SEASONAL INCIDENCE, BIOLOGY AND MANAGEMENT OF GRAPE MEALYBUG

by

Mr. Pawar Uday Anil
(Reg. No. 2017/29)

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI – 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA.

in partial fulfillment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

AGRICULTURAL ENTOMOLOGY

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

POST GRADUATE INSTITUTE
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DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

**POST GRADUATE INSTITUTE
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RAHURI – 413 722, DIST. - AHMEDNAGAR
MAHARASHTRA, INDIA.**
2023

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part
there of has not been submitted
by me or other person to any
other University or Institution
for a Degree or
Diploma

Place : MPKV, Rahuri

Date : / /2023

(Pawar Uday Anil)

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CERTIFICATE

This is to certify that the thesis entitled, **“SEASONAL INCIDENCE, BIOLOGY AND MANAGEMENT OF GRAPE MEALYBUG”** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri Dist. Ahmednagar (Maharashtra) in partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRICULTURAL ENTOMOLOGY,** embodies the results of a piece of *bona fide* research work carried out by **Mr. PAWAR UDAY ANIL,** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

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

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Place : MPKV, Rahuri

Date : / /2023 (S. A. Ranpise)

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Place : M.P.K.V., Rahuri

Date :   /   /2023   **(Uday Anil Pawar)**

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LIST OF ABBREVIATIONS

%	:	per cent
/	:	Per
@	:	at the rate
>	:	greater than
CD	:	Critical Difference
cm	:	Centimeter
Conc.	:	Concentration
CV	:	Coefficient of Variation
DAS	:	Days After Spraying
EC	:	Emulsifiable Concentrate
et al.	:	et alia (And others)
Etc	:	Etcetera
Fig.	:	Figure
g	:	Gram
ha	:	Hectare
i.e.	:	id est. (That is)
L	:	Litre
Ltd.	:	Limited
m	:	Meter
mg	:	Milligram
ml	:	Milliliter
Mm	:	Milimeter
No.	:	Number
NS	:	Non Significant
ppm	:	Parts per million
Pvt.	:	Private
Rs.	:	Rupees
SD	:	Standard deviation
SE(m)±	:	Standard error of mean
SG	:	Soluble granules
SL	:	Soluble liquid
Sig.	:	Significant
SMW	:	Standard meteorological week
Spp.	:	Species
Sr. No.	:	Serial Number
t	:	Tonne
Tr.	:	Treatment
WG	:	Wettable Granules

ABSTRACT

"SEASONAL INCIDENCE, BIOLOGY AND MANAGEMENT OF GRAPE MEALYBUG"

by

Mr. Pawar Uday Anil

A candidate for the degree
of
DOCTOR OF PHILOSOPHY (AGRICULTURE)
in
AGRICULTURAL ENTOMOLOGY
2023

Research Guide	**:**	**Dr. R.V. Datkhile**
Discipline	**:**	**Agricultural Entomology**

The present investigation entitled, "Seasonal incidence, biology and management of grape mealybug" was carried out during 2017-18 to 2019-20 period at MPKV, Rahuri, Maharashtra. The field experiments on seasonal incidence and bio-efficacy of insecticides were conducted at AICRP on Fruits, Department of Horticulture, Horticulture farm, MPKV., Rahuri. The survey on the usage pattern of pesticides against grape mealybug was undertaken in Ahmednagar, Pune, Solapur, Sangli and Nashik districts of western Maharashtra. The laboratory study on biology of grape mealybug was undertaken at Insect Culture Room, Department of Entomology, Biocontrol laboratory, MPKV, Rahuri.

Studies on seasonal incidence of grape mealybug, *Maconellicoccus hirsutus* (Green) made during 2018-19 and 2019-20 revealed that grape mealybugs were present throughout the year in vineyard both the years, respectively. The number of egg sacs per vine was higher when maximum temperature increased and morning and evening relative humidity decreased. During both the years, highest egg sacs count was observed in the last week of March (13^{th} SMW) and first week of April (14^{th} SMW). The nymphal population also showed highly significant positive correlation with maximum temperature, highly significant negative correlation with morning and evening relative humidity and significant negative correlation with rainfall. Maximum nymphal count was

registered during last week of March (13th SMW) in both the years. Minimum nymphal population for the year 2018-19 observed at the third week of August (33rd SMW) whereas for the year 2019-20 minimum nymphal population was observed on third week of September (38th SMW). In general both the years the number of egg sacs and nymphal population start decreasing from September to the end of November and goes on increasing from December till March. Similarly maximum count of mealybug adults and colonies was recorded in the last week of March (13th SMW) for both years respectively. The mealybug population was governed chiefly by the combined effects of three factors *i.e.* temperature, relative humidity and rainfall. High temperature proved most congenial for its multiplication while high relative humidity and high rainfall were detrimental for survival of mealybug population.

Studies on the biology of grape mealybug, *M. hirsutus* (Green) on pumpkin during the summer (April, 2018) and winter (October, 2018) season revealed that pre-ovipositional period ranged from 3 to 4 and from 6 to 7 days with an average of 3.40 ± 0.52 days and 6.40 ± 0.52 days. The ovipositional period ranged from 5 to 6 days and 7 to 8 days with an average of 5.30 ± 0.48 days and 7.30 ± 0.48 days, respectively. The hatching percentage of eggs varied from 76.67 to 86.67 and 90.00 to 93.33 per cent with an average of 83.33 ± 2.80 and 91.33 ± 1.42 per cent during summer and winter, respectively. During summer the fecundity ranged from 337 to 428 with an average of 374 ± 40.2 eggs while during winter it ranged from 352 to 496 with an average of 421 ± 49.7 eggs. During summer season the incubation period was 4.20 ± 0.70 and 3.55 ± 0.76 days, the nymphal period was 23.8 ± 1.15 and 21.5 ± 1.13 days, the adult longevity was 8.80 ± 0.68 and 2.40 ± 0.51 days and the total life span was 36.8 ± 1.52 and 27.5 ± 1.44 days in case of female and male, respectively. The incubation period, nymphal period and the adult longevity for female was 7.05 ± 0.83, 25.2 ± 1.30 and 14.2 ± 1.57 days and for male 6.40 ± 0.50, 22.6 ± 1.46 and 4.07 ± 0.80 days and thus accounting 46.5 ± 2.20 and 33.1 ± 1.74 days for total life span of mealy bug, respectively during winter season. The total life cycle of grape mealybug was shorter during summer than winter.

Abstract contd….. **Mr. Uday A. Pawar**

Thirty grape growers each from district *viz.*, Ahmednagar, Pune, Solapur, Sangli and Nashik of Western Maharashtra, were interviewed based on questionnaire by random selection. Results revealed that irrespective of the growing conditions, grape growers relied mainly on novel insecticides (55.83 %) followed by conventional insecticides (27.11 %) and bio-pesticides (17.06 %) for the pest management. 88.66 % growers knew severity of insect pest problems in grape, only 19.33 % growers were aware about the natural enemies and 59.33 % knew about bio-pesticides usage. 68.00 % of growers were well aware of the ill effects of pesticides. 24 % of grape growers were found using mobile applications to collect information on pest management. There is great scope to increase grower's participation in the usage of natural enemies, bio-pesticides and android applications based advisory for the pest management. Majority of the grape growers mainly relied on pesticide retailers followed by neighbours, media, university scientists and agricultural department for selecting insecticides for spraying.

The field bio-efficacy of insecticides was evaluated against *M. hirsutus* during 2017-18 and 2018-19. The experiment was conducted in randomized block design with the three replications. The observations on per cent mortality/reduction of egg sacs and (nymphs + adults) were recorded at 3, 7, 10 and 14 days after spray. Amongst the ten test insecticides, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) @ 0.75 ml /L was found to be the most effective treatment, followed by Spirotetramat 15.31 % OD @ 0.7 ml/L and Imidacloprid 17.8 % SL @ 0.45 ml/L, respectively and they were at par with each other. Though the insecticides *viz.,* Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) proved superiority in controlling the mealybugs, also registered highest yield (21.61t/ha) and exhibited relatively higher net realization, but failed to meet adequate ICBR due to higher market price. The highest Incremental Cost Benefit Ratio (ICBR) was registered in Chlorpyrifos 20 % EC @ 2 ml/L (1:46.19) followed by Lambda cyhalothrin 5 % EC @ 0.5 ml/L (1:45.92) and Imidacloprid 17.8 % SL @ 0.45 ml/L (1:42.66). Chlorpyrifos is on the verge of the ban by the government. Pest resurgence problems were associated with synthetic pyrethroids limiting them to incorporate in IPM strategies. Hence, Imidacloprid 17.8 % SL @ 0.45 ml/L, a neonicotinoid group of insecticide may be recommended against grape mealybug.

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1. INTRODUCTION

Grape (*Vitis vinifera* L.) belong to the family *Vitaceae* and is one of the most important fruit crops of temperate zone, which has acclimatized to sub-tropical and tropical agro climatic conditions prevailing in the Indian Sub-Continent (Mani *et al.*, 2014). It is widely grown in United States of America, Italy, Spain, France, Turkey, China, Argentina, Chile, Iran, South Africa, Egypt, Australia, Brazil and India. In world over, it is mainly grown for wine making, raisin making and for table purpose but in India it is mostly consumed as fresh fruit and only a small quantity is utilized for the production of raisins and wine.

The production of grapes in India is 2951 thousand MT in an area of 137 thousand ha and with a productivity of 21 MT/ha (NRC Grapes, 2019). The major grape growing states in India are Maharashtra (75.94 %), Karnataka (19.16 %), Mizoram (1.76 %), Tamil Nadu (1.55 %), Andhra Pradesh (0.58 %), Telangana (0.25 %) and Punjab (0.21 %) amounting to nearly 99 per cent of the total production. Maharashtra ranked first in production of grapes, producing about 78.30 per cent of the total production of grapes in India (Anonymous, 2018).

Grapes have a great demand in foreign market especially in the countries like United Kingdom, Saudi Arabia and UAE fetching valuable foreign exchange for the country (Anonymous, 2015). The grape sector in India includes various stakeholders such as grape growers, wineries and allied industries and has potential to continuously generate employment. India has exported the total of 1,93,690.51 MT fresh grapes of rupees 2,17,686.83 lacs to different countries during 2019-20 (APEDA, 2020).

Grapes are known as angoor in unani and draksha in ayurvedic system of medicine. As per Ashtanga Hridaya Sutrasthana, draksha is said as ‘phalottama’ *i.e.* of all the fruits, grape is the best. (Deepashri and Suchetha, 2017). Grape berries are rich in nutrition a 100 g of green or red grapes contains 104 Kcal of energy, 1.09 g of protein, 0.24 g of fat, 27.33 g of carbohydrate, of which 23.37 g is sugars, 1.4 g of fiber, 288 mg of potassium, 15 mg of calcium, 0.54 mg of iron, 11 mg of magnesium, 30 mg of phosphorus, 3 mg of sodium, 0.11 mg of zinc, 4.8 mg of vitamin C, 22 micrograms of vitamin K and 3 micrograms of folate. Grapes contain important polyphenols. Resveratrol is among them and it is mainly found in the skins of red grapes. Studies revealed that it may able to slow or prevent the growth of tumors in lymph, liver, stomach, breast, colon, skin cancer and leukaemia. (Ware, 2017).

Grape vine contains biflovonoids (Vitamin P), thiamine, niacin, Procyanidins B1 and B2 *etc.* (Rizvi *et al.*, 2019). A recent study conducted at the North Carolina State University revealed that, many subtypes of phytonutrients, such as flavanols and proanthocyanidins present in grapes were able to successfully block the activity of the main protease (MPro) in the novel coronavirus (TOI, Dec 2020).

Commercial viticulture has made considerable progress in Maharashtra. Per hectare yield obtained in the well-maintained vineyards of Thompson seedless in Maharashtra is about 30 tonnes and is reported to be the highest in the world. However, temporal changes estimated for the period 2003-2004 to 2012-2013 for area and compound growth rates analysis in Maharashtra shown that the area under grapes has increased in Western Maharashtra, particularly in Nasik district and declined in Sangli and Solapur districts. The productivity of grapes in Maharashtra has declined by 23.20 per cent and it has declined by 0.28 per cent during the last ten years (Bhosale *et al.*, 2016).

Besides the vagary of nature insect pest ravages is one of the most serious problem in grape cultivation faced by growers. All commercial varieties are susceptible to various insects. Extensive and intensive cultivation of grapes tends to attract various kinds of insect pests to the vineyards. Bournier (1977) listed 132 insects that are known to attack grape vine in the world. According to Butani (1979) over 85 species of insects are known to occur on grapes in India. The major insects infesting grapevine are mealybugs, thrips, jassids, mites, flea beetles, caterpillars, stem borers and nematodes (Yadav and Amala, 2013).

According to Azam (1983), the grape mealybug alone caused yield loss ranging from 50 to 100 per cent in the field and losses are more conspicuous subsequent to winter pruning (78 %) than after summer pruning (58 %). A total of 20 species of mealybugs have been reported infesting grape vine in the world (Babu and Azam, 1987). Total of nine identified species and one undetermined *Pseudococcus* sp. are known to attack grapevine in India, among them the most devastating species in India is unquestionably the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Pseudococcidae: Hemiptera) (Mani *et al.,* 2008). It is a species possibly native from Southeastern Asia or Australia, having a large geographic distribution, and being present in tropical and subtropical regions of the world (OEPP/EPPO, 2005). It is associated with 73 plant families in more than 200 genera (Martinez, 2007). Fletcher (1919) first reported its occurrence on grapevine in India. Severe outbreak of mealybugs was reported during 1974 in Andhra Pradesh and subsequently in several other places by (Tejkumar *et al.,* 1977).

Babu and Azam (1989) reported that the grapevine mealybug, *M. hirsutus* (Green) is a serious vineyard pest in India and its infestation was becoming more severe every year. In case of severe mealybug infestation in the nursery, young vines are often killed. Whilst, in the main field attack resulted in up to 90 per cent cluster damage. During feeding on the phloem sap, *M. hirsutus* injects into the plant a toxic saliva, resulting in malformed leaves, trunks, shoots, flowers and fruits (Kairo *et al.,* 2000). Heavily infested bunches shrivel and drop or become sticky and unfit for consumption. Raisins cannot be prepared from such infested bunches. The quality of wine is also affected and cannot be used for table purpose either. When vines are pruned the mealy bug attacks to tender developing sprouts causing stunted growth. The sugary honey dew excreted by the mealybugs encourages the growth of black sooty mould fungus (Alleyne, 2004).

Mealybugs are protected by nature’s umbrella perhaps the most important factor is the habitat of the mealybug, as the pest lives in protective areas such as cracks and crevices of the bark, at the base of petioles, on the underside of leaves and between the spaces aside berries. Eggs of the pest protected by waxy filamentous secretion of ovisac are almost impossible to reach with insecticide. Hence, Lower (1968) rightly called that mealybugs are “hard to kill insects of fruit trees”.

Rao and David (1958) stated that the mealybugs are covered with waxy coating, so effort made in the past to control the mealybug with insecticides alone did not prove to be very satisfactory. The grape mealybug has become serious on account of indiscriminate use of pesticides. Though the natural enemies are usually present in crop ecosystem, but their effectiveness is impaired by excessive use of hazardous pesticides warrants integrated pest management approach. Some species of mealybugs are able to develop resistance to insecticides (Mc Kenzie, 1967). Mruthunjayswami *et. al.,* (2016) reported that, *M. hirsutus* has developed high level of resistance against few organophosphate insecticides. Various pesticides have been tried either alone or in combinations for the control of this pest. A few of them are only temporarily effective.

They kill only those mealybugs that are exposed, those sheltering in the crevices of the bark and inside bunches escape and quickly rebuild their population and cause serious damage (Manjunath, 1985).

The management of pink mealybug is complicated by several factors; among them foremost is the lack of efficient mealybug detection and monitoring tools. Seasonal incidence and biology of this pest has needed to study contemporarily with changing climatic conditions. As more area in Pune, Ahmednagar, Aurangabad, Osmanabad and Solapur districts shifted to custard apple cultivation which alternatively serves as important host plant for mealybug incursion. Recently, invasive mealybug species *viz.*, *Pseudococcus jackbeardsleyi* and *Paracoccus marginatus* were recorded on custard apple and papaya from Pune region, respectively (Anonymous, 2017).

In preview of safety of entomopathogenic fungi towards humans, the environment and non-target it offers a safer alternative for use in IPM over chemical insecticides (Hajek and Goettel, 2007). Integration of selected strains of entomopathogenic fungi with ecofriendly insecticides can improve the control efficiency, besides decrease the amount of insecticides required, minimize the risks of environmental contamination by pesticide residues, can delay the expression of insecticide resistance and pest resurgence. Biorationals or low risk insectides are synthetic or natural compounds that effectively control insect pest and have low toxicity to non target organisms (Hara, 2000). Recently some organophosphates, insect growth regulators (IGRs) and bio-pesticides have been recommended for the management of mealybug (Suresh *et al.*, 2010; Reki *et al.,* 2019).

Considering the facts of pest incidence status, the management strategy incorporating insect growth regulator, chemical insecticide, botanical insecticide and entomopathogenic fungi alternately to ensure the problem of environmental safety and enhanced the farmer's interest in using such management strategies with sustained economic returns, the present investigation is undertaken with following objectives.

1. To study the seasonal incidence of grape mealybug, *Maconellicoccus hirsutus* (Green).
2. To study the biology of grape mealybug, *Maconellicoccus hirsutus* (Green).
3. To study pesticides usage pattern for management of grape mealybug in Western Maharashtra.
4. Bio-efficacy of insecticides against grape mealybug, *Maconellicoccus hirsutus* (Green).

2. REVIEW OF LITERATURE

The available literature pertaining to the seasonal incidence, biology and management of grape mealybug is briefly reviewed as under:

2.1. Seasonal incidence of grape mealybug, *M. hirsutus*

Rawat and Modi (1969) reported that adult female mealybugs were found abundant during December, January, May and June months in Madhya Pradesh. Singh and Ghosh (1970) studied the seasonal activity of *M. hirsutus* on mesta. They reported that the peak infestation was usually noted from the first week of September to the last week of October.

Azam (1983) noticed that the active period of *M. hirsutus* was in June to August and October to March on grapes around Hyderabad. The mealybugs were present throughout the year; however their severe infestation observed during February to March on Thompson Seedless, Anab-e-Shahi and Bangalore Blue varieties in parts of Bangalore, Tumkur and Bangarpet districts of Karnataka (Manjunath, 1985).

Babu and Azam (1987) recorded the population density of *M. hirsutus* around Hyderabad during 1984-85. They found that the pest was infesting the vegetative parts of the crop from early June (1.7 female adults/twig) to the end of December (5.1 female adults/twig). Least population of female adults was present from first fortnight of September to second fortnight of October due to pruning operation. Further the mealybug again become active during January (22.5 female adults/bunch) and population increased as the grape cluster developed. Population reaches its maximum at fruit ripening stage *i.e.* (32.5 female adults/ bunch) during March.

Mani and Thontadarya (1987) recorded heavy population of the mealybug, *M. hirsutus* from January to May and subsequently low from June to December in vineyards in South India. They opined that maximum temperature showed significant positive whereas relative humidity showed a significant negative correlation with mealybug population, respectively.

Shreedharan *et al*. (1989) reported that the pest, *P. citri* was severe in summer season March-July and no incidence found in winter season October-November in mandarin orange (*Citrus reticulata* Blanw.). Their studies further revealed that weather parameter *viz.,* temperature and humidity had significant positive and negative correlation, respectively. Whereas total rainfall had no clear correlation onto the development of *P. citri.*

The mealy bugs population dynamics studies conducted during 1991-92 on pomegranate and custard apple at Rahuri, Maharashtra State indicated that, the peak mealy bug population in pomegranate orchard was recorded in April (31.50 %) and May (21.16 %) and low incidence from October (0.0 %) to December (1.0 %). Whereas in custard apple orchard the infestation of mealy bugs was much evident during October (2.50 %) and (5.80 %) in November (Anonymous, 1991).

The studies were under taken on the population dynamics of pests of pomegranate and custard apple at Rahuri from 1991-94. The incidence of mealybug was the highest during Ambebahar. The maximum build up of pest was recorded in the month of May; while the least incidence was noticed during the month of December on pomegranate, indicating a significant and positive correlation with maximum temperature, minimum temperature and significant negative correlation with morning relative humidity. In custard apple orchard, the mealy bug population was more pronounced during October - November at the time of maturity of fruits indicating non-significant negative correlation with all meteorological parameters. Another study on pests of custard apple carried out at Solapur (Maharashtra) in 1994 revealed that the infestation of mealy bug was severe and recorded its peak (85.10 % infestation of fruits/plant) in the first fortnight of December and there existed a negative correlation of mealybug infestation with minimum and maximum temperature, relative humidity and rainfall (Anonymous, 1995).

Balikai (1999) studied the seasonal incidence of *M. hirsutus* on Thompson Seedless grape at Tikota village in Karnataka from 1990 to 1992. Though mealybug population was recorded throughout the year, about two months after pruning in October, it started to increase from January and peak infestation was observed during February-March before harvesting. After harvesting, the mealybug population remained low from May to December.

Dwivedi *et al.* (2003) recorded the seasonal incidence of mango mealybug in relation to mean temperature and humidity. The population of mealybug *(Drosicha mangiferae)* was highest (84.6) at the base of the tree trunk in February and lowest (0.58) in December.

Koli (2003) opined that grape mealybug was active during September to March in Rahuri (Maharashtra). The number of egg sacs, nymphs and adults per bud varied from 0.8 to 1.83, 8.8.3 to 61.58 and 2.16 to 17.08, respectively from September to March. The egg sacs, nymphs and adults of mealybugs on grapes showed highly significant and positive correlation with maximum and minimum temperature and highly significant negative correlation with morning and evening relative humidity and non-significant negative correlation with rainfall.

Yadav *et al.* (2004) studied the population density of mealybug (*Drosicha mangiferae)* in cv. Amrapali orchard in Meerut, India. The average number of mealybugs was recorded and correlated with abiotic factors, *i.e.* average temperature, relative humidity and rain. The highest population (17.50) of mango mealybug was recorded on April 2000 at an average temperature and relative humidity of 27.43°C and 46.57 per cent, respectively. A decreasing population trend, *i.e.* 8.25 and 4.75, was observed on ending April and May 2000 at an average temperature of 31.31 and 31.55°C and relative humidity of 48.35 and 49.80%, respectively due to increasing temperature and relative humidity. The lowest population (1.50) of mango mealybug was recorded on ending May 2000 at an average temperature and relative humidity of 33.03°C and 56.75 per cent, respectively. No infestation was recorded on 31 May 2000 due to an increase of temperature (33.55°C) and relative humidity (63.05 %).

Kulkarni *et al.* (2008) studied the seasonal incidence of grape mealybug in National Centre for Grapes, Pune and reported that mealybug population was distributed sporadically and the highest population (5–6 colonies per vine) during the last week of February to the last week of March coincided with the fruiting and harvesting season.

Katke *et al.* (2009) studied the seasonal incidence of grape mealybug, *Maconellicoccus hirsutus* (Green) during 2005-2007 in relation to the prevailing as well as the previous (antecedent) four weeks (one/two/three/four lead weeks) weather. It was observed that the insect was prevalent throughout the year. Peak populations of 14.5 and 32.4 colonies per vine were observed during 36th standard week in the vegetative and 10th standard week in the fruiting season, respectively. Mealybug incidence correlated significantly and negatively with minimum temperature, bright sunshine hours and rainfall during real time and at three lead (previous) weeks, but positively with morning and afternoon relative humidity at two and three lead weeks, respectively during pre-monsoon season.

Cotton mealy bug, *P. solenopsis* (Tinsley) infestation started appearing in the month of September with a population of 0.50 /10 cm apical shoot in the 38th meteorological week. The peak population increased up to 115.42/10 cm apical shoot in the third week of January and thereafter reached suddenly to 180.42/10 cm apical shoot in the 7th meteorological week. Later on infestation of mealybug declined gradually and remained 146.64/10 cm of apical shoot in the 14th meteorological week (Hanchinal *et al.*, 2010).

Singh *et al.* (2010) found that the maximum incidence mealybug was observed during first fortnight of March when maximum and minimum temperature, morning and evening relative humidity were 26.4 and 14.0°C, 90.3 and 53.7 per cent, respectively. After second fortnight of April, males were not observed when maximum and minimum temperature, morning and evening relative humidity were 37.3, 22.1°C, 61.6 and 18.9 per cent, respectively.

Bhute *et al.* (2012) reported that rainfall and minimum temperature had negative correlation whereas maximum temperature had a positive correlation with the build up of cotton mealybug, *Phenacoccus solenopsis*.

Garcia-Álvarez *et al.* (2014) studied the seasonal distribution and reproductive potential of the pink hibiscus mealybug, *M. hirsutus* (Green) in Nayarit, Mexico and recorded that populations of mealybug were lower during August to October, moderate during November to February and highest during March to June.

Sathe *et al.* (2014) studied the incidence and damage caused by *Drosicha mangiferae* on mango at Kolhapur district during the years 2011-2013 and recorded that the pest occurred on the crop in December and caused extensive damage by sucking cell sap from tender leaves, stem, flowering and fruiting bodies which resulted in extensive fall of flowering and fruiting bodies. The mealybug population was associated with crop upto ripening of fruits.

Prasanna and Balikai (2015) studied the seasonal incidence of grapevine mealy bug, *M. hirsutus* (Green) for two consecutive years during 2009-10 and 2010-11. The infestation of mealy bug egg masses and colonies was observed throughout the year with peak incidence during fruiting season December to March months. The mealy bug showed negative correlation with relative humidity, rainfall, minimum temperature and positive correlation with maximum temperature and bright sunshine hours, respectively.

Dixit *et al.* (2016 a) assessed the effect of temperature, relative humidity and rainfall on development of various stages of mealybugs on custard apple under field condition during August- December, 2014. The incidence of mealy bug was observed in orchard in 37th meteorological week 2014. They noticed mealybug population shot up (105.32 mealy bug per fruit) in the 45th meteorological week and after that it gradually decreases. The non-significant correlation between mealybug development with respect to various weather parameters studied, clearly indicates that once the population of mealy bug started increasing climatic factors played little role in the development.

Angu *et al.* (2017) studied the seasonal incidence of mealybug on grapevine at Hyderabad from July, 2014 to March, 2015. They revealed that incidence of mealybug on grapevine started increasing from the first standard week of January 2015 and continued to increase thereafter till up to the harvesting of bunches.

Das and Chakraborty (2018) found that the mango mealybug, *D. mangiferae* first appeared on 7th meteorological week and natural higher infestation of mealybug was present during 15th to 17th meteorological week. The population decreases mostly from 18th to 20th meteorological week. The mealybug population showed significant positive correlation with minimum temperature and relative humidity gradient whereas, significant negative correlation with minimum relative humidity, respectively.

Gaikwad *et al.* (2018) studied the seasonal incidence of papaya mealybug, *Paracoccus marginatus* during 2013-2014. They reported that the *P. marginatus* was prevalent throughout the year. The peak activity of papaya mealybug was observed from 13th to 18th meteorological week. The maximum population was recorded (105.8 mealybugs/5 cm^2/leaf/plant) in the 18th meteorological week. Further, their study revealed that mealybug incidence was positively correlated with maximum temperature and sunshine hours, respectively. Whereas, it was negatively correlated with minimum temperature, rainfall and relative humidity, respectively.

Gundappa *et al.* (2018) studied dynamics of mango mealybug in the mango growing agro-ecology of Lucknow region in Uttar Pradesh during three consecutive seasons (2013-2015). Wider variations in the occurrence of mango mealybug were inferred from the study across 22 locations and three respective seasons. The peak incidence of mango mealybug was found at 7th, 3rd and 10th SMW during the mango seasons of 2013, 2014 and 2015, respectively. The mango mealybug incidence showed significant positive corelation with maximum relative humidity and rainfall across the seasons.

Harde *et al.* (2018) studied the seasonal incidence of mealybug on *Bt* cotton at Jalna, Maharashtra. The results of two years study revealed that highest incidence of mealybug observed about 10 % during 5th week of September in 2009-10 and 9 % incidence during 3rd week of October in 2010-11. Correlation studies further shown that mealybug had positive correlation with maximum temperature, minimum temperature and maximum relative humidity in both the season.

Seasonal abundances of the sucking insects, *viz.,*mealybug, white fly and scale insects were monitored during September, 2016 to June, 2017 in a guava *Psidium guajava* orchard. Sucking insect was monitored by weekly observation on the leaves. The mealybug, white fly and scale insects were abundant during 4th week of November to 4th week of January and they showed fluctuations in their population. The mealybug, white fly and scale insects had peak abundance in the 1st week of January, 4th week of November and 1st week of December, respectively. The daily mean temperature and relative humidity influenced the abundance of the mealybug. Temperature individually contributed 30.0 per cent abundance. Whereas, temperature with relative humidity combined had 34.8 per cent (Amin *et al.,* 2019).

Jadhao *et al.* (2019) studied the seasonal incidence of major sucking pests of pomegranate *viz.,*aphids, thrips, mealybugs and coccinellides at Parbhani during 1st to 52nd meteorological weeks of 2014. The data indicated that the sucking pest population was high from 1st week of January to 2nd week of March (1st to 11th SMW) and 3rd week of October to last week of December (42nd to 52nd SMW).

Field experiment on seasonal incidence of mealybug on cotton was conducted in Coimbatore, Tamil Nadu during 2016-2017. Results revealed that peak population of *Phenacoccus solenopsis* (400.75 insects/plant) was recorded in October, that decreased slowly during January (100.6 insects/plant) and there was least population during February - March. Correlation analysis between weather parameters and mealybug activity indicated positive correlation with maximum temperature, minimum temperature, relative humidity and negative correlation with rainy days (Thangavel and Ganapathy, 2019).

Zia and Haseeb (2019) recorded seasonal incidence of cotton mealybug, *Phenacoccus solenopsis* on okra, *Abelmoschus esculentus* at weekly interval from May to

September 2017. The results showed that the population of mealybug started building up from the month of May and reached its peak in 3rd and 4th week of August. The population showed negative correlation with maximum temperature and positive correlation with relative humidity, respectively.

Baidya and Chatterjee (2020) studied the seasonal incidence of different insect pests and natural enemies of mulberry under Terai agro-ecological region, West Bengal, India from January 2017 to March 2018. Studies revealed that high incidence of pink mealybug was reported in March and declined in August with a least population during December. The peak population of pink mealybug was observed on 31st SMW, 2017 with 61.9 nymph and adult per 10 cm twig. The population of pink mealybug was found to be significantly and positively correlated with maximum temperature but, significantly negatively correlated with rainfall.

Prabakaran *et al.* (2021) studied the population dynamics of sucking pests of guava under a high-density planting system at Tamil Nadu Agricultural University, Coimbatore during 2016–2017. They found that maximum incidence of mealybugs *viz.,Ferrisia virgata* (122.00/ 3 leaves/ tree) was during 12th SMW, likely maximum counts of *Planococcus citri* was during the 16th SMW (102.00/ 3 leaves/ tree) and that of *Paracoccus marginatus* (108/ 3 leaves/ tree) during the 13th SMW. They also observed a positive correlation with maximum temperature, solar radiation, respectively and a negative one with minimum temperature, relative humidity and rainfall, respectively for the incidence of sucking pests.

Chowdhury *et al.* (2022) carried out a year-long study at Jahangirnagar University Campus Dhaka, Bangladesh; during September 2004 to August 2005 and reported that Coccids are amongst the most destructive pests in varying degrees to the horticultural crops. They evaluated the prevalence of its fauna *viz.,Ferrisia virgata* followed by *Chloropulvinaria pisdii, Planococcus pacificus, Perissopneumon ferox, Icerya aegyptiaca*, *Aspidiotus destructor*, *Crypticerya jacobsoni*, *Icerya minor*, *Rastrococcus spinosus, Pseudococcus citriculus*, *Maconellicoccus hirsutus, Cerococcus indicus*, and *Coccus hesperidum*. The coccid population started to increase after the winter season and maintained a steady level up to the end of the rainy season (March to August). They noticed that rain did not make any significant differences (F = 1.445, df = 11, P = 0.168) in the pest infestation. Whereas the mean number of coccids at different months was positively correlated with the monthly average temperature (r = 0.390) and relative humidity (r = 0.412), respectively.

2.2 Biology of grape mealybug, *M. hirsutus*

Mani (1986) observed life history of grape mealy bug *M. hirsutus* (Green) at 24°C to 28 °C temperature. A female laid eggs in the range of 350 to 500. Observed Fecundity was 510.52 ± 30.24 and 432.18 ± 21.68 eggs per female on pumpkin and grapevine, respectively. Average incubation period was 5.15 ± 0.59 days. Three nymphal instars in female and four nymphal instars in male, total nymphal period of female and male was 19-24 and 17-22 days, with an average of 21.16 ± 1.07 and 19.70 ± 0.88 days, respectively. The developmental period of female was 26 to 31 days, while, it was 24.85 days in the case of male. Total life cycle was completed in a month *i.e.* 30 days.

Babu and Azam (1987) studied the biology of *M. hirstutus* (Green) on pumpkin in Andhra Pradesh, India during June 1984 to April 1985. The duration of the life cycle on pumpkin was 24 days in April (Mean temperature 31 °C) and 48 days in November (Mean temperature 25 °C). Adult females laid on an average of 317 eggs over a period of 46.7 days with a minimum of 114 eggs in 21.3 days and maximum of 509 eggs in 69 days. Incubation period of egg was 10.9 days at 25 °C and 5.1 day at 31 °C., respectively.

Jadhav (1993) studied the life history of grape mealybug, *M. hirsutus* (Green) on sprouted potatoes at different temperatures in the laboratory (21.5°C), glass house (25.0°C) and BOD incubator (30.0°C) and reported an average fecundity of 385, 352 and 277 eggs per female at 21.5, 25.0 and 30.0°C, respectively. The total life span of female recorded was 48-58, 43-49 and 38-43 days at 21.5, 25.0 and 30.0°C temperature, respectively.

Martinez *et al.* (1998) studied the biology of *Planococcus minor* on potato sprouts at 26°C temperature and reported a fecundity of 219 eggs per female.

Shelke (2001) studied the biology of *M. hirsutus* (Green) on sprouted potatoes and reported that, the incubation period for female and male ranged from 5-10 and 5-9 days, with average of 6.9 and 6.7 days, respectively at 21-22°C during winter season. While the incubation period for female and male ranged from 3-4 days with an average 3.3 and 3.4 days, respectively at 30-31°C during summer season. The duration of total nymphal period of female was 23-28 and 18-22 days with the mean of 24.9 and 19.4 days while for male it was 21-25 and 17-23 days with a mean of 22.8 and 19.6 days at

22-24°C and 30-35°C during winter and summer, respectively. The pre-ovipositional period was 6-7 and 3-4 days with a mean of 6.4 and 3.3 days and ovipositional period was 11-13 and 5-6 days with an average of 11.6 and 5.3 days during winter and summer, respectively. Fecundity was 310 - 505 and 185 - 410 eggs with a mean of 390 and 271 eggs during winter and summer, respectively. The total life span of female was 45-54 and 29-35 days with mean of 49.7 and 31.2 days and for male it was 31-37 and 23-28 days with a mean of 33.9 and 25.4 days during winter and summer, respectively on sprouted potatoes.

Serrano and Lapointe (2002) studied the biology of *M. hirsutus* (Green) and they reported that, the incubation period was 5.3 ± 0.7 and 4.6 ± 0.6 days. While hatching percentage was 91.2 ± 8.0 and 93.2 ± 7.7 on sprouted potato and pumpkin, respectively.

Marcano *et al.* (2006) studied the developmental time, fecundity and fertility of *M. hirsutus* at five constant temperatures (15, 20, 25, 30 and 35°C), using potatoes as the host. At 15°C there was no development of the nymphs observed. At temperatures of 35, 30, 25 and 20°C, the developmental time taken by female nymphs were 18.9, 17.5, 17.5 and 34.4 days and developmental time for the male nymphs were 17.3, 20.2, 19.1 and 35 days, respectively. The longevity of mated females was 16.6, 22.6, 20.7 and 30.8 days and unmated females was 46.7, 59.5, 57.5 and 87 days and the males was 4.6, 3.8, 6.7 and 5.5 days. The total time for development was 42.8, 50.5, 50.7 and 82.7 days for mated females and 74.8, 84.4, 86.8 and 139.3 days for unmated females and 29.9, 33, 37.8 and 58.6 days for males. The fecundity was 231.2, 230.7, 244.5 and 205.1 eggs per female and the fertility was 96.54, 100.00, 98.27 and 95.76 per cent, respectively.

Tanwar *et al.* (2007) recorded the biology of *M. hirsutus* (Green) and reported that egg development accomplished between 3 and 9 days. There are three nymphal instars in female and four in males which lasts for 22-25 days. The last instar of the male is an inactive stage with wing buds within a cocoon of mealy wax. Individual mealybugs may take as long as 30 days to grow through all the nymphal stages under normal conditions.

Katke *et al*. (2009) studied the biology of grape mealy bug, *M. hirsutus* (Green) on pumpkin during winter and summer season. They observed distinctly segmented, soft oval body adult female is longer than male whereas, adult male were orange coloured, minute, very active and distinguished from female with the presence of one pair of wings and two caudal filaments on the last abdominal segment. The total nymphal period of female and male were 24.8 ± 1.17 and 23.3 ± 1.07 days, respectively during winter season. Whereas, in summer the total nymphal periods lasted for 23.6 ± 1.02 and 21.6 ± 0.89 days, respectively. The oviposition period between from 7 to 9 days and 6 to 9 days with an average of 8.7 ± 0.72 and 7.9 ± 0.69 days during winter and summer, respectively. The longevity of adult female ranged between 13 to 16 days, with a mean 15.6 ± 0.81 days and for male it ranged between 3 to 5 days, with mean of 4.1 ± 0.53 days. The total life span of *M. hirsutus* (Green) accounted for 45.9 ± 1.92 and 32.8 ± 1.72 days for female and male, respectively during winter season. While it accounted for 42.5 ± 1.54 and 29.0 ± 1.23 days for female and male, respectively during summer season.

Rishikumar *et al*. (2009) studied the life history of *P. solenopsis* in Sirsa. The number of ovisac varied on an average from 2-4 per female. The mealy bug was found as a prolific breeder with mean reproductive potential based on crawler production per female in a range from 289 to 517 on cotton. The numbers of nymphal stages recorded were 3 both in female and male (two nymphal instars and a cocoon). Both 1st and 2nd instar mealybug lacked mealy wax secretion. The first instar mealybug/crawlers lacked permanent feeding site because of high motility. The total nymphal duration in case of male and female was 13-15 days and 14-19 days, respectively. In the last instar female nymph the appearance of mealy wax scale covering entire body was observed but in male secretion of cocoon (puparia) was observed leading to emergence of short lived winged males with two long waxy caudal filaments at the posterior end. The longevity of males and females was 1-1.8 days and 13-16 days, respectively.

Ahmed and Shaaban (2010) conducted studies on the biology of *P. citri* (Risso) on citrus, grape and guava in Egypt and results showed that, the life cycle of the citrus mealybug, *P. citri* at 30°C were 21.4 ± 2.45, 32.6 ± 2.44 and 38.8 ± 1.56 days, respectively and these results indicated that, *P. citri* (Risso) prefers citrus followed by guava and grape.

