisar of my dissertation entitled **"Seasonal incidence and management of Greater wax moth, *Galleria mellonella* Linnaeus in *Apis mellifera* L. colonies and stored combs".**

I also undertake that, patent, if any, arising out of the research work conducted during the programme shall be filed by me only with due permission of the competent authority of CCSHAU, Hisar.

Lalita Panwar