The biology of the mealybug *P. solenopsis* was studied on cotton under laboratory conditions between August and October of 2009 with mean temperature and relative humidity of 23.3 - 30.2^{o}C and 40.5-92.5 per cent, respectively, in central India. The developmental period from immature crawler to adult stage was greater for males (18.7 ± 0.9 days) compared to females (13.2 ± 1.8 days), probably due to the additional moult to the pupal stage in males. Survival of second instars was lower (45.5 %) than first and third instars (71.4 %). Females showed dynamic patterns of fecundity with the number of crawlers produced per female ranging between 128 and 812, with a mean of 344 ± 82. The reproductive period lasted 30.2 ± 8.2 days. Parthenogenesis with ovoviviparity (96.5 %) was dominant over the oviparous (3.5 %) mode of reproduction. Adult females lived 42.4 ± 5.7 days. Males accounted for less than 5% of the population, and lived 1.5 ± 0.1 days (Vennila *et al.*, 2010).

Patil *et al.* (2011) studied the life cycle of mealybug, *Maconellicoccus hirsutus*, on different hosts at different constant temperatures. *Hibiscus rosasinensis* was found to be the most suitable host with the highest number of eggs, crawlers and adults along with greater longevity of 21 days. Fruits of tinda, *Praecitrullus fistulosus* were found to be the second most suitable host after *Hibiscus rosasinensis*. Females reared at 25 and 42°C produced significantly fewer eggs and reduced number of crawlers, adults, adult weight and longevity. The egg production, number of crawlers and adult formation increased with temperature until 38°C. The developmental time also decreased with an increase in temperature from 25 to 42°C.

Seni and Sahoo (2011) studied the biology of mealybug, *Rastrococcus iceryoides* (Green) on citrus and recorded that, the female and male nymphs moulted thrice and four times, respectively in 18-24 (20.41 ± 3.16) days and 16-22 (19.50 ± 1.00) days at 26- 36°C and 84-91 per cent relative humidity to attain their adulthoods. They also recorded that, the pre-oviposition and oviposition period, fecundity and incubation period of eggs were 6 -11 days, 4 - 6.9 days, 168 – 298 eggs per female and 5.2-7.6 days, respectively.

Sahito *et al*. (2012) noticed that mealybug, *Maconellicoccus hirsutus*, completed its life cycle from eggs to death in 32-35 days, while female survived for 41-52 days at 25 ± 2°C, under laboratory condition.

Kumar *et al.* (2014) studied the biology of *Paracoccus marginatus* at GKVK, Bangalore and recorded that, the females had three nymphal instars without any pupal stage, while the male had three nymphal instars besides, pre-pupal and pupal stages. The total nymphal period for female ranged from 14 to 21 days, (mean- 17.32 ± 1.6 days) while for male the range was 16 to 23 days, (mean- 18.9 ± 1.3 days). Bisexual and parthenogenetic modes of reproduction were observed. The fecundity of the female mealybug ranged from 248 to 967, with an average of 618.9 ± 19 eggs.

Chong *et al*. (2015) studied the biology of *M. hirsutus* revealed that, the adult female were wingless, oval, flattened in profile and 2-3 mm in length. Body was greyish pink and cover with thin white cotton like wax. Posterior tufts of cotton like waxy deposits were often present. Adult male were gnat like with pink or orange body and about 1 mm in length with single pair of wings and pair of elongated wax pencils.

Suroshe *et al.* (2016) studied the life history of *P. solenopsis* on *Parthenim r*esults revealed that males and females of mealybug, *Phenacoccus solenopsis* Tinsley went through four and three nymphal instars, with total life cycle of 14.06 ± 1.09 and 15.53 ± 0.83 days, respectively. Pre-mating, pre-ovipositional, ovipositional and post ovipositional periods were observed to be 2.11 ± 1.26, 7.66 ± 0.70, 10.22 ± 2.68 and 3.77 ± 1.71 days, respectively. The adult longevity was 47.125 ± 7.01 (for unmated females), 3.66 ± 0.81 (for unmated males), 24.66 ± 4.5 (for mated females) and 1.33 ± 0.50 days (for mated males). Reproduction was sexual and ovoviviparous, wherein only mated females laid eggs (167.77 ± 25.57/female). Life span (life cycle duration and adult longevity) observed was 61.5 ± 6.95, 18.66 ± 0.82, 38.44 ± 4.95 and 17.13 ± 0.97 days for unmated females, unmated males, mated females and mated males, respectively.

Karacaoglu and Satar (2017) studied some bioecological characteristics of Planococcus citri, under different temperature regimes during 2015-2016 at Citrus Pest Laboratory, Cukurova University, Turkey. The results of their study reveals that, shortest egg stage development period for females and males were 2.7 and 2.7 days at alternating temperatures of 25/30°C (12:12 hr), respectively. The first nymphal stage lasted 7.86 days for females and 8.1 days for males at 25°C. The longest duration for the second nymphal stage was obtained at 15°C with 25.7 and 22.5 days for females and males, respectively. While third nymphal stage for *P. citri* females completed in 7.0 days at 25°C and the pupal stage for *P. citri* males lasted 7.8 days at 25°C. The development thresholds of females and males were 8.5 and 9.5°C, respectively. Also, thermal constants of females and males were 666.67 and 500.00 degree-days and optimum development temperature determined was 25/30°C.

Biological studies were carried out on citrus mealybug, *P. citri* (Risso) (Hemiptera: Pseudococcidae) at Department of Plant Protection Research Institute, Sharkia Branch, Egypt during the 2010–2016. Results revealed that the accumulated degrees days (ADD) for male and female stages had significant varying effects on developmental periods, adult longevity and life cycle and generation period of *P. citri;*

reared on pumpkin fruits compared with those reared on potato sprouts. The periods of citrus mealybug stages were significantly reduced gradually by increasing of rearing degree of the tested temperatures *i.e.* 20, 25 and 30°C. The mathematical method showed that the accumulated degree days which required for completing one generation for females were 418.11 ADD unit (Mahamoud *et al.*, 2017).

Naik *et al.* (2017) studied the biology of *Maconellicoccus hirsutus* on custard apple. The result showed that, the female had three nymphal instars without any pupal stage, while male had three nymphal instars besides, pre-pupal and pupal stages. The developmental period from immature crawler to adult stage was greater for males (32.5 ± 4.63 days) compared to females (26 ± 2.05 days). Females showed dynamic patterns of fecundity with the ranged from 356 to 444 with an average fecundity of 407.8 ± 23.72 eggs per ovisac. Bisexual and parthenogenetic mode of reproduction was observed in case of *M. hirsutus.*

Iqra *et al.* (2020) studied the papaya mealybug (PMB), *Paracoccus marginatus* Williams and Granara de Willink, life cycle on two hosts, sprouted potato (*Solanum tuberosum*) and long bottle gourd (*Lagenaria siceraria*) under semi-controlled laboratory conditions and shown that, the total lifespan of *P. marginatus* on sprouted potato was 38.8 ± 4.4 days for female and 25 ± 2.3 days for male while on long bottle gourd, it was 30.8 ± 5.8 days for female and 22.4 ± 2.6 days for male, respectively. The observed nymphal period of the PMB female varies from 15 to 20 (17.8 ± 2.28) days on sprouted potato and 13 to 17 days (15.0 ± 2.0) on long bottle gourd. The nymphal period exhibited by the PMB male on sprouted potato and long bottle gourd was 22.2 ± 2.0 and 20.8 ± 2.3 days, correspondingly. Longevity was not affected by hosts for males and averaged 2.6 ± 0.5 days. In contrast, the longevity of the female on both hosts found dissimilar; for sprouted potato and long bottle gourd, it was 21.6 ± 2.6 and 17.8 ± 2.8 days, respectively. The fertility of PMB female on sprouted potato and long bottle gourd was observed as 168.8 ± 60.5 and 103.4 ± 30.8 crawlers (the first instar nymphs of PMB) per female, respectively. Parthenogenesis occurred in PMB on both of the laboratory hosts. Sprouted potatoes found better laboratory host as compared to long bottle gourd.

Karanjekar (2019) studied the biology of *M. hirsutus* on sprouted potatoes revealed that, the yellowish oval shape eggs were turned to pinkish coloured toward hatching. Incubation period varied from 3.8 to 4.1 days with hatching percentage of 76.67 per cent. The female had three nymphal instars, while male had four nymphal instars. The average duration of Ist, IInd and IIIrd instars of female were 6.9, 6.7 and 7.2 days, respectively. The Ist, IInd, IIIrd and IVth nymphal instars of male required 7.0, 6.4, 1.5 and 5.4 days, respectively. Adult female was sac like, pinkish coloured and wingless, while adult male was orange coloured with pair of wing and clearly visible two caudal filaments on the last abdominal segment. The adult survived for 8.9 days and 2.6 days in case of female and male, respectively. The male to female sex ratio was 4:1 observed. A generation of female was completed in 33.8 days while it required 26.7 days for male. Females showed dynamic pattern of fecundity with ranged from 179 to 387 with an average of 278 eggs per ovisac.

2.3 Pesticides usage pattern for management of mealybugs

The literature reveals that information on the pesticide usage pattern is meager. Hence related information on other crops/pests previewed.

Pyrethroids may have a range of toxic effects on humans and as a result, careful control of Maximum Residue Limits (MRL) in foodstuff is warranted. Mahdavian and Somashekar (2010) procured twenty two samples of grapes from Bangalore City Markets in 2007 with the objective of determining the contamination of α-cypermethrin and fenvalerate residues. The samples were analysed by multi residue method and determined by gas chromatography using ECD (Electron Capture Detector) gained average recoveries ranged from 73.5 to 83.5 per cent. Further the results showed that all the samples were contaminated with pesticides and urban consumers were at a risk of purchasing fresh fruits of higher levels of residues, beyond the MRL as defined by the FAO/WHO, The screening also showed higher concentration of cypermethrin in comparison to fenvalerate residue was present in samples.

Grapes grown in Bijapur district (Karnataka) were analysed for pesticide residue content by Pujeri *et al.* (2010) all the 8 fruit samples analysed showed the presence of one or the other group of pesticides. Only two samples showed pesticide residue content below the European MRL. The detected pesticides were Chlorothalonil, Chloropyriphos, Monocrotophos, Triazophos, Cypermethrin, Lamda Cyhalothrin, Matalaxyl, Flusilazole, Hexaconazole, Myclobutanil, Penconazole, Propiconazole, Triadimenol, Difenoconazole, Carbendazim, Azoxystrobin.

Dried grapes make the ideal low-calorie snack. The formation of gray mold during the drying of the grapes can severely decrease raisin production. Turgut *et al.* (2010) sampled dried grapes from 99 farms in the Aegean region of Turkey. They reported that pesticide residues were only present in samples originating from vineyards using conventional farming practices. Further pesticides *viz.*,chlorpyrifos methyl, chlorpyrifos ethyl, deltamethrin, lambda-cyolathrin, dichlofluanid, iprodione, and procymidone were detected in the dried grapes.

Patil and Katti (2012) reported that improper and unsafe use of agrochemicals, especially pesticides is not only harmful to environment but also to human health. They were interviewed a total of 100 agricultural labourers in Maharashtra and found that more than 75 per cent of labourers used either “moderately hazardous” or “highly hazardous” pesticides as classified by World Health Organisation (WHO). Moreover, 88 per cent did not use any form of protection, while handling pesticides. Poverty and illiteracy were greatly responsible for improper handling of pesticides.

Dey *et al.* (2013) studied the pesticide usage pattern in the three districts of Barak valley, Assam and revealed that the farmers often used pesticides ranging from high to extremely hazardous categories like organochlorine, organophosphate and carbamate. Various signs and symptoms of diseases/ physiological disorders were observed and the relative risk was also observed to be high. Lack of adoption of adequate protective measures increased the declining state of the health of farmers in the region.

Vegetable and fruit samples collected in five regions of Andhra Pradesh were tested for the presence of organochlorine (OC), organophosphorus (OP), and synthetic parathyroid (SP) compounds using a gas chromatograph equipped with electron capture and thermo sensitive detectors; of the samples tested, 36.60 per cent were found to have pesticide residues. Further the Organochlorine compounds α-endosulfan, β-endosulfan, were detected in 3.33 per cent and Synthetic pyrethroids compound residues, such deltamethrin were detected in 1.66 per cent of the samples with residues, respectively. Organophosphorus compound residues such as chlorpyrifos, profenofos, ethion, dimethoate, Malathion, Quinalphos and methyl parathion were found in 22 per cent of the samples with residues, which were taken from all vegetable and fruit (Harinathareddy *et al.*, 2014).

Sutharsan *et al.* (2014) conducted a study to find out pesticide usage practices of farmers on vegetable cultivation in Batticaloa district, Sri Lanka revealed that pesticides usage was higher in the studied area. Around 90 per cent of the farmers applied more than the recommended dosage and frequency of the pesticides. It was noticed that more than 89 per cent of the farmers harvested their produce before the recommended pre harvest interval.

Deore (2015) studied pesticide usage pattern in Ahmednagar, Dhule, Pune and Nashik locations against diamondback moth (DBM) on cabbage. Survey results indicated that farmers were relied mostly on chemical insecticides to control the diamondback moth, Chlorpyrifos, quinalphos, profenophos, cypermethrin, lambda-cyhalothrin, flubendiamide and chlorantraniliprole were the most widely used insecticides. Most of the cabbage growers from all four locations followed routine or calendar spraying pattern and farmers did sprayings at an interval of 6 to 10 days with maximum 6 to 8 sprays.

Deviprasad *et al.* (2015) studied the pesticide usage pattern in four districts of Karnataka. The results indicated that majority of the farmers used synthetic pesticides formulations for crop protection. The widely used insecticides were Chlorpyrifos, monocrotophos, cypermethrin, and quinalphos. Fungicides included copper oxide, carbendazim and mancozeb. Glyphosate and paraquat were the common herbicides used, respectively. Survey study results further also revealed that, multiple formulations of pesticides were used on a single crop.

Diop *et al.* (2016) determined the impact of pesticide use practices on vegetables contamination in the Niayes zone of Dakar, Senegal. They were surveyed 200 farmers to collect data regarding application of pesticides, application intervals, measuring tools and dosage compliance with good agricultural practices. Of the 175 vegetables samples collected cabbage, lettuce and tomato (31, 88, and 57) samples, respectively were analysed for residues of 21 pesticides revealed that, 65 per cent of tomato samples, 71 per cent of lettuce and 93 per cent of cabbage contained one or more detectable residues of pesticides. Among the monitored pesticides dicofol, chlorpyrifos, DDTs, dimethoate, and lamda - cyhalothrin were the most predominant and found in at least 35 per cent in each vegetable sample.

Pesticides are most significant among various agrochemicals in the sense that these act as protective umbrella for the crops. Kale (2016) studied the pesticides use pattern on geographical perspective. He was pointed that, Western Maharashtra region is quite large and covers an area of 57,235.00 Sq. Km. Grape and sugarcane based farming was mainly followed by farmers in Pune, Satara, Sangli, Kolhapur and Solapur districts. High consumption of agrochemicals above 30g/ha was observed in Tahsils *viz.*,Tasgaon, Kagal, Hatkanagale, Wai, Phaltan, Panhala, Karveer, Bhudargad, Bawda, Shirol, Walwa, Palus and Mahabaleshwar.

Kelageri *et al.* (2016) studied pesticides use pattern and awareness of farmers towards good agricultural practices (GAP) in the tomato growing farms and in polyhouses of Telangana during 2014. Awareness on pesticide related issues was varying among poly house and open field farmers with some commonality, where 35.71 per cent poly house farmers know about recommended pesticides while only 16.67 per cent open field farmers aware on this issue. However, in general, all farmers contacted pesticide dealer for recommendations and some farmers prefer to contact scientists (38-43 %). Most farmers were unaware about pesticide classification and toxicity symbols on packing. Various insecticides used belonging to different chemical group starting from conventional organophosphates to new groups like anthranilamides, but majority were not recommended on tomato by Central Insecticide Board and Registration Committee (CIBRC). The study was highlighted the need for targeted trainings to farmers on the scientific management of pesticides and awareness generation programmes regarding GAPs to achieve food safety at farm level.

Kocturk *et al.* (2016) studies revealed that Turkey have been trying to decrease pesticide residues in vegetables and fruits. Data collected from 72 grape farmers shows that the variable and total costs per hectare for grape production was 3,497.85 $/ha and 4,923.35 $/ha, respectively. The maximum shares for total costs were incurred on pesticide (19.88 %), land rent (19.66 %), fertilizer (11.56 %) and irrigation (11.31 %) respectively.

Vemuri *et al.* (2016) carried out the survey on pesticide usage pattern by interviewing farmers growing capsicum in open fields and poly houses based on the questionnaire prepared. Their study revealed that, education levels of poly house farmers are high compared to open field farmers. Likely awareness on pesticide related issues is varying among poly house and open field farmers with some commonality, where 28.57 per cent poly house farmers know about recommended pesticides while only 10 per cent open field farmers are aware of this issue. Generally all farmers contact pesticide dealer for recommendations. Poly house farmers prefer to contact scientists (35.71 %) and open field farmers prefer to contact agricultural officers (33.33 %). Most farmers are unaware about pesticide classification and toxicity symbols on packing. Farmers are aware about insecticide endosulfan has banned, but only 21.42 per cent poly house and 11.66 per cent open field farmers know about ban of monocrotophos on vegetables.

Abi Saab *et al.* (2017) reported that high susceptibility to diseases of fine table grapes cultivars were demand intensive use of pesticides. To increase the production and productivity farmers are growing pomegranates under high density planting. Elango and Sridharan (2017) reported that almost all the farmers depended on chemical pesticides for the management of pests of pomegranate. A field survey was carried out on pesticide usage pattern in four major pomegranate growing districts of Tamil Nadu *viz.,*Coimbatore, Erode, Tiruppur and Karur where pomegranate was cultivated under high density planting. The pest management strategy employed by farmers was use of insecticides and majority of the farmers (76.6 %) depends on imidacloprid for managing the pests, 66.0 per cent of farmers used monocrotophos as next alternative while, chlorantraniliprole, fipronil and dimethoate represents 60, 46.6 and 40 per cent, respectively.

Among different classes of pesticides used in India, the share of insecticides (60 %) is high followed by fungicides (19 %), herbicides (16 %), bio pesticides (3 %) and others (3 %). It is estimated that around 13-14 per cent of total pesticides used in the country are applied on vegetables of which insecticides account for two-thirds of total pesticides used in vegetables (IIVR, 2017). Among different vegetable crops, the maximum pesticide usage was in chilli (5.13 kg a.i /ha) followed by brinjal (4.60 kg a.i /ha), cole crops (3.73 Kg a.i/ ha) and okra (2-3 kg a.i /ha) (Indira Devi *et al.*, 2017).

Meenambigai and Bhuvaneswari (2017) surveyed 120 farmers in six major okra growing districts of Tamil Nadu *viz.,*Vellore, Salem, Dharmapuri, Dindigul, Coimbatore and Trichy during 2016. Farmers found using twenty four listed pesticides belonging slightly to highly hazardous toxicity class, the widely used pesticides were imidacloprid (36.67 %), acephate (33.33 %), exodus (15.00 %), flubendiamide (14.17 %) and dimethoate (14.17 %). Major source of information on pesticide was pesticide dealers (75.83 %). A very few respondents sprayed based on the recommended dose (20.83 %) and gave attention towards pesticide label (5.83 %). Majority of the farmers were followed the common waiting period of 1 day after spraying (65.00 %) and spraying interval of 10-14 days (52.33 %). Study clearly highlight that the farmer's knowledge was lagging on the recommended pesticides, dosage, safe harvest interval, label claim and personnel protection during spraying operation.

Priyadarshini *et al*. (2017) carried out survey on pesticide usage pattern in curry leaf growing areas in Medak district of Telangana; Anantapur and Guntur districts of Andhra Pradesh during 2014-15. Farmers growing curry leaf were interviewed by utilizing the questionnaire to assess their knowledge regarding general awareness on pesticide recommendations and use awareness. Study revealed that among farmers with some commonality, where 35.71 per cent farmers know about recommended pesticides while only 24.29 per cent of farmers were aware of pesticide classification based on toxicity. However, in general, most of the farmers (70 %) contacted pesticide dealer for recommendations, whereas 30 per cent per cent of the farmers preferred to contact Scientists and Agricultural Officers.

Anjali *et al.* (2018) carried out an extensive survey on pests and pesticides usage pattern on exotic vegetables among the farmers in Kotagiri block, Nilgiris district of Tamil Nadu and reported that tobacco caterpillar (*Spodoptera litura* Fab.), cutworm (*Spodoptera exigua* Hubner), aphids (*Myzus persicae* Sulzer) and leaf miner (*Liriomyza trifoli* Burgess) were major pests in lettuce, whereas diamondback moth (*Plutella xylostella* L.) was a major pest in broccoli and red cabbage. Flubendiamide (39.35 % SC), spinosad (2.5 % SC), chlorantraniliprole (18.50 % SC), imidacloprid (70 % WG) and acephate (75 % SP) were widely used insecticides for management of pests of exotic vegetables by farmers.

Golge and Kabak (2018) reported that 172 pesticide residues in table grapes were found in Turkey. A total of 280 samples of table grapes were collected from supermarkets, bazaar, and greengrocer shops located in four provinces during August to October 2016; 59.6 per cent table grapes samples observed containing one or more pesticide residues while, residues above the EU maximum residue levels were present in 20.4 per cent samples. The most prevalent pesticide residues were azoxystrobin, Chlorpyrifos, boscalid, and cyprodinil, respectively. The hazard index (HI) calculated was 3.37 per cent for adults and 9.42 per cent for children. Chlorpyrifos was the major contributor (65 %) to hazard index.

Guru (2018b) investigated use pattern, efficacy and persistence of certain insecticides in capsicum grown in polyhouses during 2016-17 and 2017-18. The usage pattern of insecticides in capsicum was studied by undertaking a random survey at

Western Maharashtra (Ahmednagar, Pune and Nasik) 65 capsicum growing farmers (polyhouse – 40, shadenet – 15 and open field - 10) selected from each district and assessed with a structured questionnaire. Results showed that, either in polyhouse or in shadenet/ open field, farmers were mainly relied on conventional insecticides (65.11 and 72.38 %) followed by novel insecticides (21.98 and 24.50 %) and biopesticides (12.92 and 3.11 %) for the pest management. It was observed that farmers from Ahmednagar used higher quantity of insecticides as compared to Nasik and Pune farmers. Further insecticides were used at higher quantity in polyhouses as compared to open field. The commonly used insecticides based on their use intensity were chlorpyrifos, profenophos (organophosphates), lambda - cyhalothrin and deltamethrin (pyrethroids).

Honnakerappa and Udikeri (2018) carried out an interactive survey during 2016-17 to document insecticide usage pattern adopted by the farmers of Karnataka state to manage polyphagous pest *Helicoverpa armigera.* They reported that among the different group of insecticides farmers preferred emamectin benzoate 5 SG (39.44 %) readily followed by rynaxypyr 18.5 SC (27.22 %) and profenophos 50 EC (23.89 %), respectively.

Zengin and Karaca (2018) determined pesticides residue levels in grapes samples which taken from vineyards implemented good agricultural practice in Usak province of Western Turkey in 2017. A total of 51 grape samples from three districts were collected 45.1 per cent of the samples taken weren't detected any pesticide residue while 54.9 per cent of grape samples found residue but none of this pesticides exceeded the maximum residue limits given in Turkish Food Codex. The most common pesticides detected in grape samples with residue were spinosad, pyrimethanil and boscalid, respectively. The quantum of pesticides detected in the samples was fungicides (85 %) and insecticides (15 %).

Bouagga *et al.* (2019) collected sixty-four table grape samples from different regions of Tunisia during three consecutive years (2015–2017). They assessed 96 pesticides, including dithiocarbamates by quantification with liquid or gas chromatography coupled to tandem mass spectrometry. They found that all samples contained multiple residues (4 to 24 residues), with an average of 11.6 residues per sample. Pesticides individual concentration in grape samples was ranged from 0.01 to 5.86 mg/ kg. Further 94 per cent of the samples shown exceedance of the European Maximum Residue Limits for at least one chemical compound. Potential risk of pesticides through consumption of grapes measured by determination of predicted short term intake which is expressed as a percentage of Acute Reference Dose (ARfD), which was clearly associated with carbofuran, carbendazim, chlorpyrifos, deltamethrin, dimethoate and omethoate. Consequently, these pesticides could present a risk to the consumer's health.

Naqash *et al.* (2019) carried out study on assessment of farmer's knowledge and awareness regarding pest control technologies in the three apple growing zones of Kashmir valley during 2017-18. The primary data was collected extensively from six blocks of the Kashmir Valley, two each from North, South and the Central Zone by using multi-stage stratified sampling technique and the secondary data was also collected from various published/unpublished records. The study was pointed out the need for a detailed look on the pesticide-use pattern, distribution systems, regulatory mechanism and farmer's perception about pesticide use at a micro level. The results of the study revealed that expenditure incurred on pesticides is quite high in apple. Besides that not only the intensity of pesticide use but also the high risk pesticides are being used for crop production. Farmers (95 %) were applying pesticides indiscriminately in violation of the scientific recommendations.

Sharma *et al.* (2019) opined that pesticides are extensively used in modern agriculture and are an effective and economical way to enhance the yield quality and quantity, thus ensuring food security for the ever-growing population around the globe. Approximately 2 million tonnes of pesticides are utilized annually worldwide, where China is the major contributing country, followed by the USA and Argentina. However, by the year 2020, the global pesticide usage has been estimated to increase up to 3.5 million tonnes.

Pesticides are an integral part of modern agriculture. Yadav and Dutta (2019) carried out in-depth field surveys of 500 farmers by group discussions, personal interview, questionnaires and field observation. They found that the pesticides consumption pattern was in the order of insecticides (61.11 %), herbicides (22.22 %) and fungicides (11.11 %). The organophosphates were found the most frequently used pesticides followed by neo-nicotinoid and pyrethroid. The cotton (93.27 %) was the highest pesticide consuming crop followed by vegetables (87.2 %), wheat (66.4 %), millet (52.6 %) and mustard (12.6 %), respectively.

Kariyanna *et al*. (2020) reported that the shoot and fruit borer, *Leucinodes orbonalis* causes severe yield loss up to 90 per cent. Pesticide usage history studied on eggplant revealed that, the farmers from Dharmapuri area sprayed 22.6 times (5.4 insecticides), followed by Raichur and Guntur area with 21.6 times (8.9 insecticides) and 21.4 times with (7.9 insecticides), respectively.

The role of pesticides has become critically important with modernization of agriculture. Meitankeisangbam *et al.* (2020) studied utilization pattern of pesticides by rice growers in Thoubal district. They shown that out of 120 respondents selected randomly, majority of respondents *i.e.* 55.00 per cent used two-three insecticides along with the fungicides and 63.33 per cent used systemic + contact pesticides.

2.4 Bio-efficacy of insecticides against mealybugs

2.4.1 Efficacy of synthetic insecticides

Narasimha Rao *et al.* (1977) reported that, dichlorvos (0.15 %) with combination of fish oil rosin soap (2.5 %) gave 80 per cent mortality of mealybugs while dichlorvos (0.15 %) alone gave 67 per cent mortality.

Rao *et al.* (1988) tested three conventional insecticides *viz.,*dichlorvos, monocrotophos and dimethoate each at 0.05 per cent against grape mealybug, *M. hirsutus* on two varieties, Anab-e-Shahi and Thompson Seedless and reported that per cent knockdown in colonies at 10 days after spraying in Anab-e-Shahi was 51 and 52 by dichlorvos and dimethoate, respectively.

Wang and Su (1988) conducted studies on insecticide efficacy for the control of the citrus mealybug and reported that the pseudococcid, *Pseudococcus citri* infesting grape vine in Taiwan was effectively controlled by the application of supracide 40 per cent and dimethoate 44 per cent in early spring, just before leaves emerge on the grapevine.

Mani (1990) studied the efficacy of insecticides against *M. hirsutus* and reported that debarking of infested vines, followed by sprays of dichlorvos (0.02 %) in combination with fish oil rosin soap (2.5 %) helped to control *M. hirsutus* on grapevine.

Beevi *et al.* (1992) tested ten insecticide sprays in laboratory against eggs of mealybug, *M. hirsutus*. Hatching was least in eggs treated with neem oil (0.3 %) followed by moncrotophos (0.04 %), methyl demeton (0.04 %) and fish oil rosin soap (2.5 %) + dichlorvos (0.2 %).

Persad and Khan (2000) studied efficacy of five commonly used insecticides *viz.*, lambda - cyhalothrin, pirmiphos - methyl, triazophos, fipronil and decamethrin (deltamethrin) in the laboratory and under semi-field conditions. The pink mealybug, *M. hirsutus* was found tolerant more or less to all insecticides tested. The first instar stage was least tolerant and control effectively by application of either pirimiphos - methyl or triazophos.

Balikai (2002) conducted a field trial to evaluate the efficacy of buprofezin 25 SC during *rabi* 2001-02 against grape mealybug, *M. hirsutus*. The results revealed that buprofezin 25 SC @ 1500 ml ha^{-1} recorded least number of mealybug colonies per vine on 15^{th} day after first, second and third sprays (32.5, 20.3 and 10.8, respectively), and was at par with buprofezin 25 SC @ 1000 ml ha^{-1} (34.6, 22.6 and 13.5 colonies, respectively).

Balikai (2005) conducted a field trial during *rabi* 2000-01 to evaluate the efficacy of buprofezin 25 SC and reported that on 10^{th} day after first, second and third sprays, buprofezin 25 SC @ 2250 ml ha^{-1} recorded least number of mealybug colonies per vine (27.7, 19.3 and 8.2 colonies, respectively).

Muthukrishnan *et al.* (2005) conducted a field trial with buprofezin as foliar spray at 1125 and 1500 ml/ha for its bio-efficacy against grape mealybug *M. hirsutus* (Green) in comparison with carbosulfan and Chlorpyrifos. Buprofezin reduced the nymphal and adult population and bunch infestation and increased the fruit yield compared to untreated check and recommended insecticides like carbosulfan and Chlorpyrifos.

Biradar *et al.* (2006) reported that diafenthiuron 50 SC @ 800 and 1600 g a.i /ha gave better control of mealybugs on grapes and recorded higher fruit yields of 24.7 and 25.0 tones per hectare with higher C: B ratio of 11.1 and 11.4, respectively.

Daane *et al.* (2006) studied the effectiveness of insecticides by applying through furrow irrigation against the vine mealybug, *Planococcus ficus* in California vineyards and reported that buprofezin provided better control, comparable to both imidacloprid and Chlorpyrifos.

Marcano *et al.* (2006) evaluated insecticides *viz.*,thiamethoxam 25 % (400 g/ ha), Chlorpyrifos 35.2 % (1.5 L /ha), diazinon 21.69 % + cypermethrin 2.71 % (1 L/ha), dimethoate 38 % (1 L/ ha), avermectin 1.89 % (0.5 L /ha), imidacloprid 35 % (0.4 L /ha) in order to know the efficacy and to be able to select the most promising ones for the control of *M. hirsutus* (Green) and results indicated that Chlorpyrifos 35.2 %, diazinon 21.69 % + cypermethrin 2.71 % and thiamethoxam 25 % were the most effective insecticides for the control of the pink mealybug, respectively.

Raguraman and Premalatha (2006) reported that methomyl @ 500 - 800 g a.i/ ha was effective in controlling the population of mealybug, *M. hirsutus* on grapes. Tanwar *et al*. (2007) gave a report on recent mealybug infestations on various economic crops in India and reported nine major mealybug species (eight Pseudococcidae and one Monophlebidae). A number of pesticides: lamda cyhalothrin (Boxer 2.5 EC), bifenthrin (Talstar 10 EC), profenophos (Craker 50 EC), imidacloprid (Crown 200 SL), abamectin (Alarm 1.8 EC), emamectin benzoate (Proclaim 19 EC), Chlorpyrifos (Lorsban 40 EC), methidathion (Supracide 40 EC), carbosulphan (Advantage 20 EC), acetamiprid (Rani 20 EC) were tested in a laboratory bioassay and then in the field. After 72 hours profenophos was most effective, followed by imidacloprid and acetamiprid (with mortality rates of 68.34, 65.83 and 48.23 %, respectively).

Katke and Balikai (2008) conducted a field trial in grape vineyard at Bijapur, Karnataka during post rainy season of 2005 - 06 with twelve treatments. They recorded that the treatments, dimethoate 30 EC @ 1.7 ml + Fish oil rosin soap @ 5 g /L and dimethoate 30 EC @ 1.7 ml/ L were highly effective in the management of grape mealybug and were at par with each other.

Kumar *et al.* (2008) reported that spirotetramat 150 OD @ 75 g a.i/ha recorded significant reduction in the population of cotton mealybug, *P. solani* from 368.0/ plant to 62.8/ plant after three rounds of spraying.

Agarwal *et al.* (2009) evaluated nine treatments of spirotetramat and imidacloprid in mixtures and alone at different dosages including two checks *i.e.* thiodicarb (Larvin 75 WP) and profenophos (Curacron 50 EC). Effectiveness against mealybug on cotton was assessed three days after second spray revealed that profenophos 50 EC recorded 93.73 per cent mortality over control and was at par with spirotetramat 12 % + imidacloprid 36 % 480 SC (36 + 108 g a.i./ha) (85.09 % mortality) and thiodicarb 75 WP @ 750 g a.i./ha (84.48 % mortality).

Bhosle *et al.*, (2009) evaluated 12 insecticides as curative spray against cotton mealybug at 2nd, 7th and 14th day. Acephate 70 SP followed by profenophos 50 EC and dichlorvos 76 EC were found effective in the management of mealybug. The yield of seed cotton was significantly highest in acephate 70 SP (22.2 q/ha) and profenophos 50 EC (22.2 q/ha) which were at par with each other.

Sunitha *et al.* (2009) reported that all the three neonicotinoids *viz.*,acetamaprid 20 SP @ 0.30 g/L, imidacloprid 17.8 SL @ 0.30 ml/ L and thiamethoxam 25 WG @ 0.30 g/L were significantly superior in recording cent percent reduction in grape mealybugs at 10 days after first spray and the next best treatment was acephate 75 SP @ 1.00 g/ L (88.32 %). Similar trend was observed in the subsequent sprays. The treatments acetamaprid 20 SP @ 0.30 g /L, imidacloprid 17.8 SL @ 0.30 ml/L and thiamethoxam 25 WG @ 0.30 g/L recorded 88.08., 87.88 and 84.87 per cent reduction after second spray; while it was 93.72, 95.52, 95.30 per cent reduction after third spray and 97.37, 96.57 and 93.53 per cent reduction in mealybug population after fourth spray, respectively. Acephate 75 SP @ 1.00 g/L was on par with the above three treatments at 10 days after 2^{nd}, 3^{rd} and 4^{th} sprays in reducing mealybug population.

Ghorpade and Khilari (2010) conducted two foliar applications of imidacloprid 17.8 SL (0.30 ml/L) and thiamethoxam 25 WG (0.25 g/L) in Pune, Maharastra and reported that the insecticides reduced the pink mealybugs and thrips population on grapevines and bunches.

Karar *et al*. (2010) reported that methidathion 40 EC @ 150 ml/ha provided significant control of adult mealy bug, *Drosicha mangiferae* at all the post treatment intervals *i.e.* 60, 72 and 73 per cent mortality under field conditions in mango orchards.

Mansour *et al.* (2010) conducted pesticide trial in a grape vineyard, located in the Cap Bon Region of Tunisia by applying imidacloprid @ 1 or 2 ml per vine through the drip irrigation system for each vine and reported that imidacloprid was more effective than methidathion @ 150 ml/ha on all mealybug developmental stages.

Castle and Prabhakar (2011) conducted field experiment during 2004-2005 in 50 *M. hirsutus* infested mulberry trees which were treat with imidacloprid and second 20 trees were tested with thiamethoxam and third 10 trees retained as untreated controls. They observed that branch samples collected from all 50 trees from early August through mid October recorded a substantial reduction in *M. hirsutus* infestations in all trees treated with either insecticide, whereas infestations continued to rise in the untreated trees to a peak level in late September. By the end of the 2005 season, 10 of 20 imidacloprid treated and 9 of 20 thiamethoxam treated trees were completely free from *M. hirsutus*.

Lo and Walker (2011) conducted two field trials on commercial vineyards in New Zealand with the insecticides applied as soil drenches. In the first trial, imidacloprid applied at 0.525 g a.i. per vine reduced mealybug abundance by more than 99 per cent compared with untreated vines and autumn and spring applications were equally effective. Half this rate was less effective, although drenching in autumn was better than in spring. In the second trial, treatments were applied in winter and SCAL 5085, a neonicotinoid insecticide at 0.263 g a.i per vine provided equivalent control to imidacloprid at 0.525 g a.i. per vine.

Patil and Sathe (2011) conducted studies on management of mealybug *M. hirsutus* at NRC, Grapes, Pune, during 2009 - 10. Buprofezin (0.05 %), dichlorvos (0.15 %) and methomyl (0.08 %) appeared to be the best treatments against the second instar nymphs of *M. hirsutus* which gave 100 per cent mortality after thirteen days of insecticidal spray.

Hussain *et al.* (2012) evaluated the toxicity of insecticides of different groups in laboratory and field conditions. In laboratory conditions profenophos showed maximum mortality 93.3 and 86.67 per cent of first and second instar mealybugs, respectively. While triazophos proved to be an effective insecticide for the control of the fourth instar showing per cent mortality of 64 and 100 in leaf dip method and foliar application methods, respectively. Out of seven insecticidal band applications tested in the field conditions, cotton dipped with buprofezin proved effective by manifesting 99.10 per cent control of mango mealybug.

Kulkarni *et al.* (2012) reported that methomyl 40 SP @ 400 g a.i./ha (1.00 g/L) was significantly superior over its lower dose at 300 g a.i./ha in reducing mealybug colonies. They had also observed that, even at lower doses methomyl 40 SP @ 300 g a.i./ha were significantly superior over standard check dichlorvos at 2 ml/L.

Gowda *et al.* (2013) conducted an investigation on efficacy of insecticides against papaya mealybug, *Paracoccus marginatus* at University of Agricultural Sciences, Bangalore. Three types of insecticides were evaluated for efficacy under glasshouse conditions *viz.*,chemical insecticides, physical agents and botanicals and combination of physical agents and botanicals with the least effective chemical insecticide (dichlorvos).

Acephate 75 SP (0.075 %) and profenophos 50 EC (0.05 %) recorded highest pest mortality of 90.24 and 84.69 per cent, respectively at 7 days after spray.

Kumar *et al.* (2014) evaluated the efficacy of insecticides against *P. marginatus* at GKVK, Bangalore and results revealed that during first spray and second spray, mean per cent reduction of mealybug population was highest in profenophos 0.05 % followed by buprofezin 0.025 %.

Piragalathan *et al.* (2014) tested the efficacy of ten chemicals such as imidacloprid (1 ml/L) , acetamiprid (1 g/L), acephate (1 g/L), thiamethoxam (1 g/L), chlorantraniliprole (0.19 ml/L), profenophos (2 ml/L), abamectin (0.6 ml/L), diazinon (1.5 ml/L) and thiocyclin hydrogen oxalate (2.5 g/L) in laboratory. The cent percent mortality was obtained using imidacloprid, thiamethoxam and thiocyclin hydrogen oxalate.

Sanghi *et al.* (2015) conducted field experiment during summer seasons 2012 and 2013 to determine the efficacy of different insecticides against cotton mealy bug (*Phenacoccus solenopsis*) at Adaptive Research Farm Rahim Yar Khan, Punjab Pakistan. Five different insecticides (prophenophos 50 EC @ 2000 ml/ha, carbosulfan 20 EC @ 1250 ml/ha, imidacloprid 20 SL @ 625 ml/ha, malathion 57 EC @ 1250 ml/ha and dimethoate 40 EC @ 625 ml/ha) were evaluated. The prophenophos 50 EC (97.15 %) reduction of mealybug, was found as superior treatment followed by imidacloprid 20 SL (91.9 %) and dimethoate 40 EC (85 %). All these insecticides remained effective up to 7th day after application. Least control was observed in treatments with carbosulfan 20 EC (75.5 %) and malathion 57 EC (58 %), respectively.

Seni and sahoo (2015) assessed certain newer insecticides along with some conventional insecticides against papaya mealybug, *Paracoccus marginatus* using potato dip method. After 24 hours, Chlorpyrifos 20 EC (LC 50 21 μl/L) and thiamethoxam 25 WG (LD 50 44 mg/L) were found the most effective treatments while buprofezin 25 SC (LC 50 1000 μl/L) least effective in bioassay test. Whereas, in case of field trials, thiamethoxam 25 WG, spirotetramat 240 EC, imidacloprid 17.8 SL, dimethoate 30 EC, lamda - cyhalothrin 5 EC and buprofezin 25 SC were found promising treatments against *P. marginatus*.

Dixit *et al*. (2016 b) field investigations to manage mealybug on custard apple revealed that among the evaluated insecticide and biopesticides; *V. lecanii* @ 7.5 g/L had significantly lowest mealybug population and at par with *V. lecanii* @ 5 g/L.

followed by triazophos 40 EC @ 3 ml/l itself on par with *V. lecanii* @ 2.5 g/L. Compared to treated plots 35.52 number of colonies recorded in untreated check.

Fatima *et al*. (2016) conducted study on *M. hirsutus* infesting *Hibiscus rosa-sinensis* (Shoe flower plants). Different insecticides *viz.*,advantage 20 EC (carbosulfan), telsta 20 SL (clothianidin), imidacloprid 20 SL (imidacloprid), talstar 10 EC (bifenthrin) and their mixtures were evaluated for efficacy in the field at 0.14 % concentration. After 24, 48 and 72 hr of the spray, Talstar + imidacloprid recorded highest mortality of (68.09 %), (87.23 %) after 24 and 48 hr, respectively. Whereas, after 72 hr advantage + talstar showed highest mortality (97.56 %) followed by talstar + imidacloprid (95.75 %). The study emphasized on the use of insecticide mixtures to tackle pest resistance revealed that, talstar (42.86 %) < advantage + imidacloprid (72.22 %) < and advantage + telsta (77.78 %) mortality after 24, 48 and 72 hr, respectively.

Cotton Mealybug, *Phenacoccus solenopsis* (Pseudococcidae; Hemiptera) is an exotic polyphagous pest of several crops and has been reported from 35 different areas of the world threatening crop population. Noureen *et al.* (2016) reported that the most efficient and suitable chemicals for *P. solenopsis management* were profenofos, chlorpyrifos, imidacloprid and buprofezin. Shinde *et al*. (2016) evaluated seven insecticides against *M. hirsutus* and reported that acetamiprid 20 SP @ 0.3 g/L was significantly superior but at par with thiamethoxam 25 WG @ 0.6 g/L. Remaining treatments in their descending order of efficacies were lambda - cyhalothrin 5 EC 1 ml/L, buprofezin 25 SC @ 1.5 ml/L, triazophos 40 EC @ 2 ml/L, diafenthiuron 50 WP @ 2 g/L and fipronil 5 SC @ 2 ml/L. Acetamiprid 20 SP @ 0.3 g/L recorded highest fruit yield (25.10 t/ha) followed by thiamethoxam 25 WG @ 0.6 g/L (24.23 t/ha). Higher incremental cost benefit ratio of 1:40.9 and 1:36.4 was recorded in Acetamiprid 20 SP @ 0.3 g/L and lambda cyhalothrin 5 EC @ 1 ml/L, respectively**.**

Naik *et al.* (2017) evaluated the efficacy of selected insecticides and botanicals against *M. hirsutus* under field conditions. The results revealed that, the lowest nymphal population and highest per cent reduction was recorded in profenophos (0.05 %) followed by methyl parathion (0.05 %) while highest mealy bug population was observed in control. The reduction of mealy bug population to the insecticidal treatment in the decreasing order of their efficacy were profenophos > methyl parathion > dichlorvos > methyl parathion dust > imidacloprid > *Verticillium lecanii* > *Beauveria bassiana* > neemark.

Mansour *et al.* (2018) reviewed scientific literature and opined that, a modern insecticide, spirotetramat was a proven efficient insecticide in terms of control and safety in relation to beneficial arthropods including insect pollinators (bees) and natural enemies. While in contrast to spirotetramat, organophosphate insecticides *viz.*,chlorpyrifos (chlorpyrifosethyl), chlorpyrifos-methyl, methidathion, and malathion were disruptive to the key non-target auxiliary fauna in vineyards and citrus orchards and also highly toxic to pollinators such as honeybees and bumblebees. Neonicotinoid insecticide, imidacloprid was identified as harmful chemical to pollinator honeybees and bumblebees. So it was clear that incorporation of spirotetramat into *P. ficus* and/or *P. citri* management programs could represented a valid option if used with caution and integrated with other eco-friendly, sustainable control tools.

Ansari and Haseeb (2019) studied the toxic effects of different insecticides/ insecticide - biopesticide combinations at different concentrations against *Phenacoccus solenopsis* in laboratory conditions. The highest mortality was recorded at 1 % concentration of each treatment *viz.*,profenophos + cypermethrin (90 %), aza-d 01 % (96.67 %) followed by Chlorpyrifos + cypermethrin (75 %). Whereas, per cent mortality observed was triazophos + deltamethrin (39.33 %) > *Verticillium* (36.67 %) > *Beauveria* (34 %) > Aza-d 0.1 % (23.33 %) after 12 hours.

The pink hibiscus mealybug, *M. hirsutus* (Green) (Hemiptera : Pseudococcidae) create threat on dates in California. Ganjisaffar *et al*. (2019) studied the effects of seven insecticides and water on different life stages revealed that, water did not have any significant effect on mealybugs; moreover the insecticide treatments significantly affected all life stages. It was found that egg hatching rate ranged from 28.5 to 17.2 per cent in spirotetramat, bifenthrin, flupyradifurone, fenpropathrin, and buprofezin treatments, and much lower in sulfoxaflor (2.8 %) and acetamiprid (0.1 %) respectively. Spirotetramat and buprofezin recorded less mortality of nymphs in the first day post - treatment, but significantly increased over time and reached 42.8 and 50.6 per cent by the 6^{th} day, respectively. Insecticides shown significant effect on the feeding ability of nymphs; 73.9 to 100 per cent of nymphs ceased feeding by the 6^{th} day treated with different insecticides. By and large all test insecticides did not cause effect on mortality of adult females, but considerably reduced number of ovipositing females (51.1 to 10.6 %).

Kaur and Banu (2019) opined that mealy bug species were developed resistance against the commonly used pesticides *viz.*,chloropyrifos, DDT and parathion because of their indiscriminate use. Neonicotinoid, imidacloprid was found most effective to control mealybugs. Nagrare *et al.* (2019) investigated the resistance development in cotton mealybug *Phenacoccus solenopsis.* Mealybug colonies were collected from four locations *viz.*,Yavatmal, Wardha, Amravati and Akola districts of Maharashtra. Bio-assayed performed by leaf dip method in the laboratory indicated that very high (RF 378.29) level of resistance against buprofezin present in the mealybug population collected from Amravati. Whereas, low to very low level of resistance was evident against organophosphates (monocrotophos, chlorpyrifos, quinalphos and acephate) and thiourea derivatives (diafenthiuron) collected from all the locations.

Sequeria *et al.* (2020) studied the efficacy of commercially available chemical insecticides against cotton mealybug, *Phenacoccus solenopsis* revealed that, a single application of spirotetramat and sulfoxaflor at the rate of 96 g/ha provided variable control. Spirotetramat used in a double spray tactic (two sequential sprays, 14 – 15 days apart) without oil provided ≥ 80 % control of adult while the addition of oil (5 % v/v) increased control to ≥ 90 %. Clothianidin synergised the spirotetramat + oil combination and served as potentially useful tank mix option for quick knockdown. Sulfoxaflor used in a double spray tactic provided ≥ 90 % control of adult *P. solenopsis*. Despite arresting the development of early instar mealybugs, buprofezin was allowed to grow the population of beneficial insects.

2.4.2 Efficacy of biopesticides

Eswaramoorthy and Jayaraj (1987) reported that the *V. lecanii* was highly effective for the control of *Coccus viridis* under field condition in Tamil Nadu with fortnightly application of 1.6 x $l0^6$ spores/ml. The maximum mortality (73.1 %) of the bug occurred two weeks after second application. The mortality increased (92.6 %) when 0.05 % tween - 20 was added to the spore suspension.

Verghese (1997) studied the effect of 5 and 2.5 per cent NSKE and Azadirachtin (Econeem) 1500 ppm on newly hatched and first instar (4 day old) nymphs of *M. hirsutus* under laboratory conditions. After 24 and 48 hours of application, the mortality of early first instar nymphs was highest with 5 per cent NSKE. However, mortality of late first instar nymphs after 24 and 48 hours was maximum with Azadirachtin (1500 ppm).

Kulkarni *et al*. (2003) reported that *V. lecanni* at concentrations ranging from 2 to 6 g/L was effective against mealy bug, *Ferrisia virgata* and *Planococcus citri*. Ujjan and Shahzad, (2007) reported that direct inoculation of *M. hirsutus* with *M. anisopliae* Isolate M1912 resulted in 70 per cent reduction in the hatching of eggs.

Kharbade *et al*. (2009) reported that *M. anisopliae* @ 2000 g/ha was most effective by recording minimum of 87.46 mealybugs/5 cm shoot tip resulting in reduction of mealybugs over untreated control. This treatment was statistically on par with neem oil @ 2000 ml/ha and Dashparni @ 10 % in which average of 108.73 and 110. 33 mealybugs/5 cm shoot tip were recorded, respectively. The higher seed cotton yield of 1521 kg/ha was obtained from the treatment with *M. anisopliae* @ 2000 g/ha. Untreated control recorded maximum of 322.06 mealybugs/5 cm shoot tip and lower seed cotton yield of 913 kg/ha.

Makadia *et al*. (2009) reported that pink mealy bug, *M. hirsutus* treated with *V. lecanii* @ 2 g/L resulted in a cumulative mortality of 95.33 per cent in custard apple. Sunitha *et al.* (2009) reported that azadirachtin 0.03 % @ 5 ml/L was effective in reducing the grapevine mealy bug, *M. hirsutus* infestation (86.72 %).

Aida *et al*. (2010) recorded the reduction of mean population of the pink hibiscus mealybug, *M. hirsutus* by 65.45, 66.55, 65, 67.6, 82.53 and 77.35 per cent with spray of Biofly (*Beauveria. bassiana*) @ 1.5 ml/L, Biovar (*B. bassiana*) @ 2 g/L, Bioranza (*M. anisopliae*) @ 2 g/L, Admiral @ 0.75 ml/L, Cidar @ 1.5 ml/L and orange oil @ 8 ml/L, respectively after four weeks of spray.

According to Banu *et al*. (2010) the entomopathogens, *V. lecanii* @ 5 g/L (2 x 10^8 cfu /g) and *M. anisopliae* @ 5 g/L (2 x 10^8 cfu/g) showed 37.78, 55.56 and 31.11, 48.86 per cent mortality of nymphs and adult mealybugs, respectively under laboratory condition. Among them, *L. lecanii* was found to be highly pathogenic to *P. solenopsis* under laboratory condition. At an initial inoculum of 1 x 10^4 conidia/mL, the lethal time (LT 50) was 3.77 and 2.51 days for nymphs and adults, respectively.

Chavan and Kadam (2010) recorded maximum mortality (82.5 %) of one day old mealy bug, *M. hirsutus* using *V. lecanii*. Demirci *et al.* (2011) reported that the entomopathogen, *Isaria farinosa* caused 89.39 per cent mortality on citrus mealybug *Plnococcus citri* ovisacs, 84.07 per cent mortality in second nymphall stage, 84.53 per cent mortality in adult females, and 78.71 per cent mortality in first nymphal stage at 95 per cent relative humidity and at 1.9 x 10^8 conidia/ml inoculum concentration.

Ibarra-Cortes *et al.* (2012) observed that mortality of third instar mealybug was greatest when inoculated with *Metarhizium anisopliae* isolates Ma 65 and Ma 129. The isolate Ma 65 showed the best potential for developing as a microbial control agent for *M. hirsutus*.

Surulivelu *et al.* (2012) assessed three entomopathogenic fungi along with two standard check insecticides against *Phenococcus solenopsis* and *Paracoccus marginatus* on Bt cotton during 2007-08 and 2008-09. Results revealed that, *B. bassiana*, *V. lecanii* and *M. anisopliae* brought out mealybugs reduction to 39.1, 30.9 and 28.2 per cent in incidence and 69.0, 59.0 and 23.1 per cent in population, respectively. Whereas, acephate and Chlorpyrifos cause reduction to the extent of 93.8 and 87.1 per cent in incidence and 97.8 and 95.3 per cent in population, respectively.

Kulkarni and Patil (2013) reported that *V. lecanii* 50 WP 1.15 % @ 6 x 10^5 spores/g significantly reduced mealybug population (3.70 nymphs/fruit) in custard apple. The same treatment was found to be more economical as it recorded higher yield (11.28 t/ha) also on par with buprofezin spray (12.4 t/ha).

Amala *et al*. (2014) conducted an experiment to study the acute toxicity and lethal reproductive effects caused by the entomopathogenic fungi *viz.*,*B. bassiana*, *V. lecanii* and *M. anisopliae* against the pink mealybug infesting grapes. *L. lecanii* recorded significantly lower LC 50 value of 3.41 x 10^5 spores/ml in a minimum time period of 1.09 days (LT 50) with highest mortality (72.80 %). The LC 50 value of *B. bassiana* and *M. anisopliae* was 1.50 x 10^6 and 7.14 x 10^6 spores/ml with a LT 50 of value of 3.04 and 7.04 days, respectively.

Amutha and Banu (2015) investigated the basis and mode of infection of the entomopathogenic green muscardine fungus, *M. anisopliae* on the mealybug, *P. marginatus*. The pathogenesis of *M. anisopliae* on *P. marginatus* was recorded at 24, 48, 72, 96, 120, 144 and 168 hours after inoculation. The conidial adhesion and germination process of *M. anisopliae* occurred within 24 hours after inoculation. The hyphae penetrated the epicuticle and reached the endocuticle within 48 to 72 hours after inoculation. Lysis of the endocuticle occurred while the penetrant hyphae invaded into the epidermis. Invasion and colonization of hyphal bodies into the haemocoel of *P. marginatus* was observed at 72 to 120 hours after inoculation. By 120 to 144 hours after inoculation, there was considerable abundance of hyphae that extensively colonized on the host and complete invasion occurred at 168 hours after inoculation. At this stage, the larvae became moribund and died. Hyphae re-emerged out of the cuticle after 168 hours after inoculation and grew all over the surface forming a green mycelial mat. The developmental cycle of *M. anisopliae* on *P. marginatus* took 172 to 196 hours to disintegrate and kill the insect from the day of inoculation.

Illathur and Shridhar (2016) conducted an *in vitro* efficacy of different strains of *B. bassiana*, *M. anisopliae* and *L. lecanii* against *M. hirsutus* and *Ferrisia virgata*. The experimental results on per cent mortality of pink mealybug (*M. hirsutus*) adults under laboratory condition at 9^{th} day was LlMo1 (93.33 %), BbGW1 (80.00 %) and MaBm1 (63.33 %) while, the mortality of guava mealybug (*F. virgata*) adults under laboratory condition at 9^{th} day was 96.55 per cent in LlMo1, 86.21 per cent in BbBp1 and 65.52 per cent in MaBp1, respectively.

Bhadani *et al*. (2017) conducted an experiment to test the effectiveness of different doses of entomopathogenic fungi alone and its combination with two insecticides against custard apple mealybug, *M. hirsutus* and the results revealed that, the *L. lecanii* @ 2.0 g/L + profenophos 50 EC 0.025 % and *L. lecanii* @ 2 g/L + flonicamid 50 WG 0.0125 % were found to be the most effective for reducing the population of mealybug on custard apple both in laboratory condition as well as in field condition.

Anonymous (2019) studied the strategic application of four spray starting from incidence of mealybug with buprofezin 25 SC @ 1.5 ml/L followed by *b. bassiana* @ 6 g/L followed by azadirachtin 10000 ppm @ 3 ml/L followed by *L. lecanii* @ 6 g/L resulted in better control of mealybug with highest marketable yield of custard apple as well as highest benefit cost ratio (2.05) over rest of the treatments.

Manjushree and Mani (2019) evaluated three species of entomopathogenic fungi *viz.,M. anisopliae*, *B. bassiana* and *L. lecanii* at three different concentrations (1×10^7, 1×10^8 and 1×10^9 spores/ml) against *Dysmicoccus brevipes* under laboratory conditions. Experimental results revealed that, highest spore concentration of all the entomopathegenic fungi had resulted in higher mortality of mealybug. The treatment *L. lecanii* @ 1×10^9 spores/ml (66.67 %). Similarly, *B. bassiana* and *M. anisopliae* @ 1×10^9 spores/ml (60 %) and (40 %) respectively.

Rajeshwari *et al.* (2019) carried out field experiment on the effectiveness of different biorational insecticides against mealybug, *M. hirsutus* in guava at, IIHR, Bangalore during 2015-16. Results revealed that, maximum reduction of mealybug population was recorded in the treatment of organic salt 30 WS @ 5 ml/L (2.32

mealybugs/three shoots) followed by spinosad 45 SC @ 0.2 ml/L (2.45 mealybugs/three shoots) after first and second spray, respectively.

Pink Pineapple mealybug, *Dysmicoccus brevipes* Cockerell is a polyphagous pest reported to attack mostly on agricultural crops. Rishi *et al.* (2019) reported that mangroves of Airoli and Vashi creek of Thane district of Maharashtra *viz.,Avicennia marina*, *A. officinalis*, *Sonneratia alba* and *S. apetala* were infested by *D. brevipes.* In laboratory conditions neem based botanicals along with azadirachtin (0.03 %) at 1 per cent concentration caused 99.6 per cent. and neem oil 5 per cent (crude) causing 74.8 per cent mortality of *D. brevipes* after 72 hours, respectively.

Kantikar *et al.* (2020) reported that two spray applications of Brigade-BL (*Beauveria bassiana*) @ 5.0 ml/L resulted in upto 67.82 per cent reduction of mealybug, *M. hirsutus* colonies on grape. Whereas, after the fifth spray of Brigade-BL @ 5.0 ml/L 75.68 per cent reduction was noticed.

3. MATERIALS AND METHODS

Present investigations on "Seasonal incidence, biology and management of grape mealybug" were carried out during the years 2017-18 to 2019-20 at Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra State. This place located in Western Plateau and Hill Region (IX) receives an annual rainfall of 511 mm with average temperature of 25.9^{0}C. Geographically, Rahuri is situated at 19^0.23' North latitude and 47^0.53' East latitude with an altitude of 511 meters (1676 feet). The climate of Rahuri is hot and dry on whole extremely genial and is characterized by a hot summer and general dryness during major part of the year except during South-West monsoon season. Considering ongoing climate changes and enormous pressure for combat mealybug ravages by grape growers, it becomes imperative to undertake the present investigations on basic aspects with following objectives.

3.1 To study the seasonal incidence of grape mealybug, *Maconellicoccus hirsutus* (Green).

3.2 To study the biology of grape mealybug, *Maconellicoccus hirsutus* (Green).

3.3 To study pesticides usage pattern for management of grape mealybug in Western Maharashtra.

3.4 Bio-efficacy of insecticides against grape mealybug, *Maconellicoccus hirsutus* (Green)

The material used and methods adopted under the present investigations are described here in under appropriate headings and sub headings.

3.1 To study the seasonal incidence of grape mealybug, *M. hirsutus*

3.1.1 Selection of site

Well established ten year old grape vineyard located at AICRP on Fruits, Department of Horticulture, MPKV, Rahuri was selected for studying the seasonal incidence of *M. hirsutus* (Plate 3.1).

3.1.2 Meteorological data

The meteorological data from April, 2018 to March, 2019 and April, 2019 to March, 2020 had been procured from the interfaculty Department of Agronomy, (Gramin Krishi Mausam Sewa, AMFU), MPKV, Rahuri.

3.1.3 Methodology

3.1.3.1 Experimental details

1.	Location	:	AICRP on fruits, Department of Horticulture, Horticulture farm, MPKV, Rahuri
2.	Crop and variety	:	Grape, Thompson Seedless
3.	Spacing	:	3.0 m x 1.5 m
4.	Plot size	:	15.0 m x 6.0 m
5.	No. of vines	:	10
6.	Cultivation practices	:	All the horticultural package of practices recommended by MPKV, Rahuri were adopted, except the plant protection measures

3.1.3.2 Method of recording observations

In order to record seasonal incidence of grape mealybug, *M. hirsutus*, observations were taken from untreated plot for the period of two years from April 2018 to March 2020. Ten vines were selected randomly from the vineyard and number of live mealybug colonies, egg sacs, nymphs and adults were worked out at weekly interval. Seasonal incidence and peak periods of infestation was documented by collecting the absolute counts.

3.1.3.3 Correlation studies

A statistically designed field experiment was carried out to find out the seasonal population (egg sacs, nymphs, adults and colonies) of grape mealybug, *M. hirsutus* on vines. The population was then correlated with the prevailing meteorological weather parameters *viz.*,maximum temperature (^{0}C), minimum temperature (^{0}C), morning relative humidity (%), evening relative humidity (%), wind velocity (km/hr), bright sunshine hours, evaporation (mm), rainfall (mm) and rainy days (days) using standard statistical procedure as suggested by Steel and Torrie (1980) to find out the specific impact of the weather parameters on mealybug incidence and peak activity period.

3.2 To study the biology of grape mealybug, *M. hirsutus*

3.2.1 Experimental site

The life history of the grape mealybug, *M. hirsutus* was studied on red pumpkins under the laboratory conditions at Insect Culture Room, Department of Entomology, Biocontrol laboratory, MPKV, Rahuri during the summer and winter season *i.e.* the month of April, 2018 and October, 2018, respectively.

3.2.2 Experimental material

Insect rearing cages, conical flask, beaker, petri dish, glass aspirator, cotton swab, muslin cloth, thread, magnifying glass, stage and ocular micrometer, binocular microscope, plastic trays, scale, fine camel hair brush, scissor, bavistin (carbendazim) 50% WP, ethyl alcohol 70%, sodium hypochlorite *etc*. comprised the material used during experimentation.

3.2.3 Methodology

3.2.3.1 Rearing of test insect species

The method standardized by Chacko *et al.* (1978) was followed to study the life history of grape mealybug, *M. hirsutus.* Medium sized semi ripened red pumpkin fruits procured from local market were used for rearing mealybugs within laboratory. The fruits were cleaned with water to get rid of dust and disinfected with 0.1 per cent sodium hypochlorite and wiped with cloth. In order to prevent development of moulds and rotting during storage, each fruit was dipped in the bavistin 0.1 per cent fungicide suspension for 10 -15 seconds and then dried for 4 hours. Treated fruits again washed with water and dried in shade. Wounds, if any on the pumpkins were plugged with wax. The mealybug ovisacs collected from infected grape vineyard were placed on pumpkins kept in specially designed wooden cages (45 x 45 x 45 cm) having the door in the front, and other sides covered with wire mesh. The pure culture was maintained throughout the research period. The observations were recorded on pre-oviposition period, fecundity, incubation period, hatching percentage, duration of nymphal stages, adult longevity, sex ratio and duration of total life cycle.

3.2.3.2 Pre-oviposition and oviposition period

Ten gravid female mealybugs were taken from pure culture and kept on each pumpkin with fine camel hair brush to know the pre-oviposition period. Females were observed regularly for the appearance of the ovisac. The period between the completion of the third instar indicated by the presence of moulted skin and the initiation of the first ovisac was considered as the pre-oviposition period while time taken to complete egg laying considered as oviposition period.

3.2.3.3 Fecundity

In order to estimate the fecundity randomly selected twenty female crawlers of *M. hirsutus* were released on pumpkins at the rate of two per pumpkin. They were left undisturbed till the formation of ovisacs by the females. The ovisacs from individual females were taken and observed carefully under microscope for the number of eggs present within.

3.2.3.4 Hatching percentage

Hatching percentage was estimated by transferring five lots of eggs, each containing of freshly laid thirty eggs onto a moist blotting paper kept in petri dishes separately with the help of a camel hair brush. Hatching of crawlers from all the eggs was observed daily and percentage was worked out.

3.2.3.5 Incubation period

Freshly laid twenty eggs were taken from the culture and placed separately in plastic tubes, the period till they hatched was considered as the incubation period.

3.2.3.6 Duration of nymphal stages

Mealybugs remain obscure to differentiate in to male and female up to third nymphal instar. Therefore hundred freshly laid eggs were released individually on ten pumpkins. First to third instar nymphal stages were recorded daily by observing the moulted skin at the end of each instar as suggested by Satpute *et al.* (2011). After the end of third instar they were observed for the presence of wing buds. If the wing buds were found, they were designated as males (Tanwar *et al.* 2007; Katke and Balikai, 2009).

3.2.3.7 Adult longevity

The daily observations were taken for the adult longevity on individuals developing into male and female from same culture. The duration between the adult emergences till its death was considered as the adult longevity period. The observations on longevity of male and female adults were recorded separately.

3.2.3.8 Sex ratio

Male : Female sex ratio was calculated by counting number of individuals developed in to male and females from the same culture.

3.2.3.9 Total duration of life cycle

Finally, the duration of total life cycle was worked out. The prevailing temperature and relative humidity during the rearing period were recorded.

3.3 To study the pesticides usage pattern for management of grape mealybug in Western Maharashtra

3.3.1 Methodology

Pesticides usage pattern followed in Western Maharashtra to manage grape mealybugs was studied through a survey carried out during January to March 2020. Extensive grape growing areas of Western Maharashtra *viz.*,Ahmednagar, Pune, Solapur, Sangli and Nashik districts were selected for the survey. In each district thirty farmers were randomly selected and interviewed with structured questionnaire (Appendix – III). The questionnaire was prepared to collect the data on various parameters such as type of insecticide used to control grape mealybug, chemical group of the insecticides, dosages of application, frequency of spraying *etc.* Several questions were in the format of Yes/No or multiple choice answers to know the grape growers awareness.

3.4 Bio-efficacy of insecticides against grape mealybug, *M. hirsutus*

3.4.1 Experimental site

The present investigations were conducted at AICRP on fruits, Department of Horticulture, Horticulture farm, MPKV, Rahuri during 2017-18 and 2018-19.

3.4.2 Material and equipments

The field experiment was undertaken using equipment's and instruments *viz.*,laminated labels, knapsack sprayer, paraffin coated paper tags, electronic weighing balance, digital camera, magnifying lens *etc.* which were procured from the Department of Entomology, Post Graduate Institute, MPKV, Rahuri.

3.4.3 Methodology

3.4.3.1 Experimental details

1.	Location	:	AICRP on Fruits, Department of Horticulture, Horticulture farm, MPKV, Rahuri.	
2.	Design	:	Randomized Block Design	
3.	Crop and variety	:	Grape, Thompson Seedless	
4.	No. of replications	:	03	
5.	Spacing	:	3.0 m x 1.5 m	
6.	Plot size	:	6.0 m x 3.0 m	
7.	No. of treatments	:	11	
8.	No. of vines per treatment		04	
9.	Date of forward pruning	:	Year 2017-18 17/10/2017	Year 2018-19 15/10/2018
10.	Spray schedule	:	1st spray – 07.12.2017 2nd spray – 22.12.2017 3rd spray – 06.01.2018	1st spray – 03.12.2018 2nd spray – 18.12.2018 3rd spray – 02.01.2019

11. Equipment used	:	Knapsack sprayer
12. Cultivation practices	:	All the horticultural package of practices recommended by MPKV, Rahuri were adopted, except the plant protection measures

3.4.3.2 Method of foliar application

The field bio-efficacy of insecticides was evaluated against *M. hirsutus.* The experiment was conducted in randomized block design with the three replications. The details of insecticides regarding content, concentration used, trade name and source are briefed in the Table 3.1 and layout of field experiment depicted in Fig. 3.1 Three spray applications of insecticides were given. First spray was given on initiation of incidence of mealybug, second spray was applied on fifteenth day after first spray and third spray was undertaken on fifteenth day after second spray. Each selected insecticide sprayed on two vines where *M. hirsutus* damage crossed five percent and marked with paraffin coated paper tags. Water spray made in control vines. The spray suspension of respective treatment made as per the required concentration for that known quantity of insecticide was measured and dissolved in a small quantity of water, mixed well then the desired strength of spay solution was prepared by adding the required quantity of clean water. The application of spray fluid was made with the help of the knapsack sprayer through a triple-action nozzle. Due care was taken for all the vines treated at a time also avoiding the drift of spray fluid on neighboring plots. Every time the spray pump was washed with the water thoroughly well before using other insecticides.

3.4.3.3 Method of recording observations

For recording observations, the *M. hirsutus* infested two vines were selected from each treatment. Efficacy of various treatments were assessed by recording the number of mealybug colonies having egg sac, nymphs and adults present on main stem, side branches and bunches per vine one day before treatment (Pretreatment count) and post count at third, seventh, tenth and fourteenth day after each spray. Observation recorded on fourteenth day served as pre-treatment count for next spray.

3.4.3.4 Statistical analysis

Data recorded on various parameters subjected to arcsin/square root transformations; these transformed data were subjected to analysis of the variance (Panse and Sukhatme, 1985).

Table 3.1. Details of test insecticides evaluated

Tr. No.	Common Name	Trade Name	Formulation	Dose (ml or g/L)	Source
1.	*Lecanicillium lecanii*	Phule Bugicide®	1.15 % WP ($1x10^{8}$ CFU/g)	5 g	Biological Control Laboratory, MPKV, Rahuri
2.	*Metarhizium anisopliae*	Phule Metarhizium®	1.15 % WP ($1x10^{8}$ CFU/g)	5 g	Biological Control Laboratory, MPKV, Rahuri
3.	Azadirachtin	Econeem Plus	1 % EC (10000 ppm)	3 ml	M/s. Margo Bio Controls Pvt. Ltd., Bengaluru
4.	Lambda cyhalothrin	Karate	5 % EC	0.5 ml	M/s. Syngenta India Ltd., New Delhi
5.	Dichlorvos	Nuvan	76 % EC	2 ml	M/s. Tarun Enterprises Ltd., Thane
6.	Chlorpyrifos	Ramban	20 % EC	2 ml	M/s. National Pesticides and Chemicals Ltd., Amravati
7.	Buprofezin	Applaud	25 % SC	1.5 ml	M/s. Tata Rallis India Ltd. Mumbai
8.	Spirotetramat	Movento	15.31 % OD	0.7 ml	M/s. Bayer Crop Science India Ltd., Pune
9.	Imidacloprid	Tatamida	17.8 % SL	0.45 ml	M/s. Tata Rallis India Ltd. Mumbai
10.	Spirotetramat 11.1% + Imidacloprid 11.01%	Movento Energy	(240 SC)	0.75 ml	M/s. Bayer Crop Science Ltd., Pune
11.	Untreated control	---	---	---	---

3.4.3.5 Per cent reduction or mortality over control

The per cent reduction or mortality in mealybug population was calculated by modified Abbott's formula given by Fleming and Retnakaran (1985).

$$M = 100 \times [1- (Ta \times Cb)/(Tb \times Ca)]$$

Where,
M = Percentage population reduction over control
Ta = Population in treatment after spray
Ca = Population in control after spray
Tb = Population in treatment before spray
Cb = Population in control before spray

3.4.3.6 Per cent infested bunches

Mealybug infested bunches were worked out at harvest by counting total number bunches and infested bunches on number basis and weight basis.

$$\text{Per cent infested bunches (Number basis)} = \frac{\text{Number of infested bunches}}{\text{Total no. of bunches}} \times 100$$

$$\text{Per cent infested bunches (Weight basis)} = \frac{\text{Weight of infested bunches}}{\text{Weight of total bunches}} \times 100$$

3.4.3.7 Yield

To evaluate the efficacy of the different insecticides on the bunch yield, the vines of the net plot were harvested. The per cent increase in yield over control and per cent avoidable loss were calculated by using the following formulae.

Increase in yield over control (%) = [(T – C)/C] x 100

Where, T = Yield of respective treatment (t/ha)
C = Yield of untreated control (t/ha)

Avoidable loss (%) = [(T – C)/T] x 100

Where, T = Yield of respective treatment (t/ha)
C = Yield of untreated control (t/ha)

3.4.3.8 Economics of the test insecticides

In order to assess the economics of different treatments evaluated against mealybug of grapes, Incremental Cost Benefit Ratio (ICBR) was worked out. For the purpose, additional income and additional cost of treatment per hectare including labour expenditure were calculated for each treatment based on prevailing market price of pesticides.

$$\text{Incremental Cost Benefit Ratio (ICBR)} = \frac{\text{Net income (Rs/ha)}}{\text{Total cost of protection (Rs./ha)}}$$

4. RESULTS AND DISCUSSION

The investigations on Seasonal incidence, biology and management of grape mealybug were carried out during the years 2017-18 to 2019-20 at AICRP on fruits, Department of Horticulture, Horticulture farm and Department of Entomology, Biocontrol laboratory, MPKV, Rahuri, Maharashtra. The results obtained on the aspects under the studied are discussed with the following objectives:

1. To study the seasonal incidence of grape mealybug, *Maconellicoccus hirsutus* (Green)
2. To study the biology of grape mealybug, *Maconellicoccus hirsutus* (Green)
3. To study the pesticide usage pattern for management of grape mealybug in Western Maharashtra.
4. Bio-efficacy of insecticides against grape mealybug, *Maconellicoccus hirsutus* (Green)

The purpose of the discussion is to interpret and describe the significance of the present findings in light of what was already known about the research problem being investigated, and to explain any new understanding or insights about the problem after the findings have been taken into consideration.

The results presented in the preceding chapter in the form of inferences have been discussed keeping in view the earlier findings of other workers. Wherever, the suitable literature is not available, the pertinent references on other crops have been used to support the present findings.

4.1 Seasonal incidence of grape mealybug, *M. hirsutus*

The studies on seasonal incidence were carried out during 2018-19 and 2019-20, to assess the influence of certain abiotic factors on the prevailing *M. hirsutus* population (egg sacs, nymphs, adults and colonies).

4.1.1 Observations on seasonal incidence during 2018-19

The data on mealybug population (egg sacs, nymphs, adults and number of colonies) tabulated in Table 4.1 and depicted in Fig 4.1, respectively.

Egg Sacs

It could be seen from the data presented in Table 4.1 and depicted in Fig 4.1, respectively. The number of egg sacs ranged from average 0.5 to 7.1 egg sacs per vine. At the time of first observation *i.e.*, in first week of April, 2018 (14^{th} SMW) the number of egg sacs observed was (5.2 egg sacs per vine). This population was decreased slowly and reached (1.0 egg sacs per vine) at the end of fourth week of June, 2018 (26^{th} SMW) due to intermittent raining and pruning effect. Then the population gradualy increased and reached to (1.6 egg sacs per vine) in fourth week of July, 2018 (30^{th} SMW). There after due to the prevailing monsoon and fruit pruning sudden fall in population was noticed up to the third week of November, 2018 (47^{th} SMW) *i.e.*, (0.5 egg sacs per vine). After that population shown increasing trend and attained maximum population at 4^{th} week of March, 2019 (13^{th} SMW) *i.e.*, (7.1 egg sacs per vine).

The data of the average egg sac population per vine was correlated with the abiotic factors which are presented in Table 4.2. The data reveals that, the maximum temperature (r = 0.534), sunshine (r = 0.453) and evaporation (r = 0.448) were found to be highly significant positively correlated with egg sac population. The morning relative humidity (r = - 0.654) and evening relative humidity (r = - 0.708) had highly significant negative correlation with egg sac population. Also, rainy days (r = - 0.297) had significant negative correlation.

Whereas, the minimum temperature (r = - 0.112), wind velocity (r = -0.245) and rainfall (r = - 0.272) had non significant negative correlation with egg sac population.

Nymphs

The data on average nymphal population per vine is tabulated in Table 4.1 and depicted in Fig 4.1, respectively. The data reveals that, the average nymphal population ranged from 9.2 to 28.5 nymphs per vine. At the commencement of observations *i.e.*, first week of April, 2018 (14^{th} SMW) the population was (26.2 nymphs per vine), which gradualy decreased till first week of July, 2018 (27^{th} SMW) (9.6 nymphs per vine). Then the population was gradualy increased and attained first peak at first week of August, 2018 (32^{nd} SMW) (10.6 nymphs per vine). After small gradual fall it increased and second peak was observed at second week of September, 2018 (37^{th} SMW)

Table 4.1. Seasonal incidence of grape mealybug, *M. hirsutus* during 2018-19

Month	SMW	Average/Vine				Temperature (^{0}C)		Relative Humidity (%)		Wind velocity (km/hr)	Sunshine (hr)	Evaporation (mm)	Rainfall (mm)	No of rainy days (days)
		Egg sac	Nymph	Adult	Colony	Max.	Min.	Mor RH-I	Eve RH-II					
02 Apr – 08 Apr	14	5.2	26.2	11.9	8.1	37.54	19.86	40.14	19.43	1.79	7.93	7.47	0.00	0
09 Apr – 15 Apr	15	4.3	24.5	9.1	7.2	37.26	20.04	44.00	19.57	1.64	8.79	8.46	0.00	0
16 Apr – 22 Apr	16	4.2	24.0	8.9	6.5	39.31	22.31	41.29	21.29	3.64	9.97	10.46	0.14	1
23 Apr – 29 Apr	17	3.8	22.8	9.1	6.2	39.43	19.74	30.14	13.57	2.19	10.84	13.00	0.00	0
30 Apr – 06 May	18	3.2	22.2	8.9	5.4	40.66	20.99	36.14	17.00	3.94	10.60	14.34	0.00	0
07 May – 13 May	19	3.4	20.4	8.6	3.7	40.20	24.17	32.14	17.71	4.13	10.30	13.83	0.00	0
14 May – 20 May	20	3.1	20.2	8.1	4.5	39.77	24.33	36.29	19.00	4.77	9.81	13.66	0.00	0
21 May – 27 May	21	2.9	19.8	7.2	3.4	38.86	25.20	40.43	20.57	4.53	7.09	9.47	0.00	0
28 May – 03 Jun	22	2.1	16.0	5.4	1.5	38.86	24.76	64.14	34.43	4.43	7.81	7.77	4.94	2
04 Jun – 10 Jun	23	1.8	15.4	5.6	2.0	34.20	24.60	71.86	47.29	3.73	3.83	4.83	1.57	2
11 Jun – 17 Jun	24	1.7	11.2	5.2	2.5	35.34	25.01	61.86	41.71	11.59	7.80	6.06	0.00	0
18 Jun – 24 Jun	25	1.3	10.8	5.0	3.0	34.14	23.37	72.43	54.14	5.46	4.83	5.29	6.14	3
25 Jun – 01 Jul	26	1.0	10.0	4.5	2.4	32.09	22.97	72.71	53.29	7.73	4.83	5.00	9.11	2
02 Jul –08 Jul	27	1.1	9.6	4.8	1.8	31.71	23.31	76.14	59.43	8.01	3.90	5.29	3.74	1
09 Jul – 15 Jul	28	1.3	9.8	5.0	3.0	28.26	22.83	80.00	69.71	5.00	0.30	3.37	1.97	4
16 Jul – 22 Jul	29	1.5	10.0	5.2	3.2	29.40	22.99	76.71	64.71	8.67	1.84	4.09	0.63	1
23 Jul – 29 Jul	30	1.6	10.2	5.5	2.9	28.66	22.73	75.14	62.29	7.54	1.27	4.14	0.00	0
30 Jul – 05 Aug	31	1.2	10.6	4.9	3.2	31.34	23.27	71.71	53.29	7.93	4.01	5.43	0.00	0
06 Aug – 12 Aug	32	1.3	10.6	4.7	3.4	30.00	22.99	75.14	62.57	6.81	1.49	5.10	0.00	0
13 Aug – 19 Aug	33	0.9	9.2	4.0	1.0	27.86	22.53	80.71	72.86	4.83	0.59	3.63	8.34	3
20 Aug – 26 Aug	34	0.8	9.7	4.2	2.5	27.94	21.49	80.00	70.57	5.01	3.06	3.71	3.46	2
27 Aug – 02 Sep	35	0.6	10.0	4.6	2.5	29.66	21.14	74.71	61.14	3.47	5.00	4.43	0.91	1
03 Sep – 09 Sep	36	0.9	10.8	3.0	1.6	30.09	19.64	70.57	53.14	4.16	5.77	5.14	0.00	0
10 Sep – 16 Sep	37	1.3	11.2	5.3	2.5	32.40	19.50	69.14	48.71	0.83	7.60	5.47	0.00	0
17 Sep – 23 Sep	38	0.8	9.6	5.2	1.6	31.94	22.11	71.57	45.14	2.71	6.16	5.47	0.54	1
24 Sep – 30 Sep	39	1.2	10.0	4.7	1.0	33.83	22.29	71.43	44.43	1.31	8.10	6.34	0.00	0
01 Oct – 07 Oct	40	1.3	11.8	4.2	0.8	34.03	21.54	67.29	42.86	1.27	7.80	6.33	0.00	0
08 Oct – 14 Oct	41	1.5	12.0	4.0	1.1	34.03	18.37	54.71	30.14	1.57	8.80	7.06	0.00	0
15 Oct – 21 Oct	42	1.3	11.4	3.6	0.6	33.49	18.57	50.00	30.29	1.27	8.24	6.63	0.00	0
22 Oct – 28 Oct	43	1.5	10.6	3.5	0.4	34.40	16.77	46.00	31.14	0.97	8.49	6.66	0.00	0
29 Oct – 04 Nov	44	0.7	9.4	3.0	0.6	31.74	14.41	58.14	38.00	1.89	9.46	6.49	0.29	1

Table 4.1 contd…..

Month	SMW	Average/Vine				Temperature (^{0}C)		Relative Humidity (%)		Wind velocity (km/hr)	Sunshine (hr)	Evaporation (mm)	Rainfall (mm)	No of rainy days (days)
		Egg sac	Nymph	Adult	Colony	Max.	Min.	Mor RH-I	Eve RH-II					
05 Nov – 11 Nov	45	0.7	9.6	2.6	0.8	33.11	16.77	58.71	37.29	0.84	8.09	6.36	0.00	0
12 Nov – 18 Nov	46	0.8	10.1	2.5	1.2	32.49	12.94	43.43	23.29	0.84	9.96	5.89	0.00	0
19 Nov – 25 Nov	47	0.5	10.5	2.8	1.5	31.74	16.30	61.14	46.43	1.27	7.74	5.69	0.00	0
26 Nov – 02 Dec	48	0.9	10.8	3.7	1.9	30.14	11.33	54.00	31.71	0.80	9.19	5.63	0.00	0
03 Dec – 09 Dec	49	1.0	11.6	4.4	2.1	30.34	15.04	60.43	35.00	0.39	6.63	4.83	0.00	0
10 Dec – 16 Dec	50	1.4	12.4	4.6	2.5	28.11	11.33	54.71	31.14	0.69	8.00	4.87	0.00	0
17 Dec – 23 Dec	51	1.6	12.8	5.4	2.6	26.51	9.11	64.00	36.00	0.49	9.09	4.43	0.00	0
24 Dec – 31 Dec	52	1.8	13.2	5.9	3.1	27.78	8.99	51.38	29.38	0.63	8.78	4.60	0.00	0
01 Jan – 07 Jan	1	2.1	17.3	6.4	3.7	29.34	8.86	42.29	23.57	0.34	9.16	4.37	0.00	0
08 Jan – 14 Jan	2	2.3	18.0	7.0	4.1	28.49	8.93	56.86	28.14	0.20	8.24	4.36	0.00	0
15 Jan – 21 Jan	3	2.8	18.4	7.2	4.4	29.37	11.29	57.71	33.00	0.27	8.29	4.47	0.00	0
22 Jan – 28 Jan	4	2.4	19.6	8.8	4.9	27.29	10.36	60.57	42.14	1.07	6.79	4.51	0.00	0
29 Jan – 04 Feb	5	2.5	20.0	9.3	5.3	27.74	10.39	53.43	29.43	0.73	7.76	4.69	0.00	0
05 Feb – 11 Feb	6	2.8	22.4	9.6	5.5	27.57	9.06	54.00	29.29	0.97	8.30	4.53	0.00	0
12 Feb – 18 Feb	7	3.6	21.5	10.2	5.9	31.83	14.14	55.14	27.71	0.74	8.27	5.43	0.00	0
19 Feb – 25 Feb	8	4.2	22.5	11.0	6.4	34.66	15.91	49.86	24.43	0.86	9.59	6.01	0.00	0
26 Feb – 04 Mar	9	4.6	23.1	11.6	7.6	31.91	12.97	47.29	19.71	1.39	9.67	6.09	0.00	0
05 Mar – 11 Mar	10	5.2	26.4	12.0	8.4	33.31	14.09	45.14	19.86	0.89	9.20	6.39	0.00	0
12 Mar – 18 Mar	11	5.4	27.0	12.3	9.2	35.50	15.96	51.43	16.14	0.94	8.57	6.66	0.00	0
19 Mar – 25 Mar	12	6.0	28.4	12.6	10.7	36.43	16.13	46.14	14.71	1.57	8.94	7.33	0.00	0
26 Mar – 01 Apr	13	7.1	28.5	13.2	11.8	39.29	18.77	39.57	13.14	1.57	8.93	8.43	0.00	0

(11.2 nymphs per vine). After the small fall in population it again increased and attained third peak at second week of October, 2018 (41st SMW) (12.00 nymphs per vine). Due to the pruning in third week of October, 2018 (43rd SMW) the population declined to (9.4 nymphs per vine) at fifth week of October, 2018 (44th SMW). Finally the population gradually increased and fourth peak was observed at fourth week of March, 2019 (13th SMW) (28.5 nymphs per vine).

The data of average nymphal population per vine was correlated with the abiotic factors which are presented in Table 4.2. The data reveals that, the maximum temperature (r = 0.503), sunshine (r = 0.537) and evaporation (r = 0.486) were found to be highly significant positively correlated with nymphal population. The morning relative humidity (r = - 0.719) and evening relative humidity (r = - 0.771) had highly significant negative correlation with nymphal population. Also, wind velocity (r = - 0.341), rainy days (r = - 0.342) and rainfall (r = - 0.309) had significant negative correlation.

Whereas, the minimum temperature (r = - 0.213) had non significant negative correlation with nymphal population.

Table 4.2. Correlation of weather parameters with incidence of grape mealybug, *M. hirsutus* during 2018-19

Weather parameters	Correlation coefficient value			
	Egg Sac	Nymph	Adult	Colony
Max. Temperature (°C)	0.534**	0.503**	0.389**	0.351*
Min. Temperature (°C)	-0.112	-0.213	-0.177	-0.180
Morning RH (%)	-0.654**	-0.719**	-0.567**	-0.522**
Evening RH (%)	-0.708**	-0.771**	-0.633**	-0.575**
Wind velocity (Km/hr)	-0.245	-0.341*	-0.237	-0.194
Bright Sunshine (hrs)	0.453**	0.537**	0.388**	0.320*
Evaporation (mm)	0.448**	0.486**	0.358**	0.298*
Rainfall (mm)	-0.272	-0.309*	-0.250	-0.245
Rainy Days	-0.297*	-0.342*	-0.272	-0.251

* 5% level of significance df 50 = 0.273 **1% level of significance df 50 = 0.354

Adults

The data on average adult population per vine is tabulated in Table 4.1 and depicted in Fig 4.1. The data reveals that the average adult population ranged from 2.5 to 13.2 adults per vine. At the commencement of observations *i.e.,* first week of April, 2018 (14^{th} SMW) the population was (11.9 adults per vine), which gradualy decreased till fourth week of June, 2018 (26^{th} SMW) (4.5 adults per vine). Then the population was gradualy increased and attained first peak at fourth week of July, 2018 (30^{th} SMW) (5.5 adults per vine). After small gradual fall it increased and second peak was observed at second week of September, 2018 (37^{th} SMW) (5.3 adults per vine). Then the gradual decline in population observed till second week of November, 2018 (46^{th} SMW) (2.5 adults per vine). After that adults population showed increasing trend till the harvesting. Adults population attained it's third peak at fourth week of March, 2019 (13^{th} SMW) (13.2 adults per vine).

The data of average adult population per vine was correlated with the abiotic factors which are presented in Table 4.2. The data reveals that, the maximum temperature (r = 0.389), sunshine (r = 0.388) and evaporation (r = 0.358) were found to be highly significant positively correlated with adults population. The morning relative humidity (r = - 0.567) and evening relative humidity (r = - 0.633) had highly significant negative correlation with adults population. Whereas, minimum temperature (r = - 0.177), wind velocity (r = - 0.237), rainy days (r = - 0.272) and rainfall (r = - 0.250) had negative correlation with adults population.

Colonies

The data on average number of mealybug colonies per vine is tabulated in Table 4.1 and depicted in Fig 4.1, respectively. The data reveals that, the average number of colonies per vine ranged from 0.4 to 11.8. At the commencement of observations *i.e.,* first week of April, 2018 (14^{th} SMW) the population was (8.1 colonies per vine), which gradualy decreased till first week of May, 2018 (19^{th} SMW) (3.7 colonies per vine). Then the gradual decline in colonies observed till fourth week of May, 2018 (22^{nd} SMW) (1.5 colonies per vine). Then the number of colonies were gradualy increased and attained their first peak at third week of June, 2018 (25^{th} SMW) (3.0 colonies per vine). After small gradual fall it increased and second peak was observed at first week of August, 2018 (32nd SMW) (3.4 colonies per vine). After that a sudden fall was evident in number of colonies and it reached at it's lowest in fourth week of October, 2018 (43rd SMW) (0.4 colonies per vine) due to the pruning. Then number of colonies continuously increased and eventually the third peak was observed at fourth week of March, 2019 (13th SMW) (11.8 colonies per vine).

The data of average number of colonies of mealybug per vine was correlated with the abiotic factors which are presented in Table 4.2. The data reveals that the maximum temperature (r = 0.351), sunshine (r = 0.320) and evaporation (r = 0.298) were found to be significant and positively correlated with number of colonies. The morning relative humidity (r = - 0.522) and evening relative humidity (r = - 0.575) had highly significant negative correlation with number of colonies. Further, minimum temperature (r = - 0.180), wind velocity (r = - 0.194), rainy days (r = - 0.251) and rainfall (r = - 0.245) had non significant negative correlation.

4.1.2 Observations on seasonal incidence 2019-20

The data on mealybug population (egg sacs, nymphs, adults and number of colonies) tabulated in Table 4.3 and depicted in Fig 4.2, respectively.

Egg Sacs

It could be seen from the data presented in Table 4.3 and depicted in Fig 4.2, respectively. The number of egg sacs ranged from average 0.5 to 7.5 egg sacs per vine. At the time of first observation *i.e.,* in first week of April, 2019 (14th SMW) the number of egg sacs observed was (7.5 egg sacs per vine). This population was decreased slowly and reached (1.2 egg sacs per vine) at the first week of August, 2019 (32nd SMW) due to intermittent raining. Frequent up and downs were observed in egg sac population with overall decreasing trend till third week of September, 2019 (38th SMW) (0.5 egg sacs per vine). More or less same population remained upto first week of November, 2019 (45th SMW) (0.6 egg sacs per vine) due to pruning. Then the population shown increasing trend till the harvest and reached upto (5.9 egg sacs per vine) in fourth week of March, 2020 *i.e.,* (13th SMW).

The data of average egg sac population per vine was correlated with the abiotic factors which are presented in Table 4.4. The data reveals that the maximum temperature (r = 0.541), sunshine (r = 0.618) and evaporation (r = 0.488) were found to

Table 4.3. Seasonal incidence of grape mealybug, *M. hirsutus* during 2019-20

Month	SMW	Average/Vine				Temperature (^{0}C)		Relative Humidity (%)		Wind velocity (km/hr)	Sunshine (hr)	Evaporation (mm)	Rainfall (mm)	No of rainy days (days)
		Egg sac	Nymph	Adult	Colony	Max.	Min.	Mor RH-I	Eve RH-II					
02 Apr – 08 Apr	14	7.5	28.0	13.7	11.2	39.71	19.96	37.71	14.14	2.53	9.17	9.30	0.00	0
09 Apr – 15 Apr	15	6.8	27.3	12.5	10.6	40.44	21.19	35.29	13.43	2.10	9.06	9.36	0.00	0
16 Apr – 22 Apr	16	6.2	26.1	11.0	9.3	37.14	19.20	45.00	18.57	2.69	9.41	8.91	0.63	1
23 Apr – 29 Apr	17	5.3	25.6	10.3	8.3	41.26	23.99	30.57	11.71	2.49	10.53	11.11	0.00	0
30 Apr – 06 May	18	5.0	24.9	9.8	7.9	39.09	20.74	37.29	15.86	4.17	10.34	10.49	0.00	0
07 May – 13 May	19	4.7	23.6	9.3	7.5	39.29	21.73	44.29	17.57	3.34	10.53	12.14	0.00	0
14 May – 20 May	20	3.9	23.0	8.7	7.1	40.00	21.81	34.57	14.00	4.61	10.77	13.74	0.00	0
21 May – 27 May	21	3.1	22.4	8.2	6.2	41.26	25.49	38.29	16.29	4.44	10.87	14.69	0.00	0
28 May – 03 Jun	22	2.7	20.8	7.5	6.0	41.20	23.47	39.14	19.00	5.43	10.47	13.46	0.00	0
04 Jun – 10 Jun	23	2.5	18.3	6.8	5.4	39.17	26.14	51.43	30.29	5.37	6.10	11.91	1.00	1
11 Jun – 17 Jun	24	2.3	15.7	6.5	4.9	37.17	24.87	58.71	35.14	8.31	9.41	10.79	0.06	1
18 Jun – 24 Jun	25	2.0	13.8	6.3	4.6	36.06	24.33	69.86	40.00	6.23	7.80	10.91	2.60	2
25 Jun – 01 Jul	26	1.8	11.2	5.7	4.0	31.43	23.81	80.71	60.29	2.04	2.80	4.60	7.34	5
02 Jul – 08 Jul	27	1.6	10.6	5.1	3.7	30.61	23.54	79.00	63.14	4.93	1.30	4.34	5.29	3
09 Jul – 15 Jul	28	1.5	10.4	5.0	3.5	32.00	23.60	76.00	56.57	7.37	4.70	5.33	0.54	1
16 Jul – 22 Jul	29	1.3	9.9	4.8	3.0	33.83	23.24	71.43	51.29	6.44	7.77	5.87	4.57	2
23 Jul – 29 Jul	30	1.5	9.7	4.6	2.8	30.51	23.59	78.43	68.14	4.11	2.31	3.30	2.63	4
30 Jul – 05 Aug	31	1.2	9.2	4.1	2.4	27.03	22.86	87.00	77.43	4.79	0.23	1.86	6.80	6
06 Aug – 12 Aug	32	1.2	9.4	4.0	2.3	28.03	23.27	80.57	68.14	8.17	1.99	3.60	0.51	3
13 Aug – 19 Aug	33	1.4	8.9	4.3	2.0	31.00	22.47	75.14	59.57	6.96	4.29	5.43	0.20	1
20 Aug – 26 Aug	34	1.5	9.1	4.8	2.4	32.49	21.29	72.43	47.57	4.13	7.91	6.19	0.00	0
27 Aug – 02 Sep	35	0.8	8.3	3.6	1.6	31.97	22.99	75.14	55.71	4.07	5.90	5.74	12.57	4
03 Sep – 09 Sep	36	0.8	8.0	3.7	1.4	29.97	23.33	77.57	70.57	3.57	1.86	4.29	0.43	2
10 Sep – 16 Sep	37	0.9	7.7	3.9	1.4	28.77	22.47	78.57	68.43	4.64	1.36	3.67	3.09	3
17 Sep – 23 Sep	38	0.5	6.3	3.4	0.8	29.83	21.73	83.57	71.00	1.61	4.23	3.69	12.03	4
24 Sep – 30 Sep	39	1.2	7.0	4.0	1.2	30.23	21.94	83.43	66.86	0.83	4.96	3.40	5.23	3
01 Oct – 07 Oct	40	1.5	8.2	3.8	1.3	31.14	21.11	80.57	58.71	1.10	6.07	5.06	1.11	4
08 Oct – 14 Oct	41	1.3	8.6	3.5	1.5	31.69	21.13	77.00	50.29	0.76	7.13	4.83	0.40	2
15 Oct – 21 Oct	42	1.1	8.1	3.1	1.3	28.26	18.57	81.57	67.71	1.44	5.03	3.60	7.49	3
22 Oct – 28 Oct	43	0.8	7.6	2.7	0.8	25.71	20.80	87.14	79.57	1.36	2.44	1.66	20.26	6

Table 4.3 contd….

Month	SMW	Average/Vine				Temperature (^0C)		Relative Humidity (%)		Wind velocity (km/hr)	Sunshine (hr)	Evaporation (mm)	Rainfall (mm)	No of rainy days (days)
		Egg sac	Nymph	Adult	Colony	Max.	Min.	Mor RH-I	Eve RH-II					
29 Oct – 04 Nov	44	0.7	7.6	2.7	0.9	30.43	20.97	84.00	58.57	1.09	6.13	4.97	0.57	2
05 Nov – 11 Nov	45	0.6	8.0	2.4	1.3	31.09	18.41	76.14	46.14	0.60	9.03	5.46	3.34	2
12 Nov – 18 Nov	46	0.9	9.2	2.6	1.5	29.69	16.74	73.00	48.00	0.86	7.54	5.60	0.00	0
19 Nov – 25 Nov	47	1.2	9.7	3.0	2.2	30.04	15.21	74.00	45.29	0.34	7.77	5.44	0.00	0
26 Nov – 02 Dec	48	1.8	10.3	3.4	2.7	30.47	15.93	73.86	44.29	0.26	7.29	4.96	0.00	0
03 Dec – 09 Dec	49	2.6	10.8	4.0	3.2	28.77	16.41	71.14	46.86	0.27	5.43	4.91	0.00	0
10 Dec – 16 Dec	50	2.1	11.4	4.8	3.4	29.66	16.34	74.29	42.00	0.27	7.37	4.89	0.40	1
17 Dec – 23 Dec	51	2.3	12.7	5.8	3.9	28.00	15.84	78.57	46.86	0.40	5.10	4.29	0.00	0
24 Dec – 31 Dec	52	2.0	13.4	6.5	4.4	27.10	16.65	79.63	48.38	0.83	4.36	4.15	0.18	1
01 Jan – 07 Jan	1	2.2	15.6	6.9	4.9	27.00	12.03	80.86	49.00	1.33	6.76	4.66	0.00	0
08 Jan – 14 Jan	2	2.6	16.7	7.4	5.3	25.86	13.80	82.86	47.43	0.97	6.71	4.41	0.00	0
15 Jan – 21 Jan	3	2.9	17.5	7.9	5.8	25.14	11.89	83.14	43.14	0.77	8.06	4.56	0.00	0
22 Jan – 28 Jan	4	3.2	19.8	8.4	6.0	30.20	15.31	83.29	33.14	0.69	8.69	4.89	0.00	0
29 Jan – 04 Feb	5	3.5	20.5	9.0	6.7	27.37	12.89	79.57	39.71	1.07	8.89	4.96	0.00	0
05 Feb – 11 Feb	6	3.7	22.3	9.3	7.1	28.09	13.93	80.86	43.14	2.20	7.63	4.80	0.00	0
12 Feb – 18 Feb	7	3.8	23.7	10.5	7.8	30.34	16.34	81.43	33.71	0.80	7.57	4.64	0.00	0
19 Feb – 25 Feb	8	4.2	24.0	11.8	8.4	33.49	16.89	73.00	25.29	0.93	9.30	6.23	0.00	0
26 Feb – 04 Mar	9	4.9	25.1	12.4	8.9	32.38	14.11	74.88	22.00	1.71	9.46	5.65	0.00	0
05 Mar – 11 Mar	10	5.4	26.3	12.9	10.0	31.03	14.69	73.00	28.29	2.39	8.60	6.07	0.00	0
12 Mar – 18 Mar	11	5.8	26.8	13.2	10.9	32.51	15.90	67.71	26.71	1.57	8.51	6.20	0.00	0
19 Mar – 25 Mar	12	6.3	27.6	14.0	11.7	34.40	17.41	71.57	25.29	1.36	8.77	7.81	0.00	0
26 Mar – 01 Apr	13	5.9	28.3	14.5	12.6	34.20	20.24	75.29	32.14	1.39	7.33	6.69	3.34	3

be highly significant positively correlated with egg sac population. The morning relative humidity (r = - 0.593), evening relative humidity (r = - 0.827), rainfall (r = - 0.406) and rainy days (r = - 0.526) had highly significant negative correlation with egg sac population. Further, the minimum temperature (r = - 0.236) and wind velocity (r = -0.140) had non significant negative correlation with egg sac population.

Nymphs

The data on average nymphal population per vine is tabulated in Table 4.3 and depicted in Fig 4.2. The data reveals that, the average nymphal population ranged from 6.3 to 28.3 nymphs per vine. At the commencement of observations *i.e.,* first week of April, 2019 (14^{th} SMW) the population was (28.0 nymphs per vine), which gradualy decreased till fourth week of May, 2019 *i.e.,* (22^{nd} SMW) (20.8 nymphs per vine). Then the sudden fall in nymphal population was observed due to rainfall at fourth week of June, 2019 *i.e.,* (26^{th} SMW) (11.2 nymphs per vine). Further gradual decline continued till third week of September, 2019 *i.e.,* (38^{th} SMW) (6.3 nymphs per vine). Then the population was gradualy increased and attained first peak at second week of October, 2019 (41^{st} SMW) (8.6 nymphs per vine). Due to the pruning in third week of October, 2019 *i.e.,* (43^{rd} SMW) the population declined to (7.6 nymphs per vine) at fifth week of October, 2019 (44^{th} SMW). Finally the population gradually increased and second peak was observed at fourth week of March, 2020 (13^{th} SMW) (28.3 nymphs per vine).

The data of average nymphal population per vine was correlated with the abiotic factors which are presented in Table 4.4. The data reveals that, the maximum temperature (r = 0.563), sunshine (r = 0.692) and evaporation (r = 0.579) were found to be highly significant positively correlated with nymphal population. The morning relative humidity (r = - 0.600), evening relative humidity (r = - 0.879), rainfall (r = - 0.436) and rainy days (r = - 0.585) had highly significant negative correlation with nymphal population. Further, the minimum temperature (r = - 0.243) and wind velocity (r = -0.085) had non significant negative correlation with nymphal population.

Adults

The data on average adult population per vine is tabulated in Table 4.3 and depicted in Fig 4.2. The data reveals that, the average adult population ranged from 2.4 to 14.5 adults per vine. At the commencement of observations *i.e.,* first week of April, 2019 (14^{th} SMW) the population was (13.7 adults per vine), which gradualy decreased till first week of August, 2019 (32nd SMW) (4.0 adults per vine). Then the population was gradualy increased and attained first peak at third week of August, 2019 (34th SMW) (4.8 adults per vine). After small gradual fall it increased and second peak was observed at fourth week of September, 2019 (39th SMW) (4.0 adults per vine). Then the gradual decline in population observed till first week of November, 2019 (45th SMW) (2.4 adults per vine). After that adults population showed increasing trend till the harvesting. Adults population attained it's third peak at fourth week of March, 2020 (13th SMW) (14.5 adults per vine).

The data of average adult population per vine was correlated with the abiotic factors which are presented in Table 4.4. The data reveals that the maximum temperature (r = 0.464), sunshine (r = 0.581) and evaporation (r = 0.438) were found to be highly significant positively correlated with adults population. The morning relative humidity (r = -0.462), evening relative humidity (r = -0.782), rainfall (r = -0.386) and rainy days (r = -0.500) had highly significant negative correlation with adult population. Whereas, minimum temperature (r = - 0.262) and wind velocity (r = - 0.099) had non significant negative correlation with adult population.

Colonies

The data on average number of mealybug colonies per vine is tabulated in Table 4.3 and depicted in Fig 4.2, respectively. The data reveals that, the average number of colonies per vine ranged from 0.8 to 12.6. At the commencement of observations *i.e.*, first week of April, 2019 (14th SMW) the population was (11.2 colonies per vine), which gradualy decreased till second week of August, 2019 (33rd SMW) (2.0 colonies per vine). Thereafter population increased and attained the first peak at third week of August, 2019 (34rd SMW) (2.4 colonies per vine). After that the population gradually decreased till third week of Septeber, 2019 (38th SMW) (0.8 colonies per vine). More or less same population remained upto fourth week of October, 2019 (43rd SMW) (0.8 colonies per vine) due to rains of returning monsoon. Then the population shown increasing trend till the harvest and reached upto (12.6 colonies per vine) in fourth week of March, 2020 *i.e.*, (13th SMW).

The data of average number of colonies of mealybug per vine was correlated with the abiotic factors which are presented in Table 4.4. The data reveals that the maximum temperature (r = 0.503), sunshine (r = 0.607) and evaporation (r = 0.490) were found to be highly significant positively correlated with number of colonies. The morning relative humidity (r = - 0.517), evening relative humidity (r = - 0.817), rainfall (r = - 0.411) and rainy days (r = - 0.527) had highly significant negative correlation with number of colonies. Whereas, minimum temperature (r = - 0.250) and wind velocity (r = - 0.087) had non significant negative correlation with number of colonies.

Table 4.4. Correlation of weather parameters with incidence of grape mealybug, *M. hirsutus* during 2019-20

Weather parameters	Correlation coefficient value			
	Egg Sac	Nymph	Adult	Colony
Max. Temperature (℃)	0.541**	0.563**	0.464**	0.503**
Min. Temperature (℃)	-0.236	-0.243	-0.262	-0.250
Morning RH (%)	-0.593**	-0.600**	-0.462**	-0.517**
Evening RH (%)	-0.827**	-0.879**	-0.782**	-0.817**
Wind velocity (Km/hr)	-0.140	-0.085	-0.099	-0.087
Bright Sunshine (hrs)	0.618**	0.692**	0.581**	0.607**
Evaporation (mm)	0.488**	0.579**	0.438**	0.490**
Rainfall (mm)	-0.406**	-0.436**	-0.386**	-0.411**
Rainy Days	-0.526**	-0.585**	-0.500**	-0.527**

* 5% level of significance df 50 = 0.273 **1% level of significance df 50 = 0.354

In the present investigations, mealybug population (egg sac, nymph, adult and colonies) studied reveals that throughout the year mealybugs were present in the grape vineyards and peak activity period was confined mainly during fruiting to the harvesting this finding is in close agreement with Manjunath (1985), Balikai (1999) and Prasanna and Balikai (2015) they also reported that mealybug population was recorded throughout the year and peak infestation was observed during January to March months.

The studies carried out on egg sacs population during 2018-19 indicates that due to pruning and intermittent raining effect, egg sac population remain low from June to November. Egg sac population was attained peak towards the harvesting in March (13^{th} SMW) (7.1 egg sacs per vine). Similarly, during 2019-20 egg sac population peaked in March (13^{th} SMW) (7.5 egg sacs per vine). The present findings are in agreement with the findings of Koli (2003) who also reported that the egg sac population reached at its peak at the end of (13th SMW) (1.83 egg sacs/ bud). Further, Prasanna and Balikai (2015) also studied the seasonal incidence of grapevine mealybug, *M. hirsutus* for two consecutive years and opined that egg masses were at its peak in the month of March.

The nymphal population studied during 2018-19 showed that the average nymphal population ranged from 9.2 to 28.5 nymphs per vine. There were four peaks recorded in the month of August (32nd SMW), September (37th SMW), October (44th SMW) and March (13th SMW). However, during 2019-20 in all two peaks were noticed during the month of October (41th SMW) and March (13th SMW) and the average nymphal population was ranged from 6.3 to 28.3 nymphs per vine. Similar results were also found by Koli (2003) who recorded one peak of nymphal population in the (13th SMW) of March (61.58 nymphs/ bud).

The adult population studied during 2018-19 showed that the average adult population ranged from 2.5 to 13.2 adults per vine. There were three peaks recorded in the month of July (30th SMW), September (37th SMW) and March (13th SMW). Likely during 2019-20 three peaks were noticed during August (34th SMW) September (39th SMW) and March (13th SMW) and the average adult population ranged from 2.4 to 14.5 adults per vine. Babu and Azam (1987) recorded mealybug, *M. hirsutus* population around Hyderabad and opined that the pest infested the grapevines vegetattive parts from early June to December (1.7-5.1 female adults/twig) and peak infestation was observed during February-March (32.5 female adults/ bunch). Present studies outcome is also in close agreement with the findings of Koli (2003) who reported that peak adult mealybug population was observed during month of March (17.8 adult/bud).

The overall study on mealybug, *M. hirsutus* colonies for two consecutive years 2018-19 and 2019-20 showed that the average number of colonies present was 0.4 to 11.8 and 0.8 to 12.6, respectively. Mealybug colonies peaked thrice; June (25th SMW), August (32nd SMW) and March (13th SMW) during 2018-19. Whereas, peaked twice in the months of August (34th SMW) and March (13th SMW) during 2019-20, respectively. These findings in accordance with the findings of Kulkarni *et al.* (2008) they studied the seasonal incidence of grape mealybug at Pune and reported that mealybug population was distributed sporadically and the highest population (5–6 colonies per vine) was observed during the last week of February to the last week of March coincided with the fruiting and harvesting season. Further, these findings corroborates partialy with the results of Katke *et al.* (2009) who reported that peak number of mealybug colonies of 14.5 and 32.4 per vine were observed during vegetative; September (36^{th} SMW) and fruiting; March (10^{th} SMW) season, respectively.

It appears that excepting maximum temperature, bright sunshine and evaporation all the abiotic factors under the studies were found to be antagonistic tor the development of the mealybug's population (Egg sacs, nymphs, adults and colonies). In the present study significant positive correlation was observed between population of mealybug and maximum temperature, sunshine hours and evaporation. These findings are in conformity with those of Mani and Thontadarya (1987), Katke *et al.* (2009) and Angu *et al.* (2017), who reported that maximum temperature showed a significant positive correlation with the mealybug population. Further, the findings are also in partial agreement with Koli (2003) who opined that mealybugs on grapes showed highly significant and positive correlation with maximum and minimum temperature. Whereas on the contrary in the present study minimum temperature and wind velocity recorded exerting more or less non significant negative effect on the mealybug population development.

Correlation studies for relative humidity indicated that the evening and morning relative humidity showed significant negative correlation with population of mealybug. Similar findings were also registered by Mani and Thontadarya (1987), Koli (2003), Prasanna and Balikai (2015) who reported that mealybugs on grapes showed highly significant negative correlation with morning and evening relative humidity. Present study also reveals that mealybug population exhibits significant negative correlation with rainfall and rainy days this finding contradicts with the results of Shreedharan *et al.* (1989) who recorded that toatal rainfall had not clear correlation with population ome mealybug, *P.citri* in mandarin orange and Koli (2003) opined that mealybugs on grapes showed non significant negative correlation with rainfall.This might be happed due do to change in geographical locations of the observation sites.

4.2 Biology of grape mealybug, *M. hirsutus*

Understanding the biology of the pest provides valuable information for strategizing management possibilities. The present investigations were carried out under the laboratory conditions (Plate 4.1) on pumkins during the summer season (April, 2018) and winter season (October, 2018), respectively. The results obtained under the studies are discussed as under.

4.2.1 Pre-oviposition period, Oviposition period and Fecundity

The data on pre-oviposition period, oviposition period and fecundity of grape mealybug, *M. hirsutus* in summer season (April, 2018) and winter season (October, 2018) is presented in the Table 4.5.

Ten gravid female mealybugs were assessed to study the pre-oviposition period, oviposition period and fecundity, data indicates that during Summer (April, 2018) season pre-ovipositional period ranged from 3 to 4 days with an average of 3.40 ± 0.52 days and the ovipositional period ranged from 5 to 6 days with an average of 5.30 ± 0.48 days and the fecundity ranged from 337 to 428 with an average of 374 ± 40.2 eggs, during which minimum of 27.5 ºC and maximum of 31.7ºC with an average of 28.9 ± 1.02 ºC temperature prevailed with relative humidity range from 23.0 to 41.0 with an average of 31.1 ± 5.34 per cent. The present findings are more or less similar with findings of Katke and Balikai (2009) they studied the biology of grape mealybug, *M. hirsutus* in summer season and reported that pre-ovipositional period ranged from 4 to 6 days with a mean of 5.6 ± 0.61 days and the ovipositional period ranged from 6 to 9 days with a mean of 7.9 ± 0.69 days and the fecundity ranged from 396 to 467 with a mean of 412 ± 29.32 eggs. Further Karanjekar (2019) also reported that pre-ovipositional period and ovipositional period ranged from 3 to 4 days with an average of 3.4 days and 5 to 6 days with anaverage of 5.5 days, respectively. The fecundity ranged from 179 to 387 with an average of 278 eggs at an average temperature of 33.91 + 0.42 0C with relative humidity of 47.54 + 2.12 per cent.

During winter season (October, 2018), according to data recorded pre-ovipositional period ranged from 6 to 7 days with an average of 6.40 ± 0.52 days and the ovipositional period ranged from 7 to 8 days with an average of 7.30 ± 0.48 days and the fecundity ranged from 352 to 496 with an average of 421 ± 49.7 eggs, during which minimum of 25.1ºC and maximum of 29.0ºC with an average of 26.6 ± 1.11ºC temperature prevailed with relative humidity range from 34.5 to 65.0 with an average of 45.4 ± 8.38 per cent. Shelke (2001) observed that, the pre-ovipositional period was 6-7 days with a mean of 6.4 days and the ovipositional period was 11-13 days with an average of 11.6 days on potato sprouts during winter. The female laid eggs in the ovisacs in the ranged of 310 - 505 eggs with a mean of 390 eggs per female. Katke and Balikai (2009) recorded the pre-ovipositional period ranged from 6 to 7 days with an average of 6.4 ± 0.56 days and the ovipositional period ranged from 7 to 9 days with an average of 8.7 ± 0.72 days during winter season on pumpkin. Whereas, fecundity per female ranged from 426 to 573 with an average of 543 ± 42.16 eggs. The results of the present study are in conformity with above reports.

4.2.2 Hatching percentage

Hatching percentage was estimated by transferring five lots of eggs, each containing of freshly laid thirty eggs onto a moist blotting paper kept in petri dishes separately with the help of a camel hair brush. Hatching of crawlers from all the eggs was observed daily under binocular microscope. The data on hatching percentahge of eggs of grape mealybug, *M. hirsutus* in summer (April, 2018) and winter (October, 2018) is presented in the Table 4.6.

The data revealed that, during the Summer season (April, 2018) the hatching percentage of eggs varied from 76.67 to 86.67 per cent with an average of 83.33 ± 2.80 per cent eggs, during which minimum of 28.0 ºC and maximum of 31.7 ºC with an average of 29.5 ± 1.37 ºC temperature prevailed with relative humidity range from 31.00 to 41.0 with an average of 35.0 ± 3.72 per cent.

During Winter season (October, 2018), according to data recorded the hatching percentage of eggs varied from 90.00 to 93.33 per cent with an average of 91.33 ± 1.42 per cent eggs, during which minimum of 25.0ºC and maximum of 27.2ºC with an average of 26.2 ± 0.63 ºC temperature prevailed with relative humidity range from 33.0 to 44.5 with an average of 39.2 ± 3.98 per cent.

Shelke (2001) reported that hatching percentage varied from 80 to 83.33 per cent with an average of 82.67 per cent. Serrano and Lapointe (2002) reported that, hatching percentage of *M. hirsutus* was 91.2 ± 8.0 on pumpkin. According to Katke and Balikai (2009) the hatching percentage of eggs on pumpkin varied from 92.6 to 94.3 per cent with an average of 93.3 per cent and 85.4 to 87.2 with an average of 86.2 per cent during winter and summer season, respectively. The hatching percentage of eggs varied from 70.00 to 83.33 per cent with an average of 76.67 per cent at average temperature of 29.5 + 0.32 0C with relative humidity of 47.9 + 1.55 per cent reported by Karanjekar (2019). The slight deviations observed in hatching percentage from the present findings may be due to differences in the temperatures and relative humidity that prevailed at different locations.

4.2.3 Incubation period

Freshly laid twenty eggs were taken from the culture and placed separately in plastic tubes, the period till they hatched was considered as the incubation period. Initiallly the eggs were translucent and yellowish or light orange in colour. They were elongated and oval in shape. As the time lapsed translucent eggs became pinkish in colour towards hatching. (Sexes were identified in the third instar nymph coming from respective eggs). It could be seen from the data presented in Table 4.7 that, the incubation period varied from 3 to 5 days for female and 5 to 6 days for male in summer season (April, 2018) with an average of 4.20 ± 0.70 and 3.55 ± 0.76 days, respectively. During this observation period minimum of 28.0ºC and maximum of 31.7ºC with an average of 29.5 ± 1.37ºC temperature and relative humidity range from 31.00 to 41.0 with an average of 35.0 ± 3.72 per cent were recorded, respectively.

During winter season (October, 2018), according to data revealed, incubation period varied from 6 to 8 days for female and 6 to 7 days for male with an average of 7.05 ± 0.83 and 6.40 ± 0.50 days, respectively. During this observation period minimum of 25.0 ºC and maximum of 27.2 ºC with an average of 26.2 ± 0.63ºC temperature prevailed with relative humidity range from 33.0 to 44.5 with an average of 39.2 ± 3.98 per cent were recorded, respectively.

Present findings are in agreement with Mani (1986) who reported that, average incubation period was 5.15 ± 0.59 days at temperature of 24-28°C for grape mealy bug on pumpkin. Babu and Azam (1987) observed incubation period of 10.9 days at 25°C and 5.1 days at 31°C for grape mealy bug on pumpkin. Jadhav (1993) reported incubation period of 5-7, 4-6 and 3-5 days with mean of 6.10, 4.70 and 3.93 days at 21.5, 25.0 and 30.0°C, respectively on sprouted potato. According to Katke and Balikai (2009) the incubation period on pumpkin varied from 5 to 7 days for mealybug, *M. hirsutus* in winter with an average of 5.5 ± 0.48 days. Karanjekar (2019) recorded the incubation period ranged from 3 to 5 days with an average of 4.1 days in case of female and 3.8 days in case of male at 29.5 + 0.32^{0}C with relative humidity of 47.9 + 1.55 per cent.

Table 4.5. Pre-oviposition period, oviposition period and fecundity of grape mealybug, *M. hirsutus* in Summer (Apr, 2018) and Winter (Oct, 2018)

Season	Sex	Pre- oviposition period (days) N=10		Oviposition period (days) N=10		Fecundity (eggs/female) N=10		Temperature (°C)		Relative Humidity (%)	
		Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Avg.	Range	Avg.
Summer (Apr, 2018)	Female	3-4	3.40 ± 0.52	5-6	5.30 ± 0.48	337-428	374 ±40.2	27.5-31.7	28.9±1.02	23.0-41.0	31.1±5.34
Winter (Oct, 2018)	Female	6-7	6.40 ± 0.52	7-8	7.30 ± 0.48	352-496	421 ± 49.7	25.1 - 29.0	26.6 ± 1.11	34.5 - 65.0	45.4 ± 8.38

Table 4.6. Hatching percentage of eggs of grape mealybug, *M. hirsutus* in Summer (Apr, 2018) and Winter (Oct, 2018)

Lot No.	No. of Eggs Observed	Summer (Apr, 2018)					Winter (Oct, 2018)				
		Hatching (%)	Temperature (°C)		Relative Humidity (%)		Hatching (%)	Temperature (°C)		Relative Humidity (%)	
			Range	Mean ± SD	Range	Mean ± SD		Range	Mean ± SD	Range	Mean ± SD
1	30.0	86.67	28.0-31.7	29.5 ± 1.37	31.0-41.0	35.0 ± 3.72	93.33	25.0-27.2	26.2 ± 0.63	33.0-44.5	39.2 ± 3.98
2	30.0	76.67					90.00				
3	30.0	80.00					93.33				
4	30.0	86.67					90.00				
5	30.0	86.67					90.00				
Mean ± SD	30.0 ± 0.00	83.33 ± 2.80					91.33 ± 1.42				

Table 4.7. Incubation period of grape mealybug, *M. hirsutus* in Summer (Apr, 2018) and Winter (Oct, 2018).

Season	Sex*	Incubation period (days)		Temperature (°C)		Relative Humidity (%)	
		Range	Mean ± SD	Range	Avg.	Range	Avg.
Summer (Apr, 2018)	**Female**	3-5	4.20 ± 0.70	28.0-31.7	29.5 ± 1.37	31.5-41.0	35.0 ± 3.72
	Male	3-5	3.55 ± 0.76				
Winter (Oct, 2018)	**Female**	6-8	7.05 ± 0.83	25.0-27.2	26.2 ± 0.63	33.0-44.5	39.2 ± 3.98
	Male	6-7	6.40 ± 0.50				

N=20 *Identified in the third instar nymph coming from respective egg

4.2.4 Duration of nymphal stages during Summer season (Apr, 2018) and Winter season (Oct, 2018)

The data on duration of different nymphal instars of *M. hirsutus* observed during summer season (April, 2018) is presented in Table 4.8. The life stages of grape mealybug are depicted in (Plate 4.2).

Ist instar nymph

Freshly hatched nymphs were usually yellow to orange coloured; they possessed reddish colour compound eyes. The six segmented filiform antennae were held diagonally in front of the head. Neonate nymphs were oval in shape, dorsoventraly flattened and highly mobile. In this stage males and females were undistinguishable. During the summer season (April, 2018) the duration of first instar nymph lasted for 7 to 9 days with an average of 8.10 ± 0.77 days for female and 7.92 ± 0.76 days for male when minimum and maximum temperatures were 29.0 and 32.1ºC with an average of 30.4 ± 1.15ºC temperature prevailed with relative humidity range from 19.0 to 43.0 with an average of 28.7 ± 9.31 per cent.

During the winter season (October, 2018) the duration of first instar nymph lasted for 7 to 9 days with an average of 8.06 ± 8.80 days for female and 8.14 ± 0.78 days for male when minimum and maximum temperatures were 22.2 and 27.2 ºC with an average of 24.2 ± 1.55 ºC temperature prevailed with relative humidity range from 33.0 to 47.5 with an average of 40.1 ± 5.78 per cent.

Mani (1986) reported that, the duration of first instar female nymph of *M. hirsutus* was 6.71 ± 0.47 days on pumpkin. Jadhav (1993) shown that, the duration of first nymphal instar of female was 8-13, 7-11 and 6-9 days with a mean of 9.76, 8.72 and 7.50 while for male it was 0, 7-10 and 7-9 days with a mean of 0, 8.14 and 7.38 under 21.5, 25.0 and 30.0°C, respectively. Shelke (2001) reported that, the duration of first nymphal instar of female was 8-11 and 5-7 days with a mean of 9.1 and 5.7 days while for male it was 8-10 and 6-9 days with a mean of 8.6 and 7.0 days at 21-23 and 30-32°C, during winter and summer respectively. According to Katke and Balikai (2009) during summer season, the duration of first instar nymph lasted for 7 to 9 days with an average of 8.1 ± 0.76 days for female and 7.8 ± 0.69 days for male. Wheareas, during winter season, the duration of first instar nymph lasted for 7 to 9 days with a mean of 8.9 ± 0.31 for female and 8.2 ± 0.36 days for male when reared on pumpkin. Further Karanjekar (2019) recorded the duration of first instar nymph ranged from 6 to 8 days with an average of 6.9 days for female and 7.0 days for male at an average temperature of 30.1 + 0.20 0C with relative humidity of 47.75 + 2.25 per cent. Results of the present study are in line with the above reports.

IInd instar nymph

The second instar nymphs were slightly larger than first instar nymphs. The body was pinkish in colour with white thin waxy secretions on the body. It was sluggish and become stationary on suitable feeding spot. The male and female nymphs could not be distinguished till the time of ecdysis. It became faint pink before moulting and shaded whitish exuviae. During the summer season (April, 2018) the duration of second instar nymph lasted for 6 to 8 days with a mean of 7.25 ± 0.69 for female and 7.22 ± 0.68 days for male when minimum and maximum temperatures were 28.6 and 32.3 ºC with an average of 30.0 ± 1.35 ºC temperature prevailed with relative humidity range from 17.0 to 32.5 with an average of 21.8 ± 5.06 per cent.

During the winter season (October, 2018) the duration of second instar nymph lasted for 6 to 8 days with a mean of 7.20 ± 0.70 for female and 7.06 ± 0.79 days for male when minimum and maximum temperatures were 23.0 and 27.8 ºC with an average of 24.4 ± 1.60 ºC temperature prevailed with relative humidity range from 37.0 to 64.0 with an average of 53.4 ± 9.62 per cent.

Table 4.8. Duration of nymphal stages of grape mealybug, *M. hirsutus* in Summer (Apr, 2018) and Winter (Oct, 2018)

Instar	Nymphal period (days), N=100				Temperature (^{o}C)		Relative Humidity (%)	
	Female		Male		Range	Average	Range	Average
	Range	Mean ± SD	Range	Mean ± SD				
Summer (Apr, 2018)								
I	7-9	8.10 ± 0.77	7-9	7.92 ± 0.76	29.0 - 32.1	30.4 ± 1.15	19.0 - 43.0	28.7 ± 9.31
II	6-8	7.25 ± 0.69	6-8	7.22 ± 0.68	28.6 - 32.3	30.0 ± 1.35	17.0 - 32.5	21.8 ± 5.06
III	8-9	8.42 ± 0.50	1	1.00 ± 0.00	30.2 - 32.9	31.0 ± 0.85	22.0 - 33.0	27.3 ± 3.34
IV	-	-	5-6	5.37 ± 0.49	30.2 - 32.9	31.2 ± 1.00	25.5 - 33.0	28.9 ± 2.67
Total	21-26	23.8 ± 1.15	19-24	21.5 ± 1.13	28.6 - 32.9	30.5 ± 1.17	17.0 - 43.0	26.6 ± 6.95
Winter (Oct, 2018)								
I	7-9	8.06 ± 0.80	7-9	8.14 ± 0.78	22.2 - 27.2	24.2 ± 1.55	33.0 - 47.5	40.1 ± 5.78
II	6-8	7.20 ± 0.70	6-8	7.06 ± 0.79	23.0 - 27.8	24.4 ± 1.60	37.0 - 64.0	53.4 ± 9.62
III	9-11	9.94 ± 0.75	1-2	1.40 ± 0.49	22.3 - 25.2	23.3 ± 1.02	29.0 - 45.5	36.4 ± 5.30
IV	-	-	5-7	6.05 ± 0.82	22.3 - 25.2	23.3 ± 1.10	29.0 - 45.5	37.9 ± 6.15
Total	22-28	25.2 ± 1.30	19-26	22.6 ± 1.46	22.2 - 27.8	23.9 ± 1.41	29.0 - 64.0	42.4 ± 9.84

Shelke (2001) reported that, the duration of second nymphal instar of female was 7-8 and 6-7 days with a mean of 7.4 and 6.4 days while for male it was 6-8 and 5-6 days with a mean of 6.5 and 5.5 days at 22-23 and 32-33°C, during winter and summer, respectively.

Katke and Balikai (2009) observed duration of second instar nymphs on pumpkin during summer season which was lasted for 6 to 8 days with a mean of 7.3 ± 0.51 days for female and 7.2 ± 0.72 days for male, respectively while during winter season, the duration of second instar nymph lasted for 6 to 8 days with a mean of 7.5 ± 0.56 for female and 7.4 ± 0.45 days for male, respectively. The results of the present study are more or less in agreement with the above workers.

IIIrd instar nymph

The third instar female nymphs were oval to oblong in shape, orange or pinkish in colour and the whole body was fully covered with white mealy wax. During the summer season (April, 2018) the duration of third instar lasted for 8 to 9 days with an average of 8.42 ± 0.50 days, when minimum and maximum temperatures were 30.2 and 32.9ºC with an average of 31.0 ± 0.85ºC temperature prevailed with relative humidity range from 22.0 to 33.0 with an average of 27.3 ± 3.34 per cent.

During the winter season (October, 2018) the duration of third instar females lasted for 9 to 11 days with an average of 9.94 ± 0.75 days, when minimum and maximum temperatures were 22.3 and 25.2ºC with an average of 23.3 ± 1.02ºC temperature prevailed with relative humidity range from 29.0 to 45.5 with an average of 36.1 ± 5.30 per cent.

The third instar male nymphs were slender and smaller in size than that of third instar female nymph. Its colour was yellowish brown to orange. Seven segmented antennae on head and two waxy caudal filaments at the end of abdominal segment were visible; at the end of this instar male nymph shade the cast and entered in the fourth instar. During summer season (April, 2018) duration of third instar male nymphs lasted for 1 day with an average of 1.00 ± 0.00 day, when minimum and maximum temperatures were 30.2 and 32.9ºC with an average of 31.0 ± 0.85ºC temperature prevailed with relative humidity range from 22.0 to 33.0 with an average of 27.3 ± 3.34 per cent.

During the winter season (October, 2018) the duration of third instar male nymphs lasted for 1 to 2 days with an average of 1.40 ± 0.49 days, when minimum and maximum temperatures were 22.3 and 25.2 ºC with an average of 23.3 ± 1.02 ºC temperature prevailed with relative humidity range from 29.0 to 45.5 with an average of 36.1 ± 5.30 per cent.

The present findings are almost in line with Mani (1986) who reported that, the duration lasted for the third instar female and male nymphs was 7.90 ± 0.79 and 1.00 ± 0.00 days, respectively. Shelke (2001) reported that, the duration of third nymphal instar of female was 7-8 and 8-9 days with a mean of 7.3 and 8.4 days while for male it was 1-2 and 2-3 days with a mean of 1.5 and 2.3 days at 33-34°C and 23-24 °C during summer and winter season, respectively. Katke and Balikai (2009) reported that, during the summer season duration of third instar female nymphs lasted for 8 to 9 days with a mean of 8.20 ± 0.71 days, while third instar female nymphs during the winter season were taken duration of 8 to 10 days with a mean of 8.4 ± 0.67 days when reared on pumpkin. Whereas, the duration of third instar male lasted for 1.0 day with a mean of 1.0 ± 0.00 days and 1 to 2 days with an average of 1.4 ± 0.23 days during summer and winter season, respectively.

IVth instar nymph (male)

The fourth instar male nymphs were formed the flimsy white cottony cocoon around the body and lived inside. If the cocoon torned open, a nymph with well developed wing pads were visible and it almost looked like its adult. During summer season (April, 2018) fourth instar male nymphs duration was lasted for 5 to 6 days with an average of 5.37 ± 0.49 days, when minimum and maximum temperatures were 30.2 and 32.9 ºC with an average of 31.2 ± 1.00 ºC temperature prevailed with relative humidity range from 25.5.0 to 33.0 with an average of 28.9 ± 2.67 per cent.

During the winter season (October, 2018) fourth instar male nymphs duration was lasted for 5 to 7 days with an average of 6.05 ± 0.82 days, when minimum and maximum temperatures were 22.3 and 25.2 ºC with an average of 23.3 ± 1.10 ºC temperature prevailed with relative humidity range from 29.0 to 45.0 with an average of 37.9 ± 6.15 per cent.

Mani (1986) reported that, the duration of fourth nymphal instar exclusively for male was 5.59 ± 0.69 days. According to Shelke (2001) fourth nymphal instar of male lasted for duration of 5-6 and 5-7 days with a mean of 5.6 and 5.4 days at 33-34 and 23-24 °C, during summer and winter, respectively. Katke and Balikai (2009) reported that, during the summer season the duration of fourth instar males lasted for 5 to 6 days with a mean of 5.6 ± 0.73 days. Whereas, during winter season fourth instar males lasted for 5 to 7 days with a mean of 6.3 ± 0.54 days on pumpkin. The above findings of various researchers are almost in accordance with the present investigations.

4.2.5 Total nymphal period

During summer season (April, 2018) the total nymphal periods of female and male were 21 to 26 and 19 to 24 days with an average of 23.8 ± 1.15 and 21.5 ± 1.13 days, respectively. During this period minimum and maximum temperatures were 28.6 and 32.9 ºC with an average of 30.5 ± 1.17 ºC temperature prevailed with relative humidity range from 17.0 to 43.0 with an average of 26.6 ± 6.95 per cent.

During the winter season (October, 2018) the total nymphal periods of female and male were 22 to 28 and 19 to 26 days with an average of 25.2 ± 1.30 and 22.6 ± 1.46 days, respectively. During this period minimum and maximum temperatures were 22.2 and 27.8ºC with an average of 23.9 ± 1.41ºC temperature prevailed with relative humidity range from 29.0 to 64.0 with an average of 42.4 ± 9.84 per cent.

The results of the present study corroborate with the Katke and Balikai (2009) reported that, the total nymphal periods of female and male were 21-26 and 19-24 with an average of 23.6 ± 1.02 and 21.6 ± 0.89 days, respectively when reared on pumpkin during summer season. Whereas, during winter season it was 21-27 and 19-26 with an average of 24.8 ± 1.17 and 23.3 ± 1.07 days for female and male, respectively.

Shinde (2012) reported that, the total nymphal periods of female and male were ranged between 21-25 and 19-23 days with an average of 22.42 ± 1.12 and 20.86 ± 0.76 days, respectively.

Angu (2015) observed that, female grapevine mealybug reared on pumpkin took a total nymphal period of 20 to 29 days with an average of 25.7 ± 1.19 during, February and March.

Naik *et al*. (2017) reported that, on custard apple the total nymphal period of female was 22-28 days with a mean of 26.00 ± 2.05 days while for male it was 20-26 days with a mean of 24.7 ± 3.01 days

Karanjekar (2019) reported that, the total nymphal periods of female and male were 19 to 23 and 17 to 23 with an average of 20.8 and 20.3 days, respectively at average temperature of 31.53 + 1.32 ^{0}C with relative humidity of 47.5 + 2.37 per cent.

4.2.6 Adult longevity

Unlike other insects there were no physical resemblence observed in adult male and female individuals of mealybug. Females were larger than males and the body was soft oval and distinctly segmented. Besides head, totally 13 segments were clearly visible under microscope; which comprised of 3 thoracic and 10 abdominal segments. The adult females were stationary. On the other hand adult males were readily distinguishable from adult female by smaller size, fragile body and presence of one pair of opaque wings and two caudal filaments on last abdominal segment. Caudal filaments were as long as body length. Adult males were orange coloured, minute and very active.

It could be seen from the data presented in Table 4.9 that, the longivity period in summer season (April, 2018) varied from 8 to 10 days for female with an average of 8.80 ± 0.68 days, when minimum of 30.6 ºC and maximum of 34.1 ºC with an average of 32.3 ± 1.29 ºC temperature and relative humidity range from 22.00 to 33.0 with an average of 26.5 ± 3.77 per cent. For the males logivity period recorded was ranged between 2 to 3 days with an average of 2.40 ± 0.51 days, when minimum of 30.6 ºC and maximum of 32.9 ºC with an average of 31.4 ± 1.33 ºC temperature and relative humidity range from 24.5 to 29.0 with an average of 26.5 ± 2.29 per cent.

Table 4.9. Longevity of adults of grape mealybug, *M. hirsutus* in Summer (Apr, 2018) and Winter (Oct, 2018)

Period	Sex	Longevity (days) ± SD N=15		Temperature (ºC)		Relative Humidity (%)	
		Range	Mean ± SD	Range	Avg.	Range	Avg.
Summer (Apr, 2018)	Female	8-10	8.80 ± 0.68	30.6-34.1	32.3 ± 1.29	22.0 - 33.0	26.5 ± 3.77
	Male	2-3	2.40 ± 0.51	30.6-32.9	31.4 ± 1.33	24.5 - 29.0	26.5 ± 2.29
Winter (Oct, 2018)	Female	12-16	14.2 ± 1.57	20.1 - 27.2	22.4 ± 2.05	26.0 - 65.0	47.5 ± 10.49
	Male	3-5	4.07 ± 0.80	22.3 - 24.3	23.1 ± 1.06	32.0 - 59.0	38.9 ± 11.39

During winter season (October, 2018), according to data revealed, the longivity period varied from 12 to 16 days for female with an average of 14.2 ± 1.57 days, when minimum of 20.1 ºC and maximum of 27.2 ºC with an average of 22.4 ± 2.05 ºC temperature and relative humidity range from 26.0 to 65.0 with an average of 47.5 ±

10.49 per cent. For the males logivity period recorded was ranged between 3 to 5 days with an average of 4.07 ± 0.80 days, when minimum of 22.3 ºC and maximum of 24.3 ºC with an average of 23.1 ± 1.06 ºC temperature and relative humidity range from 32.0 to 59.0 with an average of 38.9 ± 11.39 per cent.

Shelke (2001) reported that, during summer season female mealybug adult survived for 8 to 10 days with the average of 8.7 days at 34.88 + 0.58°C and 45.9 + 1.88 % R.H. while in winter it was survived for 17 to 20 days with the average of 18 days at 24.47 + 0.52°C and 51.17 + 3.92 % R.H. Similarly, adult male survived for and 2 to 3 days with the averages of 2.3 days at 34.88 + 0.58°C with R.H. of 45.9 + 1.88 % and 4 to 5 days with the averages of 4.4 at 24.47 + 0.52°C with R.H. of 51.17 + 3.92 % during Summer and Winter season, respectively.

Katke and Balikai (2009) reported that, during summer season the longevity of adult reared on pumpkin ranged between 10 to 15 days with a mean of 14.2 ± 0.69 days for female and it ranged between 2 to 3 days with a mean of 2.9 ± 0.62 days for male. Whereas, the longevity of adult for female ranged between 13 to 16 days with a mean of 15.7 ± 0.81 days and for male it ranged between 3 to 5 days with a mean of 4.1 ± 0.53 days when reared on pumpkin during winter season.

Angu (2015) observed that, the longevity of adult females on pumpkin ranged between 10 to 13 days with a mean of 11.26 ± 0.98 days during February and March. Karanjekar (2019) reported that, the longevity of adult female ranged between 8 to 10 days with a mean of 8.9 days and for adult male, it was ranged between 2 to 3 days with a mean of 2.6 days at average temperature of 33.91 + 0.42^{0}C with relative humidity of 47.54 + 2.12 per cent. The results of the present study of adult longevity are almost in agreement with the above reports. Perhaps slight variation may be due to the difference in climatic condition.

4.2.7 Sex ratio

It could be seen from the data presented in Table 4.10 that in summer season (April, 2018) the male (77 individuals) to female (23 individuals) ratio was 3.35:1, when minimum of 30.6 ºC and maximum of 34.1 ºC with an average of 32.3 ± 1.29 ºC temperature and relative humidity range from 22.0 to 33.0 with an average of 26.5 ± 3.77 per cent.

During winter season (October, 2018), according to data revealed, the male (26 individuals) to female (74 individuals) ratio was 1:2.85, when minimum of 20.1 ºC and maximum of 27.2 ºC with an average of 22.4 ± 2.05 ºC temperature and relative humidity range from 26.0 to 65.0 with an average of 47.5 ± 10.49 per cent. The sex ratio found was found to be at most reversed during the winter which in turn resulted in the production of more female mealybugs which primarily entailed the damage.

The present findings in corroboration with the findings of Shelke (2001) who reported that, male to female sex ratio was 4 : 1 at 34.88 + 0.58°C with R.H. of 45.9 + 1.88 % and 1 : 3 at 24.47 + 0.52°C with R.H. 51.17 + 3.92 % during summer and winter season, respectively. Shinde (2012) reported that, on pumpkin the male to female sex ratio of grape mealy bug, *M. hirsutus* was 1:3.17. Further, Karanjekar (2019) also observed that the male to female ratio was 4 : 1 at an average temperature of 33.91 + 0.42 ^{0}C with relative humidity of 47.54 + 2.12 per cent.

Table 4.10. Sex ratio of grape mealybug, *M. hirsutus* in Summer (Apr, 2018) and Winter (Oct, 2018).

Period	No. of Individuals observed	Male	Female	Sex Ratio	Temperature (°C)		Relative Humidity (%)	
					Range	Avg.	Range	Avg.
Summer (Apr, 2018)	100	77	23	3.35:1	30.6 - 34.1	32.3 ± 1.29	22.0 - 33.0	26.5 ± 3.77
Winter (Oct, 2018)	100	26	74	1:2.85	20.1 - 27.2	22.4 ± 2.05	26.0 - 65.0	47.5 ± 10. 49

4.2.8 Total life span

The data on the total life span of *M. hirsutus* are presented in Table 4.11. During summer season (April, 2018) the incubation period, nymphal period and adult longevity of female were 4.20 ± 0.70, 23.8 ± 1.16 and 8.80 ± 0.68 days, respectively and thus accounting 36.8 ± 1.52 days with an average of 32 - 41 days for total life span, when minimum of 31.8ºC and maximum of 34.1ºC with an average of 30.8 ± 1.53ºC temperature and relative humidity range from 27.5 to 43.0 with an average of 27.4 ± 6.27 per cent. Whereas, the incubation period, nymphal period and adult longevity of male were 3.55 ± 0.76, 21.5 ± 1.11 and 2.40 ± 0.51 days, respectively and thus accounting 27.5 ± 1.44 days with an average of 24 - 32 days for total life span, when minimum of 28.0 ºC and maximum of 32.9ºC with an average of 30.3 ± 1.24ºC temperature and relative humidity range from 17.0 to 43.0 with an average of 27.6 ± 6.90 per cent.

Table 4.11. Total life span of grape mealybug, *M. hirsutus* in Summer (Apr, 2018) and Winter (Oct, 2018)

Sex	Incubation period (days)		Nymphal period (days)		Adult longevity (days)		Total Life span (days)		Temperature (°C)		Relative Humidity (%)	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Avg.	Range	Avg.
Summer (Apr, 2018)												
Female	3-5	4.20 ± 0.70	21-26	23.8 ± 1.16	8-10	8.80 ± 0.68	32-41	36.8 ± 1.52	31.8 - 34.1	30.8 ± 1.53	27.5 - 43.0	27.4 ± 6.27
Male	3-5	3.55 ± 0.76	19-24	21.5 ± 1.11	2-3	2.40 ± 0.51	24-32	27.5 ± 1.44	28.0 - 32.9	30.3 ± 1.24	17.0 - 43.0	27.6 ± 6.90
Winter (Oct, 2018)												
Female	6-8	7.05 ± 0.83	22-28	25.2 ± 1.30	12-16	14.2 ± 1.57	40-52	46.5 ± 2.20	20.1 - 27.8	23.8 ± 2.03	26.0 - 65.0	44.0 ± 9.78
Male	6-7	6.40 ± 0.50	19-26	22.6 ± 1.46	3-5	4.07 ± 0.80	28-38	33.1 ± 1.74	22.2 - 27.8	24.4 ± 1.63	29.0 - 64.0	42.5 ± 9.44

During winter season (October, 2018) the incubation period, nymphal period and adult longevity of female were 7.05 ± 0.83, 25.2 ± 1.30 and 14.2 ± 1.57 days, respectively and thus accounting 46.5 ± 2.20 days with an average of 40 - 52 days for total life span, when minimum of 20.1 ºC and maximum of 27.8 ºC with an average of 23.8 ± 2.03 ºC temperature and relative humidity range from 26.0 to 65.0 with an average of 44.0 ± 9.78 per cent. Whereas, the incubation period, nymphal period and adult longevity of male were 6.40 ± 0.50, 22.6 ± 1.46 and 4.07 ± 0.80 days, respectively and thus accounting 33.1 ± 1.74 days with an average of 28 - 38 days for total life span, when minimum of 22.2 ºC and maximum of 27.8 ºC with an average of 24.4 ± 1.63 ºC temperature and relative humidity range from 29.0 to 64.0 with an average of 42.5 ± 9.44 per cent.

Jadhav (1993) studied the biology of grape mealybug, *M. hirsutus* on potato at different temperatures and reported that, total life span of female was 48-58, 43-49 and 38-43 days with a mean of 53.20, 45.20 and 40.03 days while for male it was 0.00, 27-34 and 25- 29 with a mean of 0.00, 30.00 and 26.78 under 21.5, 25.0 and 30.0°C temperature, respectively.

Shelke (2001) reported that, total life span of female was 45-54 and 29-35 days with a mean of 49.7 and 31.2 days and for male it was 31-37 and 23-28 days with a mean of 33.9 and 25.4 days during winter and summer, respectively on pumpkin. Angu (2015) recorded that, total lifespan of female melybugs reared on pumpkin during the month of February and March was 41.7 ± 3.12 days.

Katke and Balikai (2009) reported that, during summer season on pumpkin the total life span in case of female took 42.5 ± 1.54 and 29.0 ± 1.23 days for male, respectively while the total life span of female and male occupied 45.9 ± 1.92 and 32.8 ± 1.72 days, respectively when reared on pumpkin during winter season.

Sahito *et al*. (2012) noticed that mealybug, *M. hirsutus*, males completed its life cycle in 32-35 days, while females took 41-52 days at 25 ± 2 °C, under laboratory condition. Shinde (2012) reported that, the incubation period, nymphal period and the adult longevity of female were 4.42 ± 0.39, 23.67 ± 0.72 and 12.23 ± 1.08 days, respectively and thus accounting 40.4 ± 2.04 days and the incubation period, nymphal period and adult longevity of male were 4.22 ± 0.44, 20.86 ± 0.76 and 3.43 ± 0.20 days, respectively and thus the total life span took 28.55 ± 1.21 days when reared on pumpkin, respectively. Karanjekar (2019) reported that, the mean incubation period, nymphal period and adult longevity of female were 4.1, 20.8 and 8.9 days, respectively and thus accounting 33.8 days for female. Whereas, for male, the mean incubation period, nymphal period and adult longevity were 3.8, 20.3 and 2.6 days, respectively and thus accounting 26.7 days for total life span at average temperature of 31.78 + 1.620C with relative humidity of 47.60 + 1.93 per cent. Present outcomes are in almost close agreement with findings reported by the above workers.

4.3 Pesticide usage pattern for management of grape mealybug in Western Maharashtra

A survey was conducted to study the pesticide usage pattern followed by the grape growers from January to March 2020 in major grape belt of Western Maharashtra. Ahmednagar, Pune, Solapur, Sangli and Nashik districts are predominat in grape cultivation and come under the jurisdiction of MPKV, Rahuri (Plate 4.3). The data collected on pesticide usage pattern were generated from thirty grape growers from each district who were interviewed for usage and application of different pesticides on grape to manage mealybug.

During survey, the respondents were asked about their awareness and technical know-how about insecticide use, sources of recommendations, awareness about residues persistence of insecticides, their safe waiting periods, *etc.*

4.3.1 General awareness of grape growers about pest management

The growers were surveyed for their general awareness regarding the pests, natural enemies and management practices they carried out were recorded as Yes/No answers. The data collected was converted to per cent respondents. The data pertaining to this aspect is presented in the Table 4.12 and depicted in to Fig. 4.3.

I. Awareness of pest problems

The information generated through survey indicated that, the grape growers (88.66 %) were well aware of the pest problems. The respective per cent awareness showed that growers from Ahmednagar (86.66 %), Pune (90.00 %), Solapur (83.33 %), Sangli (90.00 %) and Nashik (93.33 %) aware about various pests infesting grape crop, respectively. The growers from Nashik district were found to be more vigillient for pest problems. Overall all the growers knew the major insect’s infeting grape *viz.*,mealybug, thrips, flea (udadya) beetle, mites and stem borer. Many growers were also aware about problem of nematodes. Most of the growers frequently face the problem of mealybugs and thrips infestation while growers from Solapur and Sangli stressed the problem of mites and stem borers, respectively.

II. Awareness about natural enemies

Barely, (19.33 %) growers were aware about natural enemies encountered in their vineyards. The respective per cent awareness was Ahmednagar (13.33 %), Pune (16.66 %), Solapur (13.33 %), Sangli (23.33 %) and Nashik (30.33 %), respectively, which indicates that almost (86.67 %) growers do not know about the role of natural enemies and they primarily rely on pesticides to manage the pest problems.

Further, the information generated through the survey indicated that the growers from Nashik (30.00 %) and Sangli (23.33) were more aware of natural enemies; they had used lady bugs (predators) *viz.,. Cryptolaemus montrouzieri* and *Scymnus coccivora* sometimes to control sucking pests of grape.

III. Awareness about bio-pesticides

It was found that neem-based formulation products (neem oil and azadirachtin) were one of the commercial bio-pesticide that growers commonly applied to control insect pests. The data revealed that the biopesticides usage by growers was Ahmednagar (40.00 %), Pune (50.00 %), Solapur (56.66 %), Sangli (70.00 %) and Nashik (80.00 %), respectively.

Unfortunately, lack of quick pest knockdown as against insecticides and comparatively less promotion regarding benefits of their usage grape growers usually kept them as subsidiary option for pest management. Although, (59.33 %) growers use biopesticides and this will have more scope to use in future.

IV. Awareness about recommended pesticides in grape

The awareness about the recommended pesticides in grape was very less (12.00 %) only and many of the growers were using the pesticides which are not recommended by the Central Insecticide Board and Registration Committee (CIB and RC).

The information generated through survey also indicated that, the respective percentage about recommended pesticides in Ahmednagar (3.33 %), Pune (10.00 %), Solapur (6.66 %), Sangli (13.33 %) and Nashik (26.66 %), respectively.

Table 4.12. Awareness among the grape growers of Western Maharashtra about pest management in Ahmednagar, Pune, Solapur, Sangli and Nashik (% respondents)

Sr. No.	Particulars	Ahmednagar	Pune	Solapur	Sangli	Nashik	Mean
1.	Awareness about pest problems	86.66	90	83.33	90	93.33	88.66
2.	Awareness about natural enemies	13.33	16.66	13.33	23.33	30.00	19.33
3.	Awareness about bio-pesticides	40.00	50.00	56.66	70.00	80.00	59.33
4.	Awareness about recommended pesticides in grapes	3.33	10.00	6.66	13.33	26.66	12.00
5.	Awareness about safe waiting period (Pre-Harvest Interval)	13.33	20.00	16.66	30.00	56.66	27.33
6.	Awareness about effects of pesticide	50.00	70.00	56.66	76.66	86.66	68.00
7.	Awareness about use of mobile Applications for getting information on pest management	3.33	23.33	16.66	33.33	43.33	24.00

V. Awareness about safe waiting period (PHI)

In general, the time gap between the last pesticide application and harvest of the commodity is called as safe waiting period. Majority of the grape growers did not know about safe watting period. Very few farmers of Ahmednagar (13.33 %), Pune (20.00 %), Solapur (16.66 %), Sangli (30.00 %) and Nashik (56.66 %), respectively follow the guidelines for post harvest interval.

The major concern regarding to unfollowness was fluctuation in marketable produce prices. Generaly all growers harvest the crop early to fectch better price. So in all (27.33 %) growers only found awared about PHI, which might be a major reason for stresses of unwanted pesticide residues.

VI. Awareness about effects of pesticides

Present data showed that grape growers tend to ignore the pesticide risk. It was a routine practice for majority of growers to spray crop three to five times. The awareness found on effects of pesticides in Ahmednagar (50.00 %), Pune (70.00 %), Solapur (56.66 %), Sangli (76.66 %) and Nashik (86.66 %), respectively.

Many growers indicated that they were aware of the harmful effects of pesticides on human health. The majority of the farmers knew about the ill effects of insecticides but they were hardly using the safguards like apron, goggles, gloves *etc.* while application of pesticides. The mean awareness regarding effects of pesticides was only (68.00 %) which urges that growers should follow the safegurds to avoid ill effects of pesticides.

VII. Awareness about mobile application for getting information on pest management

From the current survey it was found that many growers were having smartphones with them, although they did not use any mobile application for scheduling the sprays. Some farmers from Ahmednagar (3.33 %), Pune (23.33 %), Solapur (16.66 %), Sangli (33.3 %) and Nashik (43.33 %) use mobile application like grape master, plantix *etc.* Besides few growers particularly from Nashik and Sangli were use mobile apllications developed by National Research Centre for Grapes.

The overall awareness on use of various mobile applications in this major grape growing belt was (24.00 %).

4.3.2 Pesticides use description and distribution pattern among grape growers of Western Maharashtra

The data presented in Table 4.13 and depicted in Fig. 4.4 is based on the survey carried out from the growers of Ahmednagar, Pune, Solapur, Sangli and Nashik districts regarding the insecticide usage distribution and handling practices while applying (Plate 4.1).

The occurrence of pests almost of all the localities was common and growers were able to differentiate between the different kinds of pests. The result observed that the mean damage caused due to pests was sucking pests 62.22, stem borer 20.00, flee beetle 14.00 and other pests (defoliators, nematodes *etc.*) 4.00 per cent, respectively.

Nuisence of mealybugs (90.66 %) and thrips (84.00 %) were the most prominent than all the other pests infesting grape crop. In Ahmednagar district pests like mealybugs (86.66 %) and thrips (83.33 %) were the most prevailing pests, which were followed by stem borer (20.00 %), flea beetle (16.66 %), mites (10.00 %) and other pests (3.33 %). In Pune also, mealybug (90.00 %) and thrips (80.00 %) were the major pests, which were followed by, flea beetle (20.00 %), stem borer (16.66 %), mites (10.00 %) and other pests (3.33 %). Similar trend was observed in Solapur district mealybugs (90.00

%), thrips (86.66 %) followed by stem borer (23.33 %), mites (13.33 %) flea beetle (10.00 %) and other pests (3.33 %). In Sangli district it was observed that mealybug (96.66 %) was the most damaging pest followed by thrips (90.33 %). Whereas, damage done by stem borer (26.66 %) was at higher side than that of mites (6.67 %), flea beetle (6.67 %) and other pests (3.33 %), respectively. In Nashik district mealybug (90.66 %) and thrips (84.00 %) were the most devastating pests, which were followed by mites (20.00 %), flea beetle (16.66 %), stem borer (13.33 %), and other pests (6.67 %).

Majority of the growers from the surveyed region were using the insecticides at recommended dose (67.33 %), while (32.67 %) of growers were using the insecticides higher than recommended dose. None of growers in all the districts were found using insecticides less than recommended dose. The highest percentage of recommended dose was practiced in Nashik, (76.66 %) followed by Sangli (70.00 %), Pune (66.66 %), Solapur (63.33 %) districts, respectively. Number of growers from Ahmednagar (40.00 %), were found utilising insecticides higher than the recommended dose followed by Solapur (36.67 %), Pune (33.33 %), Sangli (30.00 %), whereas, least number of growers form Nashik district *i.e.* (23.33 %).

The data also indicated that grape growers (43.33 %) sprayed the crop 3 to 5 times. Mojority of growers (49.33 %) generally sprayed the crop 6 to 8 times, while (7.26 %) growers were found spraying crop 9 to 12 times. Growers from Ahmednagar (80.00 %) sprayed the insecticides 3 to 5 times followed by Pune (60.00 %), Solapur (30.00 %), Sangli (20.00) and Nashik (26.66 %). 6 to 8 spray applications were observed in Sangli (76.66 %) followed by Nashik (56.66 %), Solapur (56.66 %), Pune (36.66) and Ahmednagar (20.00 %), respectively. More than 8 spays (9 to 12 times) generaly applied in Nashik (16.33 %) followed by Sangli (43.33 %), Solapur (30.00 %) and Pune (20.00 %). Further data revealed that no grower from Ahmednagar district was observed to spray crop 9 to 11 times.

It is also observed that the grape growers kept interval between the two consecutive sprays 3 to 5 days (32.00 %), 6 to 10 days (51.33 %) and 11 to 15 days (16.66 %). 3 to 5 days spray interval was common among the growers from Solapur (50.00 %) followed by Ahmednagar (46.66 %), Pune (40.00 %), Sangli (16.66 %) and Nashik (6.67 %). The spray intervals between 6 to 10 days were observed among growers of Sangli (70.00 %), Nashik (63.33 %), Pune (46.66 %), Ahmednagar (43.33 %) and

Solapur (33.33 %). Whereas spray interval between 9 to 15 days more common among growers from Nashik (30.00 %) followed by Solapur (16.66 %), Sangli (13.33 %), Pune (13.33 %) and Ahmednagar (10.00 %).

It is also observed that (66 %) of grape growers followed the scientific way of measuring the pesticides to make the solution for the application while (34.00 %) did not follow the scientific method. A perusal of data revealed that highest 76.00 % growers from Nashik measure the quantity of pesticide properly with measuring top provided along with the pesticide bottles/containers, followed by Sangli (72.00 %), Pune (69.00 %), Solapur (57.00 %) and Ahmednagar (56.00 %). The growers who did not follow scientific methods accounting for their respective percentage in ascending order showed that least in Nashik (24.00 %) followed by Sangli (28.00 %), Pune (31.00 %), Solapur (43.00 %) and Ahmednagar (44.00 %).

Mixing of two or more agrochemicals was common during the pesticide application in the surveyed area showed that 36.00 % of growers mix the different agrochemicals. Nashik growers (63.33 %) commonly used this practice rigorously as compared to Sangli (43.33 %), Solapur (30.00 %), Ahmednagar (23.33 %) and Pune (20.00 %), respectively.

The majority of the growers from the surveyed region were using the insecticides as per the retailers suggestion (29.39 %), followed by Neighbour (27.75 %) > Media (20.61 %) > Universities Scientist (13.47 %) > Agril. Department (8.77 %).

In Ahmednagar (30.61 %) growers were using the insecticides as per the retailers suggestion followed by Neighbour (28.57 %) > Media (21.43 %) > Universities Scientist (10.20 %) > Agril. department (9.18 %). In Pune district it was observed the influence on growers for pesticide usage by retailers (28.57 %) followed by Neighbour (27.55 %) > Media (23.47 %) > Universities Scientist (13.27 %) > Agril. department (7.14 %). In Solapur district it was recorded the influence on growers for pesticide usage by retailers (30.61 %) followed by similar Neighbour (30.61 %) > Media (20.41 %) > Universities Scientist (12.24 %) > Agril. department (6.12 %). Further in Sangli district it was recorded retailers (29.59 %) followed by Neighbour (26.53 %) > Media (19.39 %) > Universities Scientist (15.31 %) > Agril. department (9.18 %). Whereas, in Nashik district growers source of information found were retailers (27.55 %) followed Neighbour

(25.51 %) > Media (18.37 %) > Universities Scientist (16.33 %) > Agril. department (12.24 %).

Table 4.13. Description and distribution pattern among the grape growers of Western Maharashtra based on pesticide usage (% respondents) in Ahmednagar, Pune, Solapur, Sangli and Nashik districts

Sr. No.	Particulars	Ahmed-nagar	Pune	Solapur	Sangli	Nashik	Mean
1.	**Commonly occurring pests**	86.66	90	83.33	90	93.33	88.66
a.	Sucking pests	60.00	60.00	63.33	64.44	63.33	62.22
i.	Mealybugs	86.66	90.00	90.00	96.66	90.00	90.66
ii.	Thrips	83.33	80.00	86.66	90.00	80.00	84.00
iii.	Mites	10.00	10.00	13.33	6.67	20.00	12.00
b.	Stem borer	20.00	16.66	23.33	26.66	13.33	20.00
c.	Flea beetle	16.66	20.00	10.00	6.67	16.66	14.00
d.	Others (defoliators, nematodes, *etc.*)	3.33	3.33	3.33	3.33	6.67	4.00
2.	**Quantity of insecticide used**						
a.	Recommended dose	60.00	66.66	63.33	70.00	76.66	67.33
b.	Lower the recommended dose	0.00	0.00	0.00	0.00	0.00	0.00
c.	Higher the recommended dose	40.00	33.33	36.67	30.00	23.33	32.67
3.	**Number of sprays**						
a.	3 to 5	80.00	60.00	30.00	20.00	26.66	43.33
b.	6 to 8	20.00	36.66	56.66	76.66	56.66	49.33
c.	9 to 12	0.00	3.33	13.33	3.33	16.33	7.26
4.	**Interval of sprays**						
a.	3 to 5 days	46.66	40.00	50.00	16.66	6.67	32.00
b.	6 to 10 days	43.33	46.66	33.33	70.00	63.33	51.33
c.	11 to 15 days	10.00	13.33	16.66	13.33	30.00	16.66
5.	**Measure of pesticides**						
a.	Approximately	44.00	31.00	43.00	28.00	24.00	34.00
b.	Measuring bottle top	56.00	69.00	57.00	72.00	76.00	66.00
6.	**Mixing different pesticides during application**	23.33	20.00	30.00	43.33	63.33	36.00
7.	**Source of information**						
a.	Agriculture Department	9.18	7.14	6.12	9.18	12.24	8.77
b.	Neighbour	28.57	27.55	30.61	26.53	25.51	27.75
c.	Media	21.43	23.47	20.41	19.39	18.37	20.61
d.	Retailer	30.61	28.57	30.61	29.59	27.55	29.39
e.	University scientist	10.20	13.27	12.24	15.31	16.33	13.47

4.3.3 Pesticide usage in the Western Maharashtra based on per cent user growers

The survey was conducted to collect information regarding the number of user growers for respective insecticides used in western Maharashtra for the management of mealybug. Nineteen different insecticides were found most common in use are listed in the Table 4.14. The collected data was then converted to percentages presented in Table 4.15 and represented in Fig. 4.5 revealed that there were three groups of pesticides available in the market which the per cent growers used belonged to Conventional insecticides (76.53 %), Novel insecticides (71.88 %) and bio-insecticides (80.67 %).

Nashik district growers were ranked first in using conventional insecticides (83.33 %) followed by Sangli (76.00 %) which was almost similar to Solapur (76.00 %), then Pune (74.66) and Ahmednagar (72.00 %). Almost similar usage of novel insecticides was recorded from Nashik (80.60 %) followed by Sangli (76.48 %), Solapur (71.54 %), Pune (67.42) and Ahmednagar (63.33 %). Whereas, the per cent growers using bio-insecticides were from Nashik (91.11 %) followed by Sangli (87.78 %), Solapur (81.11 %), Pune (75.56 %) and Ahmednagar (67.77 %), respectively.

Ahmednagar

The reports showed that in the Ahmednagar district per cent of user growers for conventional insecticides (72.66 %) were most commonly used, pursued by bio-insecticides (67.67.00 %) and novel insecticides (63.33 %).

Among the Conventional group of insecticides *viz.*,Organophosphate insecticides - chlorpyrifos (86.67 %) was preferred followed by Dichlorovos (86.66 %) and Malathion (66.63 %). Carbamate group insecticide - Methomyl (43.33 %); Synthetic pyrethroid - Lamda cyhalothrin (80.00 %) growers were used. The next Novel group of insecticides itself comprises various insecticides *viz.*,Diamides - Cyantraniliprole (76.66 %) and Chlorantraniliprole (73.33 %); Phenyl pyrazole - Fipronil (93.33 %); Neo nicotinoides Clothianidin (40.00 %), Imidacloprid (96.66 %); Semi synthetic spynosins - Spinetoram (20.00 %); Spynosin - Spinosad (13.33 %); Insect growth regulator (IGR) - Buprofezin (90.00 %); Ket enol - Spirotetramat (56.66 %); Avermectin - Abamectin (63.33 %) and Carboxylic esters - Bifenazate (73.33 %) used by the growers.

Further, it was observed that bio- insecticides group - *L. lecanii* (86.66 %), *M. anisopliae* (63.33 %) and Azadirachtin (53.33 %) growers used to manage mealybug on grape vines.

Pune

In the Pune district per cent of user growers for bio-insecticides (75.56 %) were most commonly used, pursued by conventional insecticides (74.66 %) and novel insecticides (67.42 %).

Among the Conventional group of insecticides *viz.,*Organophosphate insecticides - chlorpyrifos (86.66 %) was preferred followed by Dichlorovos (90.00 %) and Malathion (53.33 %). Carbamate group insecticide - Methomyl (56.66 %); Synthetic pyrethroid - Lamda cyhalothrin (86.66 %) growers were used. The next Novel group of insecticides itself comprises various insecticides *viz.,*Diamides - Cyantraniliprole (80.00 %) and Chlorantraniliprole (76.66 %); Phenyl pyrazole - Fipronil (90.00 %); Neo nicotinoides Clothianidin (46.66 %), Imidacloprid (96.67 %); Semi synthetic spynosins - Spinetoram (23.33 %); Spynosin - Spinosad (20.00 %); Insect growth regulator (IGR) - Buprofezin (95.00 %); Ket enol - Spirotetramat (60.00 %); Avermectin - Abamectin (66.66 %) and Carboxylic esters - Bifenazate (86.67 %) used by the growers.

Further, it was observed that bio-insecticides group - *L. lecanii* (90.00 %), *M. anisopliae* (76.67 %) and Azadirachtin (60.00 %) growers used to manage mealybug on grape vines.

Solapur

In the Solapur district per cent of user growers for bio-insecticides (81.11 %) were most commonly used, pursued by conventional insecticides (76.00 %) and novel insecticides (71.54 %).

Among the Conventional group of insecticides *viz.,*Organophosphate insecticides - chlorpyrifos (90.00 %) was preferred followed by Dichlorovos (90.00 %) and Malathion (56.66 %). Carbamate group insecticide - Methomyl (60.00 %); Synthetic pyrethroid - Lamda cyhalothrin (83.33 %) growers were used. The next Novel group of insecticides itself comprises various insecticides *viz.,*Diamides - Cyantraniliprole (86.66 %) and Chlorantraniliprole (80.00 %); Phenyl pyrazole - Fipronil (90.00 %); Neo nicotinoides Clothianidin (50.00 %), Imidacloprid (100 %); Semi synthetic spynosins - Spinetoram (26.66 %); Spynosin - Spinosad (16.66 %); Insect growth regulator (IGR) -

Buprofezin (97.00 %); Ket enol - Spirotetramat (66.66 %); Avermectin - Abamectin (76.66 %) and Carboxylic esters - Bifenazate (96.67 %) used by the growers.

Further, it was observed that bio-insecticides group - *L. lecanii* (83.33 %), *M. anisopliae* (86.67 %) and Azadirachtin (73.33 %) growers used to manage mealybug on grape vines.

Sangli

In the Sangli district per cent of user growers for bio-insecticides (87.78 %) were most commonly used, pursued by novel insecticides (76.48 %) and conventional insecticides (76.00 %). Among the Conventional group of insecticide user growers for Organophosphate insecticides - chlorpyrifos (80.00 %), Dichlorovos (86.66 %) and Malathion (53.33 %). Carbamate group insecticide - Methomyl (70.00 %); Synthetic pyrethroid - Lamda cyhalothrin (90.00 %). The next Novel group of insecticides itself comprises various insecticides *viz.,*Diamides - Cyantraniliprole (86.66 %) and Chlorantraniliprole (90.00 %); Phenyl pyrazole - Fipronil (86.66 %); Neo nicotinoides Clothianidin (56.66 %), Imidacloprid (100 %); Semi synthetic spynosins - Spinetoram (40.00 %); Spynosin - Spinosad (26.66 %); Insect growth regulator (IGR) - Buprofezin (98.00 %); Ket enol - Spirotetramat (80.00 %); Avermectin - Abamectin (80.00 %) and Carboxylic esters - Bifenazate (96.67 %) used by the growers.

Further, it was observed that bio-insecticides group - *L. lecanii* (96.67 %), *M. anisopliae* (93.33 %) and Azadirachtin (73.33 %) growers used to manage mealybug on grape vines.

Nashik

In the Nashik district per cent of user growers for bio-insecticides (91.11 %) were most commonly used, pursued by conventional insecticides (83.33 %) and novel insecticides (80.60 %). Among the Conventional group of insecticides user growers for Organophosphate insecticides - chlorpyrifos (83.33 %), Dichlorovos (93.33 %) and Malathion (73.33 %). Carbamate group insecticide - Methomyl (73.33 %); Synthetic pyrethroid - Lamda cyhalothrin (93.33 %). The next Novel group of insecticides itself comprises various insecticides *viz.,*Diamides - Cyantraniliprole (90.00 %) and Chlorantraniliprole (83.33 %); Phenyl pyrazole - Fipronil (90.00 %); Neo nicotinoides Clothianidin (63.33 %), Imidacloprid (100 %); Semi synthetic spynosins - Spinetoram (53.33 %); Spynosin - Spinosad (33.33 %); Insect growth regulator (IGR) - Buprofezin

(100 %); Ket enol - Spirotetramat (86.66 %); Avermectin - Abamectin (86.66 %) and Carboxylic esters - Bifenazate (100 %) user growers.

Further, it was observed that bio- insecticides group - *L. lecanii* (96.67 %), *M. anisopliae* (93.33 %) and Azadirachtin (73.33 %) growers used to manage mealybug on grape vines.

Table 4.14. List of most commonly used insecticides and bio-pesticides of different chemical groups by the grape growers of Western Maharashtra

Sr. No.	Insecticide	Chemical group	Target Pest
1.	Chlorpyrifos 20 % EC	Organophosphate	Mealybug
2.	Dichlorvos 76 % EC	Organophosphate	Mealybug
3.	Malathion 50 % EC	Organophosphate	Mealybug
4.	Methomyl 40 % SP	Carbamate	Mealybug
5.	Lambda cyhalothrin 5 % EC	Synthetic pyrethroid	Mealybug,
6.	Cyantraniliprole 10 % OD	Diamide	Thrips
7.	Chlorantraniliprole 18.5 % SC	Diamide	Stem borer
8.	Fipronil 80 % WG	Phenyl pyrazole	Thrips
9.	Clothianidin 50 % WDG	Neo-nicotinoid	Mealybug
10.	Imidacloprid 17.8 % SL	Neo-nicotinoid	Mealybug
11.	Spinetoram 11.7 % SC	Semi-synthetic spinosyn	Thrips
12.	Spinosad 45 % SC	Spinosyn	Thrips
13.	Buprofezin 25 % SC	IGR	Mealybug
14.	Spirotetramat 15.31 % OD	Ket-enol	Mealybug
15.	Abamectin 1.9 % EC	Avermectin	Mites
16.	Bifenazate 22.6 % SC	Carboxylic ester	Mites
17.	*Lecanicillium lecanii,*	Entomopathogenic fungi	Mealybug, Thrips
18.	*Metarhizium anisopliae*	Entomopathogenic fungi	Mealybug, Stem borer
19.	Azadirachtin	Botanicals	Mealybug, Thrips

Table 4.15. Pesticide usage in the Western Maharashtra by per cent user growers in Ahmednagar, Pune, Solapur, Sangli and Nashik districts

Sr. No.	Major Group of Insecticide	Chemical group	Insecticide	Per cent user growers					
				Ahmed nagar	Pune	Solapur	Sangli	Nashik	Mean
1	Conventional insecticides (76.53 %)	Organophosphate	Chlorpyrifos 20 % EC	86.67	86.66	90.00	80.00	83.33	85.33
			Dichlorvos 76 % EC	86.66	90.00	90.00	86.66	93.33	89.33
			Malathion 50 % EC	66.66	53.33	56.66	53.33	73.33	60.66
		Carbamate	Methomyl 40 % SP	43.33	56.66	60.00	70.00	73.33	60.66
		Synthetic pyrethroid	Lambda cyhalothrin 5 % EC	80.00	86.66	83.33	90.00	93.33	86.66
			Mean	72.66	74.66	76.00	76.00	83.33	76.53
2	Novel insecticides (71.88 %)	Diamide	Cyantraniliprole 10 % OD	76.66	80	86.66	86.66	90.00	84.00
			Chlorantraniliprole 18.5 % SC	73.33	76.66	80.00	90.00	83.33	80.66
		Phenyl pyrazole	Fipronil 80 % WG	93.33	90.00	90.00	86.66	90.00	90.00
		Neo-nicotinoid	Clothianidin 50 % WDG	40.00	46.66	50.00	56.66	63.33	51.33
			Imidacloprid 17.8 % SL	96.66	96.67	100	100	100	98.67
		Semi-synthetic spinosyn	Spinetoram 11.7 % SC	20.00	23.33	26.66	40.00	53.33	32.66
		Spinosyn	Spinosad 45 % SC	13.33	20.00	16.66	26.66	33.33	22.00
		IGR	Buprofezin 25 % SC	90.00	95.00	97.00	98.00	100	96.00
		Ket-enol	Spirotetramat 15.31 % OD	56.66	60.00	66.66	80.00	86.66	70.00
		Avermectin	Abamectin 1.9 % EC	63.33	66.66	76.66	80.00	86.66	74.66
		Carboxylic ester	Bifenazate 22.6 % SC	73.33	86.67	96.67	96.67	100	90.67
			Mean	63.33	67.42	71.54	76.48	80.60	71.88
3	Bio-insecticides (80.67 %)	Entomopathogenic fungi	*Lecanicillium lecanii*	86.66	90.00	83.33	96.67	100	91.33
			Metarhizium anisopliae	63.33	76.67	86.67	93.33	96.67	83.33
		Botanicals	Azadirachtin	53.33	60.00	73.33	73.33	76.67	67.33
			Mean	67.77	75.56	81.11	87.78	91.11	80.67

Mean

From the mean data, it was observed that the order of preference for usage by the growers was bio-insecticides (80.87 %) followed by conventional insecticides (76.53 %) and novel insecticides (71.88 %) in Western Maharashtra.

Among the Conventional group of insecticides user growers for Organophosphate insecticides - Chlorpyrifos (85.33 %), Dichlorovos (89.33 %) and Malathion (60.66 %). Carbamate group insecticide - Methomyl (60.66 %); Synthetic pyrethroid - Lamda cyhalothrin (86.66 %). The next Novel group of insecticides itself comprises various insecticides *viz.*,Diamides - Cyantraniliprole (84.00 %) and Chlorantraniliprole (80.66 %); Phenyl pyrazole - Fipronil (90.00 %); Neo nicotinoides Clothianidin (51.33 %), Imidacloprid (98.67 %); Semi synthetic spynosins - Spinetoram (32.66 %); Spynosin - Spinosad (22.00 %); Insect growth regulator (IGR) - Buprofezin (96.00 %); Ket enol - Spirotetramat (70.00 %); Avermectin - Abamectin (74.66 %) and Carboxylic esters - Bifenazate (90.67 %) user growers, while user growers for bio-insecticides group - *L. lecanii* (91.33 %), *M. anisopliae* (83.33 %) and Azadirachtin (67.33 %).

Further, a perusal of data revealed that among the various group of insecticides of choice by the grape growers in Western Maharashtra for mealybug management were bio-insecticide *L. lecanii* (91.33 %) > Novel insecticide - Imidacloprid (98.67 %) > Conventional group of insecticide- Chlorpyrifos (89.33 %), respectively.

4.3.4 Pesticide usage pattern in the Western Maharashtra based on per cent pesticide utilized.

The survey was conducted to collect information regarding the per cent insecticide used in Western Maharashtra for the management of mealybug. The collected data was then converted to percentages presented in Table 4.16 and depicted in Fig 4.6, revealed that there were three groups of pesticides in use which belonged to Conventional insecticides (27.11 %), Novel insecticides (55.83 %) and bio-insecticides (17.06 %).

Ahmednagar district was ranked first in per cent usage of conventional insecticides (28.76 %) followed by Pune (27.79 %), Solapur (26.95 %), Sangli (26.62 %) and Nashik (26.43 %). Per cent Novel insecticides usage recorded showed that greater in Sangli (55.79 %) followed by Nashik (56.63 %), Solapur (55.79 %), Pune (55.33 %) and Ahmednagar (55.15 %). Whereas, the per cent bio-insecticides used were higher in

Sangli (17.75 %), Nashik (17.34 %), Solapur (17.26 %), Pune (16.87 %) and Ahmednagar (16.09 %), respectively.

Ahmednagar

The reports showed that in the Ahmednagar district per cent usage of Novel insecticides (55.15 %) were most commonly used, pursued by conventional insecticides (28.76 %) and bio-insecticides (16.09 %)

Per cent insecticide usage was revealed that among the Conventional group of insecticides *viz.*,Organophosphate insecticides - Chlorpyrifos (6.86 %), followed by Dichlorovos (6.86 %) and Malathion (5.28 %). Carbamate group insecticide - Methomyl (3.43 %); Synthetic pyrethroid - Lamda cyhalothrin (6.33 %) used. The next Novel group of insecticides itself comprises various insecticides *viz.*,Diamides - Cyantraniliprole (6.047 %) and Chlorantraniliprole (5.80 %); Phenyl pyrazole - Fipronil (7.39 %); Neo nicotinoides Clothianidin (3.17 %), Imidacloprid (7.65 %); Semi synthetic spynosins - Spinetoram (1.58 %); Spynosin - Spinosad (1.06 %); Insect growth regulator (IGR) - Buprofezin (7.12 %); Ket enol - Spirotetramat (4.49 %); Avermectin - Abamectin (5.01 %) and Carboxylic esters - Bifenazate (5.80 %), respectively.

Further, per cent usage was observed for bio-insecticides group - *L. lecanii* (6.86 %), *M. anisopliae* (5.01 %) and Azadirachtin (4.22 %) to manage mealybug on grape vines.

Pune

In the Pune district per cent insecticide usage of Novel insecticides (55.33 %) were most commonly used, pursued by conventional insecticides (27.79 %) and bio-insecticides (16.87 %).

Per cent of insecticide usage was revealed that among the Conventional group of insecticides *viz.*,Organophosphate insecticides - Chlorpyrifos (6.45 %), followed by Dichlorovos (6.70 %) and Malathion (3.97 %). Carbamate group insecticide - Methomyl (4.22 %); Synthetic pyrethroid - Lamda cyhalothrin (6.45 %) used. The next Novel group of insecticides itself comprises various insecticides *viz.*,Diamides - Cyantraniliprole (5.95 %) and Chlorantraniliprole (5.71 %); Phenyl pyrazole - Fipronil (6.70 %); Neo nicotinoides Clothianidin (3.47 %), Imidacloprid (7.20 %); Semi synthetic spynosins - Spinetoram (1.74 %); Spynosin - Spinosad (1.49 %); Insect growth regulator (IGR) - Buprofezin (7.20 %); Ket enol - Spirotetramat (4.47 %); Avermectin - Abamectin (4.96 %) and Carboxylic esters - Bifenazate (6.45 %), respectively.

Table 4.16. Per cent insecticide usage by the grape growers of Western Maharashtra in Ahmednagar, Pune, Solapur, Sangli and Nashik districts

Sr. No.	Major Group of Insecticide	Chemical group	Insecticide	Per cent user growers					
				Ahmed nagar	Pune	Solapur	Sangli	Nashik	Mean
1	Conventional insecticides (27.11 %)	Organophosphate	Chlorpyrifos 20 % EC	6.86	6.45	6.38	5.39	5.29	6.07
			Dichlorvos 76 % EC	6.86	6.70	6.38	5.84	5.92	6.34
			Malathion 50 % EC	5.28	3.97	4.02	3.60	4.65	4.30
		Carbamate	Methomyl 40 % SP	3.43	4.22	4.26	4.72	4.65	4.25
		Synthetic pyrethroid	Lambda cyhalothrin 5 % EC	6.33	6.45	5.91	6.07	5.92	6.14
			Total	28.76	27.79	26.95	25.62	26.43	27.11
2	Novel insecticides (55.83 %)	Diamide	Cyantraniliprole 10 % OD	6.07	5.96	6.15	5.84	5.71	5.94
			Chlorantraniliprole 18.5 % SC	5.80	5.71	5.67	6.07	5.29	5.71
		Phenyl pyrazole	Fipronil 80 % WG	7.39	6.70	6.38	5.84	5.71	6.40
		Neo-nicotinoid	Clothianidin 50 % WDG	3.17	3.47	3.55	3.82	4.02	3.60
			Imidacloprid 17.8 % SL	7.65	7.20	7.09	6.74	6.34	7.00
		Semi-synthetic spinosyn	Spinetoram 11.7 % SC	1.58	1.74	1.89	2.70	3.38	2.26
		Spinosyn	Spinosad 45 % SC	1.06	1.49	1.18	1.80	2.11	1.53
		IGR	Buprofezin 25 % SC	7.12	7.20	6.86	6.52	6.34	6.81
		Ket-enol	Spirotetramat 15.31 % OD	4.49	4.47	4.73	5.39	5.50	4.91
		Avermectin	Abamectin 1.9 % EC	5.01	4.96	5.44	5.39	5.50	5.26
		Carboxylic ester	Bifenazate 22.6 % SC	5.80	6.45	6.86	6.52	6.34	6.39
			Total	55.15	55.33	55.79	56.63	56.24	55.83
3	Bio-insecticides (17.06 %)	Entomopathogenic fungi	*Lecanicillium lecanii*	6.86	6.70	5.91	6.52	6.34	6.47
			Metarhizium anisopliae	5.01	5.71	6.15	6.29	6.13	5.86
		Botanicals	Azadirachtin	4.22	4.47	5.20	4.94	4.86	4.74
			Total	16.09	16.87	17.26	17.75	17.34	17.06

Further, per cent usage was observed for Bio- insecticides group - *L. lecanii* (6.70 %), *M. anisopliae* (5.71 %) and Azadirachtin (4.47 %) to manage mealybug on grape vines.

Solapur

In the Solapur district per cent of insecticide usage of Novel insecticides (55.79 %) were most commonly used, pursued by conventional insecticides (26.95 %) and bio-insecticides (17.26 %).

Per cent insecticide usage was revealed that among the Conventional group of insecticides *viz.,*Organophosphate insecticides - Chlorpyrifos (6.38 %), followed by exactly similar percentage Dichlorovos (6.38 %) and Malathion (4.02 %). Carbamate group insecticide - Methomyl (4.26 %); Synthetic pyrethroid - Lamda cyhalothrin (5.91 %) used. The next Novel group of insecticides itself comprises various insecticides *viz.,*Diamides - Cyantraniliprole (6.15 %) and Chlorantraniliprole (5.67 %); Phenyl pyrazole - Fipronil (6.38 %); Neo nicotinoides Clothianidin (3.55 %), Imidacloprid (7.09 %); Semi synthetic spynosins - Spinetoram (1.89 %); Spynosin - Spinosad (1.18 %); Insect growth regulator (IGR) - Buprofezin (6.86 %); Ket enol - Spirotetramat (4.73 %); Avermectin - Abamectin (5.44 %) and Carboxylic esters - Bifenazate (6.86 %), respectively.

Further, per cent usage was observed for bio-insecticides group - *L. lecanii* (5.91 %), *M. anisopliae* (6.15 %) and Azadirachtin (5.20 %) to manage mealybug on grape vines.

Sangli

In the Sangli district per cent of insecticide usage of Novel insecticides (56.63 %) were most commonly used, pursued by conventional insecticides (26.62 %) and bio-insecticides (17.75 %).

Per cent insecticide usage was revealed that among the Conventional group of insecticides *viz.,*Organophosphate insecticides - Chlorpyrifos (5.39 %), followed Dichlorovos (5.84 %) and Malathion (3.60 %). Carbamate group insecticide - Methomyl (4.72 %); Synthetic pyrethroid - Lamda cyhalothrin (6.07 %) used. The next Novel group of insecticides itself comprises various insecticides *viz.,*Diamides - Cyantraniliprole (5.84 %) and Chlorantraniliprole (6.07 %); Phenyl pyrazole - Fipronil (5.84 %); Neo nicotinoides Clothianidin (3.82 %), Imidacloprid (6.74 %); Semi synthetic spynosins -

Spinetoram (2.70 %); Spynosin - Spinosad (1.80 %); Insect growth regulator (IGR) - Buprofezin (6.52 %); Ket enol - Spirotetramat (5.39 %); Avermectin - Abamectin (5.39 %) and Carboxylic esters - Bifenazate (6.52 %), respectively.

Further, per cent usage was observed for bio- insecticides group - *L. lecanii* (6.52 %), *M. anisopliae* (6.29 %) and Azadirachtin (4.94 %) to manage mealybug on grape vines.

Nashik

In the Nashik district per cent of insecticide usage of Novel insecticides (56.24 %) were most commonly used, pursued by conventional insecticides (26.43 %) and bio-insecticides (17.34 %).

Per cent insecticide usage was revealed that among the Conventional group of insecticides *viz.*,Organophosphate insecticides - Chlorpyrifos (5.29 %), Dichlorovos (5.92 %) and Malathion (4.65 %). Carbamate group insecticide - Methomyl (4.65 %); Synthetic pyrethroid - Lamda cyhalothrin (5.92 %) used. The next Novel group of insecticides itself comprises various insecticides *viz.*,Diamides - Cyantraniliprole (5.71 %) and Chlorantraniliprole (5.29 %); Phenyl pyrazole - Fipronil (5.71 %); Neo nicotinoides Clothianidin (4.02 %), Imidacloprid (6.34 %); Semi synthetic spynosins - Spinetoram (3.38 %); Spynosin - Spinosad (2.11 %); Insect growth regulator (IGR) - Buprofezin (6.34 %); Ket enol - Spirotetramat (5.50 %); Avermectin - Abamectin (5.50 %) and Carboxylic esters - Bifenazate (6.34 %), respectively.

Further per cent usage was observed for Bio- insecticides group - *L. lecanii* (6.34 %), *M. anisopliae* (6.13 %) and Azadirachtin (4.86 %) to manage mealybug on grape vines.

Mean

From the mean data, it was observed that the order of preference for per cent usage of insecticides was higher in Novel insecticides (55.83 %) followed by conventional insecticides (27.11 %) and bio-insecticides (17.06 %) in Western Maharashtra.

Among the Conventional group of insecticides per cent usage were, Organophosphate insecticides - Chlorpyrifos (6.07 %), Dichlorovos (6.34 %) and Malathion (4.30 %). Carbamate group insecticide - Methomyl (4.25 %); Synthetic pyrethroid - Lamda cyhalothrin (6.14 %). The next Novel group of insecticides itself comprises various insecticides *viz.*,Diamides - Cyantraniliprole (5.94 %) and Chlorantraniliprole (5.71 %); Phenyl pyrazole - Fipronil (6.40 %); Neo nicotinoides Clothianidin (3.60 %), Imidacloprid (7.00 %); Semi synthetic spynosins - Spinetoram (2.26 %); Spynosin - Spinosad (1.53 %); Insect growth regulator (IGR) - Buprofezin (6.81 %); Ket enol - Spirotetramat (4.91 %); Avermectin - Abamectin (5.26 %) and Carboxylic esters - Bifenazate (6.39 %) used, while per cent insecticide usage for Bio-insecticides group - *L. lecanii* (6.47 %), *M. anisopliae* (5.86 %) and Azadirachtin (4.74 %).

Further, a perusal of data revealed that among the various group of insecticides higher percentage of insecticides used by grape growers in Western Maharashtra for mealybug management were Novel insecticide - Imidacloprid (7.00 %) > Conventional group of insecticide- Dichlorvos (6.34 %) > bio-insecticide *L. lecanii* (6.47 %), respectively.

In the present investigation it reveals that majority of grape growers from Ahmednagar, Pune, Solapur, Sangli and Nashik districts were aware of the severity of pest problems and were able to differentiate between the insect pests. It was observed that sucking pests were the most frequently occurring insect pests. Mealybugs were more problematic as compared to other insect pests and were the main constraint in grape cultivation. The result of present investigation cannot be compared due to lack of literature. Therefore, pertinent literature on others crops are discussed.

Malgie *et al.* (2015) reported that the farmer's knowledge about pest problems is the basic need to start over the management practices and borers and whitefly were the most troublesome pests according to the majority of the respondents in all three stages of several vegetable crops, including tomato, cabbage, string beans and lettuce. Guru *et al.* (2018a) reported that 73.23 per cent polyhouse and 21.33 per cent open field capsicum growers were well aware of the pest problems. Mawtham *et al.* (2022) conducted intensive survey in major gourd growing districts of Tamil Nadu, 96.67 per cent farmers reported melon fruit fly was major predominant pest. Shinde *et al.* (2022) reported that nearly 69.50 per cent of spinach growers were aware of the severity of pest problems and were able to differentiate between the insect pests of spinach.

Present investigation reveals that overall 19 per cent grape growers of Western Maharashtra aware about natural enemies of insect pests in their fields. The present findings are in agreement with Ramakrishnan *et al.* (2015) who reported that only 16 per cent curry leaf growers knew about natural enemies. Further, the grape growers from Nashik district (30 %) were more aware about natural enemies than growers of Ahmednagar (13 %), Solapur (13 %), Pune (16 %) and Sangli (23 %) districts. However, Shinde *et al.* (2022) reported that 66, 62 and 48 per cent of growers of Pune, Nashik and Ahmednagar districts, were aware of natural enemies of insect pests of spinach.

Present investigation reveals that grape growers of Ahmednagar, Pune, Solapur, Sangli and Nashik, respectively were aware of application of biopesticide and their benefits. This finding in corroboration with the findings of Sawant *et al.* (2018b) and Guru *et al.* (2018a) reported that majority of the cabbage and capsicum growers of Ahmednagar, Pune and Nashik districts were aware about the application of biopesticides. According to Shinde *et al.* (2022) reported that, 78, 74 and 54 per cent of spinach growers of Pune, Nashik and Ahmednagar districts were aware about the biopesticides and their benefits.

In the present study, it was found that most of the grape growers of Ahmednagar, Pune, Solapur, Sangli and Nashik districts know the harmful effects on human being but did not know about the recommendation of insecticides specific for combating mealybugs. Survey carried out by earlier workers support the present findings. Kelageri *et al.* (2016) reported that, awareness on pesticide related issues was varying among poly house and open field tomato farmers with some commonality, where 35.71 per cent poly house farmers know about recommended pesticides while only 16.67 per cent open field farmers aware on this issue. Farmers were used various insecticides belonging to different chemical group, but majority were not recommended on tomato by Central Insecticide Board and Registration Committee (CIBRC). Vemuri *et al.* (2016) study revealed that, 28.57 per cent poly house farmers know about recommended pesticides while only 10 per cent open field farmers growing capsicum were aware of this issue. Priyadarshini *et al*. (2017) studied on pesticide usage pattern in curry leaf growing areas they observed that, 35.71 per cent farmers know about recommended pesticides while only 24.29 per cent of farmers were aware of pesticide classification based on toxicity.

Present investigations revealed that majority of the grape growers from Ahmednagar, Pune, Solapur, Sangli and Nashik did not know about safe watting period of pesticides and which might be a major reason for stresses of unwanted pesticide residues. These findings are in agreement with Sutharsan *et al.* (2014) who reported that more than 89 per cent of the vegetable farmers harvested their produce before the recommended pre harvest interval. Meenambigai and Bhuvaneswari (2017) reported that, almost 65 per cent farmers of the major orkra growing area of Tamil Nadu followed the common waiting period of 1 day after spraying. According to Naqash *et al.* (2019) 95 per cent apple growers of Kashmir Valley were applying pesticides indiscriminately in violation of the scientific recommendations.

Although all the grape growers from Western Maharashra knew that the exposure to pesticide cause adverse health effects on human health 68 per cent of them had general knowledge about the adverse health effects of pesticide exposure on human health. Patil and Katti (2012) reported 75 per cent of labourers used either “moderately hazardous” or “highly hazardous” pesticides as classified by World Health Organisation and 88 per cent did not use any form of protection, while handling pesticides. According to Sawant *et al.* (2018a) 25 per cent cabbage growers, Guru *et al.* (2018a) 76.67 per cent polyhouse and 40 percent open field capsicum growers of Ahmednagar, Pune and Nashik of Western Maharashtra know the residual effects of insecticides.

Present study reveals that many growers were having smartphones with them, although few grape growers utilized mobile applications to got information related to pest management and scheduling fertilizer dosses *etc.* Nikam *et al.* (2020) reported that grapes growers from Sangli and Nashik districts of Maharashtra aware about mobile applications and it was top mosr source of information to them perhaps Low internet speed and irregular network coverage were the important constraints faced by the farmers while using mobile applications.

Grape growers faced the ravages of diferent kind of insect pests. Present study reveals that sucking pests cause major hindrance in profitable grape production. Mealybug was the major pest reported by almost all the grape growers from Ahmednagar, Pune, Solapur, Sangli and Nashik districts, respectively. Majority of the growers were used the recommended dosess of pesticdes. However, Sutharsan *et al.* (2014) reported that, Around 90 per cent of the vegetable farmers applied more than the recommended dosage and frequency of the pesticides.

Present investigations revealed that majority grape growers from Ahmednagar, Pune, Solapur, Sangli and Nashik were took 6-8 sprays to save the crop from pests and diseases and generaly kept 6-10 days spray interval. Mixing of two or more agrochemicals was a common practice followed by 36 per cent grape growers. Deore (2015) reported that, farmers in Ahmednagar, Dhule, Pune and Nashik were relied mostly on chemical insecticides and sprayed at an interval of 6 to 10 days with maximum 6 to 8 sprays to control the diamondback moth in cabbage. According to Deviprasad *et al.* (2015) farmers were used multiple formulations of pesticides on a single crop. Meitankeisangbam *et al.* (2020) observed that 55.00 per cent rice growers used two to three insecticides along with the fungicides and 63.33 per cent used systemic + contact pesticides to control the pests.

In a present study, it was found that most of the grape growers relied on pesticides retailers for selecting insecticides for spraying. The present study is in agreement with Mahantesh and Singh (2009) who reported that 36.5 per cent of farmers were mainly dependent on the advice of pesticides dealers as a source of information on pest management. Similarly, Kelageri *et al.* (2016) reported that, in general all farmers contacted pesticide dealer for information and 38-43 per cent farmer's preferred to contact scientists. According to Vemuri *et al.* (2016) generally all capsicum farmers were contacted pesticide dealer for recommendations. 35.71 per cent poly house farmers preferred to contact scientists and 33.33 per cent open field farmers preferred to contact agricultural officers for pest management advice.

Present studies on pesticide usage pattern in Western Maharashtra revealed use of overall nineteen insecticides/biopesticides. Per cent respondents for each group were conventional insecticides (76.53 %), Novel insecticides (71.88 %) and bio-insecticides (80.67 %), respectively. Kale (2016) reported that farmers in Pune, Satara, Sangli, Kolhapur and Solapur districts followed grape and sugarcane based farming. On geographical perspective Western Maharashtra region is quite large and covers an area of 57,235.00 Sq. Km ultimately high consumption of agrochemicals above 30g/ha were observed in Tasgaon, Kagal, Hatkanagale, Wai, Phaltan, Panhala, Karveer, Bhudargad, Bawda, Shirol, Walwa, Palus and Mahabaleshwar tahsils. The present findings in lined with above report.

Present investigations also highlighted respective usage of nineteen available insecticides/biopesticides *viz.*,Conventional insecticides (27.11 %), Novel insecticides (55.83 %) and bio-insecticides (17.06 %), respectively. From the highest pe cent usage it was observed that Conventional insecticides (28.76 %) in Ahmednagar whie Novel insecticides (56.63 %) and Bio- insecticides (17.75 %) in Sangli district. Guru *et al.* (2018a) conducted a survey of polyhouse and open field capsicum growers of Western Maharashtra and reported that the share of conventional insecticides (65-72 %) was more as compared to novel insecticides (22-25 %) and biopesticides (3-13 %) in both polyhouse and open field capsicum growers, respectively. Similarly, Sawant *et al.* (2018a) reported that the share of conventional insecticides was more as compared to novel insecticides and biopesticides in cabbage growing area of western Maharashtra.The findings of the above workers contradict the present findings this may be due to efficacy of insecticides against grape mealybug.

4.4 Bio-efficacy of insecticides against grape mealybug, *M. hirsutus*

In all three foliar spray applications were carried out on grape during the fruiting season belonging to the year 2017-18 and 2018-19. The field experiments were comprised of the untreated check along with ten test insecticides (Plate 4.5 and Plate 4.6). The data obtained in respect of the bio-efficacy have been presented below.

4.4.1 Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* during 2017-18

Under the field conditions on the initiation of mealybug infestation foliar applications of test insecticides were initiated. Each treatment was consisting of three sprays applied at fruit initiation stage and 15 days interval after 1st spray. Before the application, the pre-count observations were recorded. The observations on per cent egg sacs reduction were recorded in subsequent interval of 3, 7, 10 and 14 days after spraying (DAS). In addition to this, the yield of grape and the economics of the spray treatments based on fruit yield were taken into account to decide the merit of treatments.

4.4.1.1 After first spray

The data on per cent egg sac reduction have been presented in Table 4.17 and Fig 4.7. The statistical analysis of the data reveals that, the pre-treatment observations were found to be relatively homogenous and varied from average 1.67 to 2.00 egg sacs per vine. The data was observed to be non-significant. The entire test insecticides were found to be statistically superior in reduction of egg sacs on vines at all the four intervals of observations.

At 3 DAS

Among all the treatments, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) was found to be most effective as it recorded highest reduction of egg sacs (33.33 %), followed by Spirotetramat 15.31 % OD (T_8) (32.00 %), but were at par with each other. The next best treatments in the order of preference were Chlorpyrifos 20 % EC (T_6) (28.47 %), Imidacloprid 17.8 % SL (T_9) (25.00 %) and Dichlorvos 76 % EC (T_5) (23.73 %), respectively. Imidacloprid 17.8 % SL (T9) and Dichlorvos 76 % EC (T5) were at par with each other. Further, the non significant difference was observed between Lambda cyhalothrin 5 % EC (T_4) (16.67 %) and Buprofezin 25 % SC (T_7) (13.33 %). Comparatively less per cent reduction of egg sacs was observed in the treatments *viz.,L. lecanii* 1.15% WP (T_1) (8.33 %), *M. anisopliae* 1.15 % WP (T_2) (7.01 %) and Azadirachtin 1 % EC (T_3) (6.67 %), respectively and were at par with each other statistically.

$T_{10} \geq T_8 > T_6 > T_9 \geq T_5 > T_4 > T_7 > T_1 \geq T_2 \geq T_3$ was the order of efficacy.

At 7 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (46.24 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction and was found at par with the treatment Spirotetramat 15.31 % OD (T_8) (44.50 %). The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (38.56 %), Dichlorvos 76 % EC (T_5) (36.10 %) and Imidacloprid 17.8 % SL (T_9) (36.10 %), but all of them were at par with each other, and this was followed by the treatments Lambda cyhalothrin 5 % EC (T_4) (26.80 %) and Buprofezin 25 % SC (T_7) (25.00 %) were found at par. Further, the treatments *L. lecanii* 1.15% WP (T_1), *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) recorded (15.51 %), (11.17 %) and (8.39 %) egg sacs reduction, respectively. However, non significant difeerence was observed between *M. anisopliae* 1.15 % WP (T_1) and Azadirachtin 1 % EC (T_3).

$T_{10} \geq T_8 > T_6 \geq T_5 \geq T_9 > T_4 \geq T_7 > T_1 > T_2 \geq T_3$ was the order of efficacy.

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (53.83 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction this was followed by treatments Spirotetramat 15.31 % OD (T_8) (54.35 %)

and Imidacloprid 17.8 % SL (T_9) (53.83 %), but all of them were at par with each other. The next effective treatments observed were Chlorpyrifos 20 % EC (T_6) (50.00 %), Dichlorvos 76 % EC (T_5) (42.78 %) and Lambda cyhalothrin 5 % EC (T_4) (40.00 %). However, Dichlorvos 76 % EC (T_5) and Lambda cyhalothrin 5 % EC (T_4) were at par with each other. Further, a non significant difference was observed between Buprofezin 25 % SC (T_7) (33.33 %) and *L. lecanii* 1.15% WP (T_1) (32.67 %). Whereas, (25.11 %) and (17.33 %) reduction was evident in treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3), respectively.

$T_{10} \geq T_8 \geq T_9 > T_6 > T_5 \geq T_4 > T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (58.33 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction this was followed by treatments Spirotetramat 15.31 % OD (T_8) (57.26 %), Imidacloprid 17.8 % SL (T_9) (55.17 %) and Buprofezin 25 % SC (T_7) (53.33 %) and they were at par with each other. The next best treatments in the order of preference that were found at par Chlorpyrifos 20 % EC (T_6) (47.30 %), Dichlorvos 76 % EC (T_5) (45.33 %) and *L. lecanii* 1.15 % WP (T_1) (41.67 %), respectively. Further, a non significant difference was observed between Lambda cyhalothrin 5 % EC (T_4) (35.62 %) and *M. anisopliae* 1.15 % WP (T_2) (34.35 %). The least per cent reduction *i.e.,* (26.67 %) recorded in Azadirachtin 1 % EC (T_3).

$T_{10} \geq T_8 \geq T_9 \geq T_7 > T_6 \geq T_5 \geq T_1 > T_4 \geq T_2 > T_3$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (48.75 %) remained to be superior treatment in keeping highest per cent egg sacs reduction which was at par with the treatment Spirotetramat 15.31 % OD (T_8) (47.03 %). The next best treatments in the order of preference were Imidacloprid 17.8 % SL (T_9) (42.53 %) and Chlorpyrifos 20 % EC (T_6) (41.08 %) were at par with each other, this was followed by the treatments Dichlorvos 76 % EC (T_5) (36.13 %) and Buprofezin 25 % SC (T_7) (31.25 %) wherein a non significant difference was observed. Further, the treatments Lambda cyhalothrin 5 % EC (T_4) (29.77 %), *L. lecanii* 1.15 % WP (T_1) (24.55 %), *M. anisopliae* 1.15 % WP (T_2) (19.41 %) and Azadirachtin 1 % EC (T_3) (14.77 %) differ significantly with each other.

$T_{10} \geq T_8 > T_9 \geq T_6 > T_5 \geq T_7 > T_4 > T_1 > T_2 > T_3$ was the order of efficacy.

Table 4.17. Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* after first spray, 2017-18

Tr. No.	Treatments	Dose (ml or g/L)	Pre-count	Per cent mortality				
				3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15% WP (1 x 10^8 CFU/g)	5 g	2.00 (1.58)*	8.33 (16.78)**	15.51 (23.19)	32.67 (34.86)	41.67 (40.20)	24.55 (29.70)
2	*M. anisopliae* 1.15% WP (1 x 10^8 CFU/g)	5 g	2.00 (1.58)	7.01 (15.35)	11.17 (19.52)	25.11 (30.07)	34.35 (35.88)	19.41 (26.14)
3	Azadirachtin 1% EC (10000 ppm)	3 ml	1.83 (1.53)	6.67 (14.97)	8.39 (16.84)	17.33 (24.60)	26.67 (31.09)	14.77 (22.60)
4	Lambda cyhalothrin 5% EC	0.5 ml	2.00 (1.58)	16.67 (24.10)	26.80 (31.18)	40.00 (39.23)	35.62 (36.64)	29.77 (33.07)
5	Dichlorvos 76% EC	2 ml	1.83 (1.53)	23.73 (29.15)	36.10 (36.93)	42.78 (40.85)	45.33 (42.32)	36.13 (36.95)
6	Chlorpyrifos 20% EC	2 ml	1.67 (1.47)	28.47 (32.25)	38.56 (38.39)	50.00 (45.00)	47.30 (43.45)	41.08 (39.86)
7	Buprofezin 25% SC	1.5 ml	1.83 (1.53)	13.33 (21.41)	25.00 (30.00)	33.33 (35.26)	53.33 (46.91)	31.25 (33.99)
8	Spirotetramat 15.31% w/w OD	0.7 ml	2.00 (1.58)	32.00 (34.45)	44.50 (41.84)	54.35 (47.50)	57.26 (49.17)	47.03 (43.30)
9	Imidacloprid 17.8% SL	0.45 ml	1.83 (1.53)	25.00 (30.00)	36.10 (36.93)	53.83 (47.20)	55.17 (47.97)	42.53 (40.70)
10	Spirotetramat 11.1% + Imidacloprid 11.01% w/w (240 SC)	0.75 ml	1.67 (1.47)	33.33 (35.26)	46.24 (42.84)	57.08 (49.07)	58.33 (49.80)	48.75 (44.28)
11	Untreated control	---	2.00 (1.58)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	NS	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	0.03	0.72	0.95	1.23	1.30	1.03
	CD at 5%	-	NS	2.14	2.81	3.63	3.84	3.04

*Figures in parentheses are square root transformed values,
**Figures in parentheses are arc sin transformed values, DAS : Days after spraying,

4.4.1.2 After second spray

The data on per cent egg sac reduction have been presented in Table 4.18 and Fig. 4.8. The statistical analysis of the data reveals that all the test insecticides were found significantly superior over untreated control in reduction of egg sacs on vines at 3,7,10 and 14 days of observations.

At 3 DAS

Among all the treatments, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) was found exceedingly superior over all the rest of the treatments as it recorded the highest reduction of egg sacs (44.94 %). The next best treatments in the order of preference were Spirotetramat 15.31% OD (T_8) (38.89 %) and Chlorpyrifos 20 % EC (T_6) (35.22 %), which were at par with each other. Subsequently, treatments Dichlorvos 76 % EC (T_5) (29.33 %) and Imidacloprid 17.8 % SL (T_9) (27.78 %) was found at par with each other. Further, a significant differecnce was observed in treatments Lambda cyhalothrin 5 % EC (T_4) (23.43 %) and Buprofezin 25 % SC (T_7) (17.55 %). Whereas, treatments *viz.*,*L. lecanii* 1.15% WP (T_1) (11.66 %), *M. anisopliae* 1.15 % WP (T_2) (9.91 %) and Azadirachtin 1 % EC (T_3) (9.17 %) were found statistically at par with each other.

$T_{10} > T_8 \geq T_6 > T_5 \geq T_9 > T_4 > T_7 > T_1 \geq T_2 \geq T_3$ was the order of efficacy.

At 7 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (59.13 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction and was found at par with the treatment Spirotetramat 15.31 % OD (T_8) (55.56 %). The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (52.89 %) and Imidacloprid 17.8 % SL (T_9) (50.00 %). Further, the treatments Dichlorvos 76 % EC (T_5) (44.44 %) and Buprofezin 25 % SC (T_7) (38.89 %) were at par with each other. A non significant difference was observed in the treatments Lambda cyhalothrin 5 % EC (T_4) (35.22 %) and *L. lecanii* 1.15% WP (T_1) (34.93 %). Whereas, a significant difference remained in the treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) in which (19.92 %) and (11.11 %) egg sac reduction was recorded.

$T_{10} \geq T_8 > T_6 \geq T_9 > T_5 \geq T_7 > T_4 \geq T_1 > T_2 > T_3$ was the order of efficacy.

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (68.21 %) was found to be a superior treatment in keeping the highest per cent egg sacs reduction this was followed by treatments Spirotetramat 15.31 % OD (T_8) (64.96 %), Imidacloprid 17.8 % SL (T_9) (63.67 %) and Chlorpyrifos 20 % EC (T_6) (61.11 %), but all of them were at par with each other. The next effective treatments observed were Dichlorvos 76 % EC (T_5) (59.96 %), Lambda cyhalothrin 5 % EC (T_4) (55.56 %) and Buprofezin 25 % SC (T_7) (54.95 %), respectively and were at par with each other. The treatment *L. lecanii* 1.15 % WP (T_1) recorded (49.95 %) reduction compared to the treatments *M. anisopliae* 1.15 % WP (T_2) (34.93 %) and Azadirachtin 1 % EC (T_3) (29.93 %), respectively.

$T_{10} \geq T_8 \geq T_9 \geq T_6 > T_5 \geq T_4 \geq T_7 > T_1 > T_2 \geq T_3$ was the order of efficacy.

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (77.29 %) was found to be the most superior treatment in keeping the highest per cent egg sacs reduction; but remained at par with the treatments Spirotetramat 15.31 % OD (T_8) and Imidacloprid 17.8 % SL (T_9) in which (72.75 %) and (70.55 %) egg sacs reduction recorded, respectively. The next best treatments in the order of preference were Buprofezin 25 % SC (T_7) (63.67 %), *L. lecanii* 1.15 % WP (T_1) (59.13 %) and Chlorpyrifos 20 % EC (T_6) (55.56 %), respectively and they were at par with each other. Further, a non significant difference was observed between the treatments, Dichlorvos 76 % EC (T_5) (54.59 %) and Lambda cyhalothrin 5 % EC (T_4) (50.05 %). Whereas, *M. anisopliae* 1.15 % WP (T_2) (40.96 %) and Azadirachtin 1 % EC (T_3) (31. 88 %) showed a significant difference.

$T_{10} \geq T_8 \geq T_9 > T_7 \geq T_1 \geq T_6 > T_5 \geq T_4 > T_2 > T_3$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (62.39 %) remained to be superior treatment in keeping highest per cent egg sacs reduction which was at par with the treatment Spirotetramat 15.31 % OD (T_8) (58.04 %). The next best treatments in the order of preference were Imidacloprid 17.8 % SL (T_9) (53.00 %), Chlorpyrifos 20 % EC (T_6) (51.20 %) and Dichlorvos 76 % EC (T_5) (47.08 %) which were at par with each other. Further, non significant differance was observed between the treatments *viz.*,Buprofezin 25 % SC (T_7), Lambda cyhalothrin 5 % EC (T_4) and *L. lecanii* 1.15 % WP (T_1) which recorded (43.77 %), (41.07 %) and (38.92 %) reduction, respectively. (26.43 %) and (20.52 %) reduction of egg sacs was observed in the treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3), respectively which was far less than other promising treatments.

$T_{10} \geq T_8 > T_9 \geq T_6 \geq T_5 > T_7 \geq T_4 \geq T_1 > T_2 > T_3$ was the order of efficacy.

Table 4.18. Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* after second spray, 2017-18

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality				
			3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	11.66 (19.97)	34.93 (36.23)*	49.95 (44.97)	59.13 (50.26)	38.92 (38.60)
2	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	9.91 (18.35)	19.92 (26.51)	34.93 (36.23)	40.96 (39.79)	26.43 (30.94)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	9.17 (17.63)	11.11 (19.47)	29.93 (33.17)	31.88 (34.38)	20.52 (26.94)
4	Lambda cyhalothrin 5 % EC	0.5 ml	23.43 (28.95)	35.22 (36.40)	55.56 (48.19)	50.05 (45.03)	41.07 (39.86)
5	Dichlorvos 76 % EC	2 ml	29.33 (32.79)	44.44 (41.81)	59.96 (50.75)	54.59 (47.63)	47.08 (43.33)
6	Chlorpyrifos 20 % EC	2 ml	35.22 (36.40)	52.89 (46.66)	61.11 (51.42)	55.56 (48.19)	51.20 (45.69)
7	Buprofezin 25 % SC	1.5 ml	17.55 (24.77)	38.89 (38.58)	54.95 (47.84)	63.67 (52.93)	43.77 (41.42)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	38.89 (38.58)	55.56 (48.19)	64.96 (53.70)	72.75 (58.53)	58.04 (49.63)
9	Imidacloprid 17.8 % SL	0.45 ml	27.78 (31.81)	50.00 (45.00)	63.67 (52.93)	70.55 (57.13)	53.00 (46.72)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	44.94 (42.10)	59.13 (50.26)	68.21 (55.68)	77.29 (61.54)	62.39 (52.17)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	0.83	1.22	1.58	1.78	1.29
	CD at 5%	-	2.45	3.59	4.66	5.24	3.82

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

4.4.1.3 After third spray

The data on per cent egg sac reduction have been presented in Table 4.19. and Fig. 4.9. The statistical analysis of the data reveals that the entire test insecticides were found to be statistically superior in the reduction of egg sacs on vines at all the four intervals of observations.

At 3 DAS

Among all the treatments, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) was found exceedingly superior over all the rest of the treatments as it recorded the highest reduction of egg sacs (60.74 %). The second consecutive best treatment was Spirotetramat 15.31 % OD (T_8) (58.33 %). The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (54.17 %) and Dichlorvos 76 % EC (T_5) (50.00 %) and were at par with each other, followed by Imidacloprid 17.8 % SL (T_9) (45.83 %), Lambda cyhalothrin 5 % EC (T_4) (33.33 %), Buprofezin 25 % SC (T_7) (25.00 %) and *L. lecanii* 1.15% WP (T_1) (20.83 %). However, Buprofezin 25 % SC (T_7) and *L. lecanii* 1.15 % WP (T_1) was at par. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (16.67 %) and Azadirachtin 1 % EC (T_3) (14.81 %).

$T_{10} \geq T_8 > T_6 \geq T_5 > T_9 > T_4 > T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

At 7 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (72.03 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction and was found at par with the treatments Spirotetramat 15.31% OD (T_8) (70.37 %) and Chlorpyrifos 20 % EC (T_6) (66.67 %). The next best treatments in the order of preference were, Imidacloprid 17.8 % SL (T_9) (64.03 %), Dichlorvos 76 % EC (T_5) (60.03 %) and Lambda cyhalothrin 5 % EC (T_4) (56.04 %) and they were at par with each other. Further, Buprofezin 25 % SC (T_7) (52.04 %) and *L. lecanii* 1.15 % WP (T_1) (48.04 %) were at par, while a signigicant difference was observed between the treatments *M. anisopliae* 1.15 % WP (T_2) (36.05 %) and Azadirachtin 1 % EC (T_3) (20.06 %), respectively.

$T_{10} \geq T_8 \geq T_6 > T_9 \geq T_5 \geq T_4 > T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (88.89 %) was found to be a superior treatment in keeping the highest per cent egg sacs reduction and was found at par with the treatments Spirotetramat 15.31 % OD (T_8) (85.19 %), Imidacloprid 17.8 % SL (T_9) (83.33 %). The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (79.17 %), Dichlorvos 76 % EC (T_5) (74.07 %) and Lambda cyhalothrin 5 % EC (T_4) (70.37 %) and they were at par with each other. Further, Buprofezin 25 % SC (T_7) (66.67 %) and *L. lecanii* 1.15% WP (T_1) recorded (55.56 %) were at par, followed by *M. anisopliae* 1.15 % WP (T_2) (48.15 %) and Azadirachtin 1 % EC (T_3) (33.33 %) reduction of egg sacs, respectively.

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_5 \geq T_4 > T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

Table 4.19. Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* after third spray, 2017-18

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality				
			3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	20.83 (27.15)*	48.04 (43.88)	55.56 (48.19)	67.88 (55.48)	48.08 (43.90)
2	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	16.67 (24.10)	36.05 (36.90)	48.15 (43.94)	53.60 (47.06)	38.62 (38.42)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	14.81 (22.63)	20.06 (26.61)	33.33 (35.26)	39.33 (38.84)	26.88 (31.23)
4	Lambda cyhalothrin 5 % EC	0.5 ml	33.33 (35.26)	56.04 (48.47)	70.37 (57.02)	68.03 (55.57)	56.94 (48.99)
5	Dichlorvos 76 % EC	2 ml	50.00 (45.00)	60.03 (50.79)	74.07 (59.39)	72.02 (58.06)	64.03 (53.15)
6	Chlorpyrifos 20 % EC	2 ml	54.17 (47.39)	66.67 (54.74)	79.17 (62.85)	77.78 (61.88)	69.45 (56.45)
7	Buprofezin 25 % SC	1.5 ml	25.00 (30.00)	52.04 (46.17)	66.67 (54.74)	75.02 (60.01)	54.68 (47.69)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	58.33 (49.80)	70.37 (57.02)	85.19 (67.37)	95.83 (78.22)	77.43 (61.64)
9	Imidacloprid 17.8 % SL	0.45 ml	45.83 (42.61)	64.03 (53.15)	83.33 (65.90)	92.86 (74.50)	71.51 (57.74)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	60.74 (51.20)	72.02 (58.06)	88.89 (70.53)	96.43 (79.11)	79.52 (63.09)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	1.22	1.65	2.26	1.74	1.91
	CD at 5%	-	3.60	4.86	6.66	5.14	5.63

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (96.43 %) was found to be the most superior treatment in keeping the highest per cent egg sacs reduction; but remained at par with the treatments Spirotetramat 15.31 % OD (T_8) and Imidacloprid 17.8 % SL (T_9) in which (95.83 %) and (92.86 %) egg sacs reduction was recorded, respectively. The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (77.78 %), Buprofezin 25 % SC (T_7) (75.02 %) and Dichlorvos 76 % EC (T_5) (72.02 %) were at par with each other. Further, treatments Lambda cyhalothrin 5 % EC (T_4) (68.03 %) and *L. lecanii* 1.15 % WP (T_1) (67.88 %) showed a non significant difference, followed by *M. anisopliae* 1.15 % WP (T_2) (53.60

%) and Azadirachtin 1 % EC (T_3) (39.33 %).

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_7 \geq T_5 > T_4 \geq T_1 > T_2 > T_3$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (79.52 %) remained to be superior in keeping the highest per cent egg sacs reduction which was at par with the treatment Spirotetramat 15.31 % OD (T_8) (77.43 %) and Imidacloprid 17.8 % SL (T_9) (71.51 %). The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (69.45 %) and Dichlorvos 76 % EC (T_5) (64.03 %) which were at par with each other. Further, non significant differences were observed between the treatments *viz.*,Buprofezin 25 % SC (T_7), Lambda cyhalothrin 5 % EC (T_4) and *L. lecanii* 1.15 % WP (T_1) which recorded (56.94 %), (48.08 %) and (48.8 %) reduction, respectively. Whereas, (38.62 %) and (26.88 %) reduction of egg sacs were observed in the treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3), respectively.

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_5 > T_4 \geq T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

4.4.2 Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* during 2018-19

Under the field conditions on the initiation of mealybug infestation foliar applications of test insecticides were initiated. Each treatment was consisting of three sprays applied at the fruit initiation stage and 15 days intervals after 1st spray. Before the application, the pre-count observations were recorded. The observations on per cent egg sacs reduction were recorded in subsequent intervals of 3, 7, 10 and 14 days after spraying (DAS). In addition to this, the yield of grape and the economics of the spray treatments based on fruit yield was taken into account to decide the merit of treatments.

4.4.2.1 After first spray

The data on per cent egg sac reduction have been presented in Table 4.20. and Fig.4.10. The statistical analysis of the data reveals that; the pre-treatment observations were found to be relatively homogenous and varied from an average 1.67 to 2.00 egg sacs per vine. The data was observed to be non-significant. The entire test insecticides were found to be statistically superior in the reduction of egg sacs on vines at all four dates of observations.

At 3 DAS

Among all the treatments, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) was found to be most effective as it recorded the highest reduction of egg sacs (35.22 %), followed by Spirotetramat 15.31 % OD (T_8) (33.33 %); and were at par with each other. The next best treatments in the order of preference were Chlorpyrifos 20 % EC (T_6) (31.34 %) and Imidacloprid 17.8 % SL (T_9) (27.78 %) were at par with each other. Further, Dichlorvos 76 % EC (T_5) (25.09 %), Lambda cyhalothrin 5 % EC (T_4) (17.55 %) and Buprofezin 25 % SC (T_7) (14.91 %). However, Lambda cyhalothrin 5 % EC (T_4) and Buprofezin 25 % SC (T_7) were at par with each other. Comparatively less per cent reduction of egg sacs was observed in the treatments *viz.,L. lecanii* 1.15% WP (T_1) (11.11 %), *M. anisopliae* 1.15 % WP (T_2) (9.91 %) which was at par, while least per cent reduction of egg sacs was observed in Azadirachtin 1 % EC (T_3) (6.37 %).

$T_{10} \geq T_8 > T_6 \geq T_9 > T_5 > T_4 \geq T_7 > T_1 \geq T_2 > T_3$ was the order of efficacy.

At 7 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (56.30 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction and was found at par with the treatment Spirotetramat 15.31% OD (T_8) (52.89 %). The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (47.00 %), Imidacloprid 17.8 % SL (T_9) (41.11 %) and Dichlorvos 76 % EC (T_5) (35.22 %) and they were at par with each other, and this was followed by the treatments Lambda cyhalothrin 5 % EC (T_4) (29.33 %) and Buprofezin 25 % SC (T_7) (29.33 %) were found at par. Further, the treatments *L. lecanii* 1.15% WP (T_1), *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) recorded (17.55), (11.66 %) and (11.11 %) egg sacs reduction, respectively. However, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_1) and Azadirachtin 1 % EC (T_3).

$T_{10} \geq T_8 > T_6 > T_9 > T_5 > T_4 \geq T_7 > T_1 > T_2 \geq T_3$ was the order of efficacy.

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (66.67 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction this was followed by treatments Spirotetramat 15.31 % OD (T_8) (64.96 %), Imidacloprid 17.8 % SL (T_9) (61.11 %) and Chlorpyrifos 20 % EC (T_6) (59.96 %); and they were at par with each other. The next effective treatments observed were Dichlorvos

76 % EC (T_5) (55.56 %) and Lambda cyhalothrin 5 % EC (T_4) (50.00 %). However, Dichlorvos 76 % EC (T_5) and Lambda cyhalothrin 5 % EC (T_4) were at par. Further, a non significant difference was observed between Buprofezin 25 % SC (T_7) (44.44 %) and *L. lecanii* 1.15% WP (T_1) (38.89 %). Whereas, (33.33 %) and (16.67 %) reduction was evident in treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3), respectively.

$T_{10} \geq T_8 \geq T_9 \geq T_6 > T_5 \geq T_4 > T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

Table 4.20. Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* after first spray, 2018-19

Tr. No.	Treatments	Dose (ml or g/L)	Pre-count	Per cent mortality				
				3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15% WP (1 x 10^8 CFU/g)	5 g	2.67 (1.78)*	11.11 (19.47)**	17.55 (24.77)	38.89 (38.58)	43.82 (41.45)	27.84 (31.85)
2	*M. anisopliae* 1.15% WP (1 x 10^8 CFU/g)	5 g	2.83 (1.82)	9.91 (18.35)	11.66 (19.97)	33.33 (35.26)	35.22 (36.40)	22.53 (28.34)
3	Azadirachtin 1% EC (10000 ppm)	3 ml	2.67 (1.78)	6.37 (14.62)	11.11 (19.47)	16.67 (24.10)	27.78 (31.81)	15.48 (23.17)
4	Lambda cyhalothrin 5% EC	0.5 ml	2.50 (1.73)	17.55 (24.77)	29.33 (32.79)	50.00 (45.00)	33.33 (35.26)	32.55 (34.79)
5	Dichlorvos 76% EC	2 ml	2.67 (1.78)	25.09 (30.06)	35.22 (36.40)	55.56 (48.19)	49.95 (44.97)	41.46 (40.08)
6	Chlorpyrifos 20% EC	2 ml	2.33 (1.68)	31.34 (34.04)	47.00 (43.28)	59.96 (50.75)	44.44 (41.81)	45.69 (42.53)
7	Buprofezin 25% SC	1.5 ml	2.50 (1.73)	14.91 (22.71)	29.33 (32.79)	44.44 (41.81)	55.56 (48.19)	36.06 (36.91)
8	Spirotetramat 15.31% w/w OD	0.7 ml	2.83 (1.82)	33.33 (35.26)	52.89 (46.66)	64.96 (53.70)	66.67 (54.74)	54.46 (47.56)
9	Imidacloprid 17.8% SL	0.45 ml	2.67 (1.78)	27.78 (31.81)	41.11 (39.88)	61.11 (51.42)	62.55 (52.27)	48.14 (43.93)
10	Spirotetramat 11.1% + Imidacloprid 11.01% w/w (240 SC)	0.75 ml	2.83 (1.82)	35.22 (36.40)	56.3 (48.62)	66.67 (54.74)	68.79 (56.04)	56.75 (48.88)
11	Untreated control	---	2.50 (1.73)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	NS	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	0.04	0.76	1.06	1.49	1.51	1.17
	CD at 5%	-	NS	2.24	3.14	4.40	4.44	3.44

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (68.79 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction this was followed by treatments Spirotetramat 15.31 % OD (T_8) (66.67 %)

and Imidacloprid 17.8 % SL (T_9) (62.55 %), but all of them were at par with each other. The next best treatments in the order of preference were found at par Buprofezin 25 % SC (T_7) (55.56 %) and Dichlorvos 76 % EC (T_5) (49.95 %). Further, a non significant difference was observed between Chlorpyrifos 20 % EC (T_6) (44.44 %) and *L. lecanii* 1.15 % WP (T_1) (43.82 %). *M. anisopliae* 1.15 % WP (T_2) (35.22 %) and Lambda cyhalothrin 5 % EC (T_4) (33.33 %) were also found at par with each other. The least per cent reduction *i.e.,* (27.78 %) was recorded in Azadirachtin 1 % EC (T_3).

$T_{10} \geq T_8 \geq T_9 > T_7 \geq T_5 > T_6 \geq T_1 > T_2 \geq T_4 > T_3$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (56.75 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction which was at par with the treatment Spirotetramat 15.31 % OD (T_8) (54.46 %). The next best treatments in the order of preference were Imidacloprid 17.8 % SL (T_9) (48.14 %) and Chlorpyrifos 20 % EC (T_6) (45.69 %) were at par with each other, this was followed by the treatments Dichlorvos 76 % EC (T_5) (41.46 %) and Buprofezin 25 % SC (T_7) (36.06 %) wherein a non significant difference was observed. Further, a non significant difference was observed between Lambda cyhalothrin 5 % EC (T_4) (32.55 %) and *L. lecanii* 1.15 % WP (T_1) (27.84 %). Comparatively less per cent reduction of egg sacs was found in *M. anisopliae* 1.15 % WP (T_2) (22.53 %) and Azadirachtin 1 % EC (T_3) (15.48 %), respectively.

$T_{10} \geq T_8 > T_9 \geq T_6 > T_5 \geq T_7 > T_4 \geq T_1 > T_2 > T_3$ was the order of efficacy.

4.4.2.2 After second spray

The data on per cent egg sac reduction have been presented in Table 4.21. and Fig. 4.11. The statistical analysis of the data reveals that the entire test insecticides were found to be statistically superior in the reduction of egg sacs on vines at all four dates of observations.

At 3 DAS

Among all the treatments, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) was found exceedingly superior over all the rest of the treatments as it recorded the highest reduction of egg sacs (47.62 %). The next best treatments in the order of preference were Spirotetramat 15.31 % OD (T_8) (38.10 %) and Chlorpyrifos 20

% EC (T_6) (36.42 %) were at par with each other. Subsequently, treatments Dichlorvos 76 % EC (T_5) (31.88 %) and Imidacloprid 17.8 % SL (T_9) (28.57 %) were found at par with each other. Further, a significant difference was observed in treatments Lambda cyhalothrin 5 % EC (T_4) (23.81 %) and Buprofezin 25 % SC (T_7) (19.05 %). Whereas, treatments *viz.,L. lecanii* 1.15% WP (T_1) (12.50 %) and *M. anisopliae* 1.15 % WP (T_2) (9.91 %) were at par. The least per cent reduction was observed in Azadirachtin 1 % EC (T_3) (9.17 %).

$T_{10} > T_8 \geq T_6 > T_5 \geq T_9 > T_4 > T_7 > T_1 \geq T_2 > T_3$ was the order of efficacy.

At 7 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (61.90 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction and was found at par with treatment Spirotetramat 15.31 % OD (T_8) (56.04 %). The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (54.59 %) and Imidacloprid 17.8 % SL (T_9) (50.00 %). Further, the treatments Dichlorvos 76 % EC (T_5) (45.50 %) and Buprofezin 25 % SC (T_7) (56.04 %) were at par with each other, followed by *L. lecanii* 1.15 % WP (T_1) (36.42 %) and Lambda cyhalothrin 5 % EC (T_4) (36.42 %) was found on par with each other. Whereas, a significant difference remained in the treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) in which (20.83 %) and (13.71 %) egg sac reduction was recorded.

$T_{10} \geq T_8 > T_6 \geq T_9 > T_5 \geq T_7 > T_1 \geq T_4 > T_2 > T_3$ was the order of efficacy.

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (70.83 %) was found to be a superior treatment in keeping the highest per cent egg sacs reduction this was followed by treatments Spirotetramat 15.31 % OD (T_8) (66.67 %), Imidacloprid 17.8 % SL (T_9) (66.67 %) and Chlorpyrifos 20 % EC (T_6) (63.67 %), but all of them were at par with each other. The next effective treatments observed were Dichlorvos 76 % EC (T_5) (62.50 %), Lambda cyhalothrin 5 % EC (T_4) (58.33 %) and Buprofezin 25 % SC (T_7) (54.17 %), respectively and were at par with each other. The treatment *L. lecanii* 1.15 % WP (T_1) recorded (50.00 %). Whereas, in *M. anisopliae* 1.15 % WP (T_2) (33.33 %) and Azadirachtin 1 % EC (T_3) (29.17 %) reduction was recorded and both these were at par with each other.

$T_{10} \geq T_8 \geq T_9 \geq T_6 > T_5 \geq T_4 \geq T_7 > T_1 > T_2 \geq T_3$ was the order of efficacy.

Table 4.21. Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* after second spray, 2018-19

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality				
			3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	12.50 (20.70)*	36.42 (37.12)	50.00 (45.00)	60.03 (50.79)	39.74 (39.08)
2	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	9.91 (18.35)	20.83 (27.15)	33.33 (35.26)	41.67 (40.20)	26.44 (30.94)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	9.17 (17.63)	13.71 (21.73)	29.17 (32.69)	32.05 (34.48)	21.03 (27.29)
4	Lambda cyhalothrin 5 % EC	0.5 ml	23.81 (29.21)	36.42 (37.12)	58.33 (49.80)	48.04 (43.88)	41.65 (40.19)
5	Dichlorvos 76 % EC	2 ml	31.88 (34.38)	45.5 (42.42)	62.50 (52.24)	52.04 (46.17)	47.98 (43.84)
6	Chlorpyrifos 20 % EC	2 ml	36.42 (37.12)	54.59 (47.63)	63.67 (52.93)	56.04 (48.47)	52.68 (46.54)
7	Buprofezin 25 % SC	1.5 ml	19.05 (25.88)	40.96 (39.79)	54.17 (47.39)	64.03 (53.15)	44.55 (41.87)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	38.10 (38.12)	56.04 (48.47)	66.67 (54.74)	76.02 (60.68)	59.21 (50.31)
9	Imidacloprid 17.8 % SL	0.45 ml	28.57 (32.31)	50.00 (45.00)	66.67 (54.74)	72.02 (58.06)	54.32 (47.48)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	47.62 (43.64)	61.90 (51.88)	70.83 (57.31)	80.02 (63.45)	65.09 (53.78)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	0.84	1.23	1.66	1.85	1.32
	CD at 5%	-	2.48	3.64	4.89	5.46	3.91

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (80.02 %) was found to be most superior treatment in keeping the highest per cent egg sacs reduction but remained at par with the treatments Spirotetramat 15.31 % OD (T_8) and Imidacloprid 17.8 % SL (T_9) in which (76.02 %) and (72.02 %) egg sacs reduction recorded, respectively. The next best treatments in the order of preference were Buprofezin 25 % SC (T_7) (64.03 %), *L. lecanii* 1.15 % WP (T_1) (60.03 %) and Chlorpyrifos 20 % EC (T_6) (56.04 %), respectively, and all they were at par with each other. Further, a non significant difference was observed between the treatments, Dichlorvos 76 % EC (T_5) (52.04 %) and Lambda cyhalothrin 5 % EC (T_4) (48.04 %).

Whereas, *M. anisopliae* 1.15 % WP (T_2) (41.67 %) and Azadirachtin 1 % EC (T_3) (32.05 %) showed significant differences.

$T_{10} \geq T_8 \geq T_9 > T_7 \geq T_1 \geq T_6 > T_5 \geq T_4 > T_2 > T_3$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (65.09 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction which was at par with the treatment Spirotetramat 15.31 % OD (T_8) (59.21 %). The next best treatments in the order of preference were Imidacloprid 17.8 % SL (T_9) (54.32 %), Chlorpyrifos 20 % EC (T_6) (52.68 %) and Dichlorvos 76 % EC (T_5) (47.98 %) which were at par with each other. Further, non significant differences were observed between the treatments *viz.,*Buprofezin 25 % SC (T_7), Lambda cyhalothrin 5 % EC (T_4) and *L. lecanii* 1.15 % WP (T_1) which recorded (44.55 %), (41.65 %) and (39.74 %) reduction, respectively. (26.44 %) and (21.03 %) reduction of egg sacs was observed in the treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3), respectively and both were at par with each other.

$T_{10} \geq T_8 > T_9 \geq T_6 \geq T_5 > T_7 \geq T_4 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

4.4.2.3 After third spray

The data on per cent egg sac reduction have been presented in Table 4.22. and Fig. 4.12. The statistical analysis of the data reveals that the entire test insecticides were found to be statistically superior in the reduction of egg sacs on vines at all the four intervals of observations.

At 3 DAS

Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (65.36 %) remained to be most superior treatment in keeping the highest per cent reduction of egg sacs which was at par with the treatment Spirotetramat 15.31 % OD (T_8) (61.51 %). The next best treatments in the order of preference were Chlorpyrifos 20 % EC (T_6) (55.14 %) and Dichlorvos 76 % EC (T_5) (49.96 %) and were at par with each other, followed by Imidacloprid 17.8 % SL (T_9) (46.11 %), Lambda cyhalothrin 5 % EC (T_4) (34.57 %) and Buprofezin 25 % SC (T_7) (26.87 %). Further, *L. lecanii* 1.15 % WP (T_1) (19.17 %), *M. anisopliae* 1.15 % WP (T_2) (17.18 %) and Azadirachtin 1 % EC (T_3) (15.2 %) were found at par with each other, respectively.

$T_{10} \geq T_8 > T_6 \geq T_5 > T_9 > T_4 > T_7 > T_1 \geq T_2 \geq T_3$ was the order of efficacy.

Table 4.22. Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* after third spray, 2018-19

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality				
			3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	19.17 (25.97)*	48.15 (43.94)	55.14 (47.95)	68.94 (56.13)	47.85 (43.77)
2	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	17.18 (24.49)	37.04 (37.49)	48.24 (43.99)	55.14 (47.95)	39.40 (38.88)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	15.32 (23.04)	19.17 (25.97)	34.44 (35.93)	39.33 (38.84)	27.07 (31.35)
4	Lambda cyhalothrin 5 % EC	0.5 ml	34.57 (36.01)	55.56 (48.19)	71.45 (57.70)	67.88 (55.48)	57.37 (49.24)
5	Dichlorvos 76 % EC	2 ml	49.96 (44.98)	69.21 (56.30)	75.85 (60.57)	71.45 (57.70)	66.62 (54.71)
6	Chlorpyrifos 20 % EC	2 ml	55.14 (47.95)	70.37 (57.02)	79.3 (62.94)	76.91 (61.28)	70.43 (57.06)
7	Buprofezin 25 % SC	1.5 ml	26.87 (31.22)	53.81 (47.19)	68.94 (56.13)	75.85 (60.57)	56.37 (48.66)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	61.51 (51.65)	74.07 (59.39)	86.2 (68.19)	95.15 (77.28)	79.23 (62.89)
9	Imidacloprid 17.8 % SL	0.45 ml	46.11 (42.77)	66.67 (54.74)	86.2 (68.19)	93.10 (74.77)	73.02 (58.71)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	65.36 (53.95)	77.78 (61.88)	88.45 (70.13)	96.67 (79.49)	82.07 (64.95)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	1.26	1.82	1.92	1.80	2.00
	CD at 5%	-	3.72	5.36	5.67	5.31	5.89

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 7 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (77.78 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction and was found at par with the treatments Spirotetramat 15.31 % OD (T_8) (74.07 %) and Chlorpyrifos 20 % EC (T_6) (70.37 %). The next best treatments in the order of preference were, Dichlorvos 76 % EC (T_5) (69.21 %) and Imidacloprid 17.8 % SL (T_9) (66.67 %) were at par with each other. Further, Lambda cyhalothrin 5 % EC (T_4) (55.56 %), Buprofezin 25 % SC (T_7) (53.81 %) and *L. lecanii* 1.15% WP (T_1) (48.15 %) were at par, while, a significant difference was observed between the treatments *M.*

anisopliae 1.15 % WP (T_2) (37.04 %) and Azadirachtin 1 % EC (T_3) (19.17 %), respectively.

$T_{10} \geq T_8 \geq T_6 > T_5 \geq T_9 > T_4 \geq T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (88.45 %) remained to be most superior treatment in keeping the highest per cent egg sacs reduction and was at par with the treatments Spirotetramat 15.31 % OD (T_8) (86.20 %), Imidacloprid 17.8 % SL (T_9) (86.20 %). The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (79.30 %), Dichlorvos 76 % EC (T_5) (75.85 %) and Lambda cyhalothrin 5 % EC (T_4) (71.45 %), but all of them were at par with each other, this followed by Buprofezin 25 % SC (T_7) (68.94 %). Further, *L. lecanii* 1.15 % WP (T_1) (55.14 %), *M. anisopliae* 1.15 % WP (T_2) (48.24 %) and Azadirachtin 1 % EC (T_3) (34.44 %) reduction of egg sacs was recorded, respectively. However, *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) were at par with each other.

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_5 \geq T_4 > T_7 > T_1 \geq T_2 > T_3$ was the order of efficacy.

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (96.67 %) was found to be the most superior treatment in keeping the highest per cent egg sacs reduction, but at par with the treatments Spirotetramat 15.31 % OD (T_8) and Imidacloprid 17.8 % SL (T_9) in which (95.15 %) and (93.10 %) egg sacs reduction was recorded, respectively. The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (76.91 %), Buprofezin 25 % SC (T_7) (75.85 %), Dichlorvos 76 % EC (T_5) (71.45 %) and *L. lecanii* 1.15 % WP (T_1) (68.94 %), but all they were at par with each other. Further, treatments Lambda cyhalothrin 5 % EC (T_4) (67.88 %), *M. anisopliae* 1.15 % WP (T_2) (55.14 %) and Azadirachtin 1 % EC (T_3) (39.33 %) of reduction were recorded, respectively.

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_7 \geq T_5 \geq T_1 > T_4 > T_2 > T_3$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (82.07 %) remained to be the most effective treatment in keeping the highest per cent egg sacs reduction which was at par with the treatment Spirotetramat 15.31 % OD (T_8) (79.23 %).

The next best treatments in the order of preference were, Imidacloprid 17.8 % SL (T_9) (73.02 %), Chlorpyrifos 20 % EC (T_6) (70.43 %) and Dichlorvos 76 % EC (T_5) (66.62 %) which were at par with each other. Further, non significant differences were observed between the treatments *viz.*,Lambda cyhalothrin 5 % EC (T_4), Buprofezin 25 % SC (T_7) and *L. lecanii* 1.15 % WP (T_1) which recorded (57.37 %), (56.37 %) and (47.85 %) reduction, respectively. Whereas, (39.40 %) and (27.07 %) reduction of egg sacs was observed in the treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3), respectively.

$T_{10} \geq T_8 > T_9 \geq T_6 \geq T_5 > T_4 \geq T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

4.4.3 Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* during 2017-18 and 2018-19 (Pooled)

The pooled data on the efficacy of various insecticides during 2017-18 and 2018-19 are presented in Table 4.23 and Fig.4.13. The mean per cent reduction of egg sacs during 2017-18 and 2018-19 (Pooled) computed in subsequent intervals of 3, 7, 10 and 14 days after spraying (DAS) indicated that all the insecticidal treatments were significantly superior in reducing the per cent egg sacs on vines.

At 3 DAS

Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (47.87 %) remained to be the most superior treatment in keeping the highest per cent egg sacs reduction which was at par with the treatments Spirotetramat 15.31 % OD (T_8) (43.69 %) and Chlorpyrifos 20 % EC (T_6) (40.13 %). The next best treatments in the order of preference were Dichlorvos 76 % EC (T_5) (35.00 %) and Imidacloprid 17.8 % SL (T_9) (33.51 %) were at par, followed by, Lambda cyhalothrin 5 % EC (T_4) (24.89 %) and Buprofezin 25 % SC (T_7) (19.45 %) but, were at par. Further, *L. lecanii* 1.15 % WP (T_1) (13.93 %), *M. anisopliae* 1.15 % WP (T_2) (11.77 %) and Azadirachtin 1 % EC (T_3) (10.25 %) were found at par with each other.

$T_{10} \geq T_8 \geq T_6 > T_5 \geq T_9 > T_4 \geq T_7 > T_1 \geq T_2 \geq T_3$ was the order of efficacy.

At 7 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (62.23 %) remained to be superior treatment in keeping the highest per cent egg sacs reduction and was found at par with the treatments Spirotetramat 15.31 % OD (T_8) (58.91 %) and Chlorpyrifos 20 % EC (T_6) (55.01 %). The next best treatments in the order of preference were, Imidacloprid 17.8 % SL (T_9) (51.32 %) and Dichlorvos 76 % EC (T_5) (48.12 %) which were at par. Further, Buprofezin 25 % SC (T_7) (40.01 %), Lambda cyhalothrin 5 % EC (T_4) (39.90 %) and *L. lecanii* 1.15% WP (T_1) (33.43 %), but all they at par with each other. A significant difference was observed between the treatments *M. anisopliae* 1.15 % WP (T_2) (22.78 %) and Azadirachtin 1 % EC (T_3) (13.93 %).

$T_{10} \geq T_8 \geq T_6 > T_9 \geq T_5 > T_7 \geq T_4 \geq T_1 > T_2 > T_3$ was the order of efficacy.

Table. 4.23. Bio-efficacy of insecticides against egg sacs of grape mealybug, *M. hirsutus* during 2017-18 and 2018-19 (Pooled)

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality			
			3 DAS	7 DAS	10 DAS	14 DAS
1	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	13.93 (21.91)*	33.43 (35.32)	47.04 (43.30)	56.91 (48.97)
2	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	11.77 (20.06)	22.78 (28.51)	37.18 (37.57)	43.49 (41.26)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	10.25 (18.67)	13.93 (21.91)	26.81 (31.18)	32.84 (34.96)
4	Lambda cyhalothrin 5 % EC	0.5 ml	24.89 (29.93)	39.90 (39.17)	57.62 (49.38)	50.49 (45.28)
5	Dichlorvos 76 % EC	2 ml	35.00 (36.27)	48.42 (44.09)	61.79 (51.82)	57.56 (49.35)
6	Chlorpyrifos 20 % EC	2 ml	40.13 (39.31)	55.01 (47.88)	65.54 (54.05)	59.67 (50.58)
7	Buprofezin 25 % SC	1.5 ml	19.45 (26.17)	40.01 (39.24)	53.75 (47.15)	64.58 (53.48)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	43.69 (41.37)	58.91 (50.13)	70.39 (57.03)	77.28 (61.53)
9	Imidacloprid 17.8 % SL	0.45 ml	33.51 (35.37)	51.32 (45.76)	69.14 (56.25)	74.38 (59.59)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	47.87 (43.78)	62.23 (52.08)	73.36 (58.93)	79.59 (63.14)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig
	SE (M) ±	-	1.52	1.67	1.77	2.48
	CD at 5%	-	4.48	4.94	5.23	7.30

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (73.36 %) remained to be the most superior treatment in keeping the highest per cent egg sacs reduction and was at par with the treatments Spirotetramat 15.31 % OD (T_8) (70.39 %), Imidacloprid 17.8 % SL (T_9) (69.14 %) and Chlorpyrifos 20 % EC (T_6) (65.54 %). The next best treatments in the order of preference were, Dichlorvos 76 % EC (T_5) (61.79 %) and Lambda cyhalothrin 5 % EC (T_4) (57.62 %) and Buprofezin 25 % SC (T_7) (53.75 %), but all of they were at par with each other, followed by *L. lecanii* 1.15 % WP (T_1) (47.04 %), *M. anisopliae* 1.15 % WP (T_2) (37.18 %) and Azadirachtin 1 % EC (T_3) (26.81 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 > T_5 \geq T_4 \geq T_7 > T_1 > T_2 > T_3$ was the order of efficacy.

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (79.59 %) was found to be the most superior treatment in keeping the highest per cent egg sacs reduction but at par with the treatments Spirotetramat 15.31 % OD (T_8) and Imidacloprid 17.8 % SL (T_9) in which (77.28 %) and (74.38 %) egg sacs reduction recorded, respectively. The next best treatments in the order of preference were, Buprofezin 25 % SC (T_7) (64.58 %), Chlorpyrifos 20 % EC (T_6) (59.67 %), Dichlorvos 76 % EC (T_5) (57.56 %) and *L. lecanii* 1.15 % WP (T_1) (56.91 %) and they were at par with each other. Further, treatments Lambda cyhalothrin 5 % EC (T_4) (50.49) and *M. anisopliae* 1.15 % WP (T_2) (43.49 %) were at par. The least per cent reduction of egg sacs was noticed in Azadirachtin 1 % EC (T_3) (32.84 %).

$T_{10} \geq T_8 \geq T_9 > T_7 \geq T_6 \geq T_5 \geq T_1 > T_4 \geq T_2 > T_3$ was the order of efficacy.

4.4.4 Bio-efficacy of insecticides against (nymphs + adults) of grape mealybug, *M. hirsutus* during 2017-18

4.4.4.1 After first spray

The data on (nymphs + adults) mortality have been presented in Table 4.24. and Fig. 4.14. The statistical analysis of the data reveals that the pre-treatment observations were found to be relatively homogenous and varied from an average of 23.83 to 25.00 (nymphs + adults) per vine. The data was observed to be non-significant. The entire test insecticides were found to be statistically superior in mortality of nymphs and adults on vines at all four intervals 3,7,10 and 14 days of observations.

At 3 DAS

Among all the treatments, Chlorpyrifos 20 % EC (T_6) (32.00 %) was found to be the most effective as it recorded the highest per cent mortality of (nymphs +

adults) (32.00 %), followed by Dichlorvos 76 % EC (T_5) (31.33 %), Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (30.67), Spirotetramat 15.31% OD (T_8) (29.33 %) and Imidacloprid 17.8 % SL (T_9) (28.67 %), but all they at par with each other. The next best treatments in the order of preference were, Lambda cyhalothrin 5 % EC (T_4) (22.67 %), Buprofezin 25 % SC (T_7) (12.00 %), *L. lecanii* 1.15 % WP (T_1) (9.33 %), *M. anisopliae* 1.15 % WP (T_2) (6.67 %) and Azadirachtin 1 % EC (T_3) (4.67 %).

$T_6 \geq T_5 \geq T_{10} \geq T_8 \geq T_9 > T_4 > T_7 > T_1 > T_2 > T_3$ was the order of efficacy.

At 7 DAS

The Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) was found to be the most promising treatment and recorded (43.51 %) per cent mortality of (nymphs + adults), however at par with the treatments Spirotetramat 15.31% OD (T_8) (41.57 %), Imidacloprid 17.8 % SL (T_9) (40.92 %) and Chlorpyrifos 20 % EC (T_6) (38.97 %). The next best treatments in the order of preference were, Dichlorvos 76 % EC (T_5) (37.02 %) and Lambda cyhalothrin 5 % EC (T_4) (36.37 %) were at par, this was followed by the Buprofezin 25 % SC (T_7) (20.79 %) and *L. lecanii* 1.15% WP (T_1), (19.49 %). However, Buprofezin 25 % SC (T_7) and *L. lecanii* 1.15% WP (T_1) were found at par with each other. Further, *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) was recorded (16.24) and (9.75 %) mortality of (nymphs + adults), respectively.

$T_{10} \geq T_8 \geq T_9 \geq T_6 > T_5 \geq T_4 > T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (53.83 %) remained to be superior treatment in keeping the highest per cent mortality of (nymphs + adults) this was at par with Spirotetramat 15.31 % OD (T_8) (59.75 %) and Imidacloprid 17.8 % SL (T_9) (55.35 %). The next best treatments in the order of preference were Chlorpyrifos 20 % EC (T_6) (52.83 %) and Dichlorvos 76 % EC (T_5) (47.80 %) and they were at par with each other. Further, non significant differences were observed between Lambda cyhalothrin 5 % EC (T_4) (42.77 %), Buprofezin 25 % SC (T_7) (40.88 %) and *L. lecanii* 1.15% WP (T_1) (38.99 %), followed by *M. anisopliae* 1.15 % WP (T_2) (34.59 %), Azadirachtin 1 % EC (T_3) (17.33 %).

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_5 > T_4 \geq T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

Table. 4.24. Bio-efficacy of insecticides against (nymphs + adults) of grape mealybug, *M. hirsutus* after first spray, 2017-18

Tr. No.	Treatments	Dose (ml or g/L)	Pre-count	Per cent mortality				
				3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15% WP (1 x 10^8 CFU/g)	5 g	25.00 (5.05)*	9.33 (17.79)**	19.49 (26.20)	38.99 (38.64)	54.32 (47.48)	30.53 (33.54)
2	*M. anisopliae* 1.15% WP (1 x 10^8 CFU/g)	5 g	24.83 (5.03)	6.67 (14.97)	16.24 (23.77)	34.59 (36.02)	44.44 (41.81)	25.49 (30.32)
3	Azadirachtin 1% EC (10000 ppm)	3 ml	24.17 (4.97)	4.67 (12.48)	9.75 (18.19)	17.33 (24.60)	28.40 (32.20)	15.04 (22.82)
4	Lambda cyhalothrin 5% EC	0.5 ml	24.83 (5.03)	22.67 (28.43)	36.37 (37.09)	42.77 (40.84)	38.89 (38.58)	35.18 (36.38)
5	Dichlorvos 76% EC	2 ml	24.00 (4.95)	31.33 (34.04)	37.02 (37.48)	47.8 (43.74)	43.83 (41.46)	40.00 (39.23)
6	Chlorpyrifos 20% EC	2 ml	25.00 (5.05)	32.00 (34.45)	38.97 (38.63)	52.83 (46.62)	49.38 (44.64)	43.30 (41.15)
7	Buprofezin 25% SC	1.5 ml	24.33 (4.98)	12.00 (20.27)	20.79 (27.13)	40.88 (39.75)	56.79 (48.90)	32.62 (34.83)
8	Spirotetramat 15.31% w/w OD	0.7 ml	23.83 (4.93)	29.33 (32.79)	41.57 (40.15)	55.97 (48.43)	67.90 (55.49)	48.69 (44.25)
9	Imidacloprid 17.8% SL	0.45 ml	24.50 (5.00)	28.67 (32.37)	40.92 (39.77)	55.35 (48.07)	66.67 (54.74)	47.90 (43.80)
10	Spirotetramat 11.1% + Imidacloprid 11.01% w/w (240 SC)	0.75 ml	25.00 (5.05)	30.67 (33.63)	43.51 (41.27)	59.75 (50.62)	69.75 (56.63)	50.92 (45.53)
11	Untreated control	---	24.33 (4.98)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	NS	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	0.12	0.76	0.98	1.29	1.57	1.11
	CD at 5%	-	NS	2.24	2.88	3.82	4.64	3.28

*Figures in parentheses are square root transformed values,
**Figures in parentheses are arc sin transformed values, DAS : Days after spraying,

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (69.75 %) remained to be superior treatment in keeping the highest per cent mortality of (nymphs + adults) this was at par with Spirotetramat 15.31 % OD (T_8) (67.90 %) and Imidacloprid 17.8 % SL (T_9) (66.67 %). The next best treatments in the order of preference were Buprofezin 25 % SC (T_7) (56.79 %), *L. lecanii* 1.15 % WP (T_1) (54.32 %) and Chlorpyrifos 20 % EC (T_6) (49.38 %), but all they at par with each other. Further, non significant differences were observed between *M. anisopliae* 1.15 % WP (T_2) (44.44 %), Dichlorvos 76 % EC (T_5) (43.83 %) and Lambda cyhalothrin 5 % EC (T_4) (38.89 %), respectively. The least per cent reduction of (nymphs + adults) was recorded in Azadirachtin 1 % EC (T_3) (28.40 %).

$T_{10} \geq T_8 \geq T_9 > T_7 \geq T_1 \geq T_6 > T_2 \geq T_5 \geq T_4 > T_3$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (50.92 %) remained to be superior treatment in keeping the highest per mortality of (nymphs + adults) this was at par with Spirotetramat 15.31 % OD (T_8) (48.69 %) and Imidacloprid 17.8 % SL (T_9) (47.90 %). The next best treatments in the order of preference were Chlorpyrifos 20 % EC (T_6) (43.30 %) and Dichlorvos 76 % EC (T_5) (40.00 %) but were at par. Further, non significant differences were observed between Lambda cyhalothrin 5 % EC (T_4) (35.18 %), Buprofezin 25 % SC (T_7) (32.62 %) and *L. lecanii* 1.15 % WP (T_1) (30.53 %), respectively. Comparatively less mortality was observed between *M. anisopliae* 1.15 % WP (T_2) (25.49 %) and Azadirachtin 1 % EC (T_3) (15.04 %), respectively.

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_5 > T_4 \geq T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

4.4.4.2 After second spray

The data on mortality of (nymphs + adults) have been presented in Table 4.25. and Fig. 4.15. The statistical analysis of the data reveals that all insecticides were found to be statistically superior in reduction of nymphs and adults on vines at all four intervals of observations.

At 3 DAS

Among all the treatments, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) recorded the highest per cent mortality of (nymphs + adults) (46.33 %) was found exceedingly superior over all rest of the treatments except Spirotetramat 15.31% OD (T_8) (39.63 %). The next best treatments in the order of preference were Chlorpyrifos 20 % EC (T_6) (34.14 %) and Dichlorvos 76 % EC (T_5) (30.48 %) were at par with each other. Subsequently, Imidacloprid 17.8 % SL (T_9) (28.04 %) and Lambda cyhalothrin 5 % EC (T_4) (24.38 %) were at par with each other, this was followed by Buprofezin 25 % SC (T_7) (20.72 %). Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (12.18 %) and *L. lecanii* 1.15% WP (T_1) (10.35

%). Whereas, least (7.31 %) (nymphs + adults) mortality was recorded in Azadirachtin 1 % EC (T_3).

$T_{10} > T_8 > T_6 \geq T_5 > T_9 \geq T_4 > T_7 > T_2 \geq T_1 > T_3$ was the order of efficacy.

Table. 4.25. Bio-efficacy of insecticides against (nymphs + adults) of grape mealybug, *M. hirsutus* after second spray, 2017-18

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality				
			3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	10.35 (18.77)*	36.41 (37.11)	49.46 (44.69)	56.77 (48.89)	38.25 (38.20)
2	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	12.18 (20.43)	23.69 (29.13)	35.88 (36.80)	43.23 (41.11)	28.75 (32.42)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	7.31 (15.69)	18.49 (25.47)	30.44 (33.49)	38.54 (38.38)	23.70 (29.13)
4	Lambda cyhalothrin 5 % EC	0.5 ml	24.38 (29.59)	34.67 (36.07)	52.18 (46.25)	48.96 (44.40)	40.05 (39.26)
5	Dichlorvos 76 % EC	2 ml	30.48 (33.51)	45.08 (42.18)	63.05 (52.56)	59.38 (50.41)	49.50 (44.71)
6	Chlorpyrifos 20 % EC	2 ml	34.14 (35.75)	52.02 (46.16)	64.13 (53.21)	60.42 (51.01)	52.68 (46.54)
7	Buprofezin 25 % SC	1.5 ml	20.72 (27.08)	38.72 (38.48)	51.64 (45.94)	65.63 (54.11)	44.18 (41.66)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	39.63 (39.01)	60.69 (51.17)	72.29 (58.24)	76.56 (61.04)	62.29 (52.11)
9	Imidacloprid 17.8 % SL	0.45 ml	28.04 (31.97)	41.03 (39.83)	70.11 (56.86)	74.48 (59.66)	53.42 (46.96)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	46.33 (42.90)	57.22 (49.15)	73.92 (59.29)	79.17 (62.85)	64.16 (53.23)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	0.84	1.22	1.78	1.93	1.35
	CD at 5%	-	2.48	3.59	5.24	5.71	3.99

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 7 DAS

The treatment Spirotetramat 15.31 % OD (T_8) (60.69 %) was found promising treatment in keeping the highest per cent mortality of (nymphs + adults) which was at par with Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (57.22 %). The next best treatments in the order of preference were, Chlorpyrifos 20 % EC (T_6) (52.02 %), Dichlorvos 76 % EC (T_5) (45.08 %) and Imidacloprid 17.8 % SL (T_9) (42.08 %). However, Dichlorvos 76 % EC (45.08 %) (T_5) and Imidacloprid 17.8 % SL (T_9)

(42.08 %) were at par, followed by Buprofezin 25 % SC (T_7) (38.72 %), *L. lecanii* 1.15 % WP (T_1) (34.93 %) and Lambda cyhalothrin 5 % EC (T_4) (34.67 %), but all of them were at par. Whereas, in *M. anisopliae* 1.15 % WP (T_2) (23.69 %) and Azadirachtin 1 % EC (T_3) (18. 49 %) were recorded minimum mortality, respectively.

$T_8 \geq T_{10} > T_6 > T_5 \geq T_9 > T_7 \geq T_1 \geq T_4 > T_2 > T_3$ was the order of efficacy.

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (72.29 %) was found to be the most superior treatment in keeping the highest per cent mortality of (nymphs + adults) this was followed by treatments Spirotetramat 15.31 % OD (T_8) (72.29 %) and Imidacloprid 17.8 % SL (T_9) (70.11 %) and all them were at par with each other. The next best treatments in the order of preference were Chlorpyrifos 20 % EC (T_6) (64.13 %) and Dichlorvos 76 % EC (T_5) (63.05 %) were at par with each other. Further, non significant differences were observed between Lambda cyhalothrin 5 % EC (T_4) (52.18 %), Buprofezin 25 % SC (T_7) (51.64 %) and *L. lecanii* 1.15 % WP (T_1) (49.46 %), respectively. Whereas, *M. anisopliae* 1.15 % WP (T_2) (35.88 %) and Azadirachtin 1 % EC (T_3) (30.44 %) were at par with each other.

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_5 > T_4 \geq T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (79.17 %) was found to be the most superior treatment in keeping the highest per cent mortality of (nymphs + adults) but remained at par with the treatments Spirotetramat 15.31 % OD (T_8) and Imidacloprid 17.8 % SL (T_9) in which (76.56 %) and (74.48 %) mortality of (nymphs + adults) recorded, respectively. The next best treatments in the order of preference were Buprofezin 25 % SC (T_7) (65.63 %), Chlorpyrifos 20 % EC (T_6) (60.42 %), Dichlorvos 76 % EC (T_5) (59.38 %) and *L. lecanii* 1.15 % WP (T_1) (56.77 %) were at par. Further, a non significant difference was observed between the treatments, Lambda cyhalothrin 5 % EC (T_4) (48.96 %) and *M. anisopliae* 1.15 % WP (T_2) (43.23 %). Whereas, Azadirachtin 1 % EC (T_3) was recorded the least mortality (38.54 %) of (nymphs + adults).

$T_{10} \geq T_8 \geq T_9 > T_7 \geq T_6 \geq T_5 \geq T_1 > T_4 \geq T_2 > T_3$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (64.16 %) remained to be superior treatment in keeping the highest per cent mortality of (nymphs + adults) and was found at par with the treatment Spirotetramat 15.31 % OD (T_8) (62.29 %). The next best treatments in the order of preference were Imidacloprid 17.8 % SL (T_9) (53.42 %), Chlorpyrifos 20 % EC (T_6) (52.68 %) and Dichlorvos 76 % EC (T_5) (49.50 %) which were at par with each other. Further, non significant differences were observed between the treatments *viz.*,Buprofezin 25 % SC (T_7), Lambda cyhalothrin 5 % EC (T_4) and *L. lecanii* 1.15 % WP (T_1) which recorded (44.18 %), (40.05 %) and (38.25 %) mortality, respectively. (28.75 %) and (23.70 %) mortality of (nymphs + adults) was observed within the treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) respectively, which were at par with each other.

$T_{10} \geq T_8 > T_9 \geq T_6 \geq T_5 > T_7 \geq T_4 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

4.4.4.3 After third spray

The data on per cent mortality of (nymphs + adults) have been presented in Table 4.26. and Fig.4.16. The statistical analysis of the data reveals that all test insecticides were found to be statistically superior in mortality of nymphs and adults on vines at 3, 7, 10 and 14 days of observations.

At 3 DAS

The treatment Spirotetramat 15.31 % OD (T_8) (55.96 %) was found to be the most superior treatment in keeping the highest per cent mortality of (nymphs + adults) and were at par with the treatments, Dichlorvos 76 % EC (T_5) (54.41 %), Chlorpyrifos 20 % EC (T_6) (52.34 %), Imidacloprid 17.8 % SL (T_9) (50.78 %) and Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (49.75 %). The next best treatments in the order of preference were Lambda cyhalothrin 5 % EC (T_4) (37.31 %), followed by, Buprofezin 25 % SC (T_7) (27.47 %), *L. lecanii* 1.15% WP (T_1) (23.32 %) and *M. anisopliae* 1.15 % WP (T_2) (22.29 %) and all these three were at par. Whereas, Azadirachtin 1 % EC (T_3) (15.55 %) was recorded least mortality.

$T_8 \geq T_5 \geq T_6 \geq T_9 \geq T_{10} > T_4 > T_7 \geq T_1 \geq T_2 > T_3$ was the order of efficacy.

Table 4.26. Bio-efficacy of insecticides against (nymphs + adults) grape mealybug, *M. hirsutus* after third spray, 2017-18

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality				
			3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	23.32 (28.88)*	51.03 (45.59)	70.59 (57.16)	85.58 (67.68)	57.63 (49.39)
2	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	22.29 (28.17)	42.35 (40.60)	50.98 (45.56)	60.10 (50.83)	43.93 (41.51)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	15.55 (23.22)	31.13 (33.91)	45.10 (42.19)	67.31 (55.13)	39.77 (39.10)
4	Lambda cyhalothrin 5 % EC	0.5 ml	37.31 (37.65)	57.15 (49.11)	83.33 (65.90)	73.53 (59.04)	62.83 (52.43)
5	Dichlorvos 76 % EC	2 ml	54.41 (47.53)	66.84 (54.84)	84.80 (67.05)	74.52 (59.68)	70.14 (56.88)
6	Chlorpyrifos 20 % EC	2 ml	52.34 (46.34)	68.88 (56.09)	87.25 (69.08)	75.96 (60.64)	71.11 (57.49)
7	Buprofezin 25 % SC	1.5 ml	27.47 (31.61)	50.01 (45.01)	77.94 (61.99)	88.46 (70.14)	60.97 (51.34)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	55.96 (48.42)	70.41 (57.05)	79.41 (63.01)	98.08 (82.04)	75.97 (60.65)
9	Imidacloprid 17.8 % SL	0.45 ml	50.78 (45.45)	64.29 (53.30)	78.43 (62.33)	97.12 (80.23)	72.66 (58.47)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	49.75 (44.86)	70.92 (57.37)	84.31 (66.67)	99.04 (84.38)	76.01 (60.67)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	1.25	1.71	2.20	1.97	1.98
	CD at 5%	-	3.70	5.05	6.49	5.81	5.83

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 7 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (70.92 %) was found to be the most superior treatment in keeping the highest per cent mortality of (nymphs + adults) and at par with the treatments Spirotetramat 15.31 % OD (T_8) (70.41 %), Chlorpyrifos 20 % EC (T_6) (68.88 %), Dichlorvos 76 % EC (T_5) (66.84 %) and Imidacloprid 17.8 % SL (T_9) (64.29 %). The next best treatments in the order of preference were Lambda cyhalothrin 5 % EC (T_4) (57.15 %), *L. lecanii* 1.15 % WP (T_1) (51.03 %) and Buprofezin 25 % SC (T_7) (50.01 %) and all they were at par with each other. Further, a significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (42.35 %) and Azadirachtin 1 % EC (T_3) (31.13 %).

$T_{10} \geq T_8 \geq T_6 \geq T_5 \geq T_9 > T_4 \geq T_1 \geq T_7 > T_2 > T_3$ was the order of efficacy.

At 10 DAS

The treatment Chlorpyrifos 20 % EC (T_6) (87.25 %) emerged as most superior treatment, but remained at par with the treatments, Dichlorvos 76 % EC (T_5) (84.80 %), Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (84.31 %), Lambda cyhalothrin 5 % EC (T_4) (83.33 %) and Spirotetramat 15.31 % OD (T_8) (79.41 %). The next best treatments in the order of preference were, Imidacloprid 17.8 % SL (T_9) (78.43 %), Buprofezin 25 % SC (T_7) (77.94 %) and *L. lecanii* 1.15 % WP (T_1) (70.59 %) and all they were at par with each other. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (50.98 %) and Azadirachtin 1 % EC (T_3) (45.10 %).

$T_6 \geq T_5 \geq T_{10} \geq T_4 \geq T_8 > T_9 \geq T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (99.04 %) again remained to be the most superior treatment in keeping the highest per cent mortality of (nymphs + adults), but at par with the treatments Spirotetramat 15.31 % OD (T_8) (98.08 %) and Imidacloprid 17.8 % SL (T_9) (97.12). The next best treatments in the order of preference were, Buprofezin 25 % SC (T_7) (88.46 %) and *L. lecanii* 1.15 % WP (T_1) (85.58 %) were at par, followed by Chlorpyrifos 20 % EC (T_6) (75.96 %), Dichlorvos 76 % EC (T_5) (74.52 %), Lambda cyhalothrin 5 % EC (T_4) (73.53 %) and Azadirachtin 1 % EC (T_3) (67.31 %) and were found at par with each other. Further, (60.10 %) of mortality of (nymphs + adults) was recorded in *M. anisopliae* 1.15 % WP (T_2).

$T_{10} \geq T_8 \geq T_9 > T_7 \geq T_1 > T_6 \geq T_5 \geq T_4 \geq T_3 > T_2$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (76.01 %) remained to be the most superior treatment in keeping the highest per cent mortality of nymphs and adults also at par with the treatments Spirotetramat 15.31 % OD (T_8) (75.97 %), Imidacloprid 17.8 % SL (T_9) (72.66 %), Chlorpyrifos 20 % EC (T_6) (71.11 %) and Dichlorvos 76 % EC (T_5) (70.14 %). The next best treatments in the order of effectiveness were, Lambda cyhalothrin 5 % EC (T_4) (62.83 %), Buprofezin 25 % SC (T_7) (60.97 %) and *L. lecanii* 1.15 % WP (T_1) (57.63 %) and all they were at par. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (43.93 %) and Azadirachtin 1 % EC (T_3) (39.77 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 > T_4 \geq T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

4.4.5 Bio-efficacy of insecticides against (nymphs + adults) of grape mealybug, *M. hirsutus* during 2018-19

4.4.5.1 After first spray

The data on (nymphs + adults) mortality have been presented in Table 4.27. and Fig.4.17. The statistical analysis of the data reveals that the pre-treatment observations were found to be relatively homogenous and varied from an average of 23.17 to 24.67 (nymphs + adults) per vine. The data was observed to be non-significant. The entire test insecticides were found to be statistically superior in the mortality of nymphs and adults on vines at 3, 7, 10 and 14 days of observations.

At 3 DAS

Among all the treatments, Chlorpyrifos 20 % EC (T_6) was found to be the most effective as it recorded the highest per cent mortality of (nymphs + adults) (33.61 %), followed by Dichlorvos 76 % EC (T_5) (32.23 %), Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (31.54 %) and Spirotetramat 15.31 % OD (T_8) (30.84 %) and all they were at par with each other. The next best treatments in the order of preference were, Imidacloprid 17.8 % SL (T_9) (29.46 %), Lambda cyhalothrin 5 % EC (T_4) (23.93 %), Buprofezin 25 % SC (T_7) (12.86 %), *L. lecanii* 1.15 % WP (T_1) (10.10 %), *M. anisopliae* 1.15 % WP (T_2) (7.33 %) and Azadirachtin 1 % EC (T_3) (5.95 %). However, *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) were at par with each other.

$T_6 \geq T_5 \geq T_{10} \geq T_8 > T_9 > T_4 > T_7 > T_1 > T_2 \geq T_3$ was the order of efficacy.

At 7 DAS

The Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) was found to be the most promising treatment and recorded highest (43.72 %) per cent mortality of (nymphs + adults), however at par with Spirotetramat 15.31 % OD (T_8) (42.39 %), Imidacloprid 17.8 % SL (T_9) (41.07 %) and Chlorpyrifos 20 % EC (T_6) (39.08 %). The next best treatments in the order of preference were, Dichlorvos 76 % EC (T_5) (37.76 %) and Lambda cyhalothrin 5 % EC (T_4) (36.43 %) which were at par, followed by Buprofezin 25 % SC (T_7) (21.86 %) and *L. lecanii* 1.15 % WP (T_1), (20.54 %).

However, Buprofezin 25 % SC (T_7) and *L. lecanii* 1.15 % WP (T_1) were found at par with each other. Further, *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) were recorded (16.57 %) and (10.61 %) mortality of (nymphs + adults), respectively.

$T_{10} \geq T_8 \geq T_9 \geq T_6 > T_5 \geq T_4 > T_7 \geq T_1 > T_2 > T_3$ was the order of efficacy.

Table 4.27. Bio-efficacy of insecticides against (nymphs + adults) of grape mealybug, *M. hirsutus* after first spray, 2018-19

Tr. No.	Treatments	Dose (ml or g/L)	Pre-count	Per cent mortality				
				3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15% WP (1 x 10^8 CFU/g)	5 g	24.17 (4.97)*	10.10 (18.53)**	20.54 (26.95)	36.58 (37.22)	52.94 (46.69)	30.04 (33.24)
2	*M. anisopliae* 1.15% WP (1 x 10^8 CFU/g)	5 g	24.67 (5.02)	7.33 (15.71)	16.57 (24.02)	35.36 (36.49)	44.70 (41.96)	25.99 (30.65)
3	Azadirachtin 1% EC (10000 ppm)	3 ml	23.5 (4.90)	5.95 (14.12)	10.61 (19.01)	17.67 (24.86)	28.82 (32.47)	15.76 (23.39)
4	Lambda cyhalothrin 5% EC	0.5 ml	24.33 (4.98)	23.93 (29.29)	36.43 (37.13)	43.29 (41.14)	38.82 (38.54)	35.62 (36.64)
5	Dichlorvos 76% EC	2 ml	24.5 (5.00)	32.23 (34.59)	37.76 (37.91)	48.77 (44.30)	44.70 (41.96)	40.87 (39.74)
6	Chlorpyrifos 20% EC	2 ml	24.33 (4.98)	33.61 (35.43)	39.08 (38.69)	54.26 (47.44)	49.99 (44.99)	44.24 (41.69)
7	Buprofezin 25% SC	1.5 ml	24.17 (4.97)	12.86 (21.01)	21.86 (27.88)	41.46 (40.08)	55.88 (48.38)	33.02 (35.07)
8	Spirotetramat 15.31% w/w OD	0.7 ml	24.67 (5.02)	30.84 (33.73)	42.39 (40.62)	56.7 (48.85)	68.82 (56.06)	49.69 (44.82)
9	Imidacloprid 17.8% SL	0.45 ml	24.33 (4.98)	29.46 (32.87)	41.07 (39.86)	56.09 (48.50)	68.23 (55.69)	48.71 (44.26)
10	Spirotetramat 11.1% + Imidacloprid 11.01% w/w (240 SC)	0.75 ml	24.67 (5.02)	31.54 (34.17)	43.72 (41.39)	60.97 (51.34)	71.76 (57.90)	52.00 (46.15)
11	Untreated control	---	23.17 (4.87)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	NS	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	0.12	0.78	0.99	1.31	1.61	1.13
	CD at 5%	-	NS	2.31	2.91	3.87	4.75	3.33

*Figures in parentheses are square root transformed values,
**Figures in parentheses are arc sin transformed values, DAS : Days after spraying,

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (60.97 %) remained to be superior treatment in keeping the highest per cent mortality of (nymphs + adults) this was at par with Spirotetramat 15.31 % OD (T_8) (56.70 %) and Imidacloprid 17.8 % SL (T_9) (56.09 %). The next best treatments in the order of efficacy were Chlorpyrifos 20 % EC (T_6) (54.26 %) and Dichlorvos 76 % EC (T_5) (48.77

%) but at par with each other. Further, a non significant difference was observed between Lambda cyhalothrin 5 % EC (T_4) (43.29 %) and Buprofezin 25 % SC (T_7) (41.46 %). Whereas, *L. lecanii* 1.15 % WP (T_1) (36.58 %) and *M. anisopliae* 1.15 % WP (T_2) (35.36 %) were also at par. The least mortality of (nymphs + adults) was recorded in Azadirachtin 1 % EC (T_3) (17.67 %).

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_5 > T_4 \geq T_7 > T_1 \geq T_2 > T_3$ was the order of efficacy.

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (71.76 %) remained to be the most effective treatment in keeping the highest per cent mortality of mealybugs (nymphs + adults) this was at par with treatments Spirotetramat 15.31 % OD (T_8) (68.82 %) and Imidacloprid 17.8 % SL (T_9) (68.23 %). The next best treatments in the order of effectiveness were Buprofezin 25 % SC (T_7) (55.88 %), *L. lecanii* 1.15 % WP (T_1) (52.94 %) and Chlorpyrifos 20 % EC (T_6) (49.99 %) and all they were at par with each other. Further, non significant differences were observed between *M. anisopliae* 1.15 % WP (T_2) (44.70 %), Dichlorvos 76 % EC (T_5) (44.70 %) and Lambda cyhalothrin 5 % EC (T_4) (38.82 %), respectively, followed by Azadirachtin 1 % EC (T_3) (28.82 %).

$T_{10} \geq T_8 \geq T_9 > T_7 \geq T_1 \geq T_6 > T_2 \geq T_5 \geq T_4 > T_3$ was the order of efficacy.

Mean

From the mean data of the mortality at 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (52.00 %) remained to be the most superior treatment in keeping the highest mortality of mealybug (nymphs + adults). However, this was at par with Spirotetramat 15.31 % OD (T_8) (49.69 %) and Imidacloprid 17.8 % SL (T_9) (48.71 %). The next best treatments in the order of preference were Chlorpyrifos 20 % EC (T_6) (44.24 %) and Dichlorvos 76 % EC (T_5) (40.87 %) and they were at par. Further, a non significant difference was observed between Lambda cyhalothrin 5 % EC (T_4) (35.62 %) and Buprofezin 25 % SC (T_7) (33.02 %), while *L. lecanii* 1.15 % WP (T_1) (30.04 %) and *M. anisopliae* 1.15 % WP (T_2) (25.99 %) were remained at par. The least mortality was recorded in Azadirachtin 1 % EC (T_3) (15.76 %).

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_5 > T_4 \geq T_7 > T_1 \geq T_2 > T_3$ was the order of efficacy.

4.4.5.2 After second spray

The data on mortality of (nymphs + adults) have been presented in Table 4.28. and Fig.4.18. The results revealed that all test insecticides were found to be statistically superior in mortality of nymphs and adults on vines at 3, 7, 10 and 14 days of observations.

At 3 DAS

Among all the treatments, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (47.43 %) was found exceedingly superior over all rest of the treatments as it was recorded the highest per cent mortality of (nymphs + adults). The next best treatments in the order of preference were Spirotetramat 15.31 % OD (T_8) (40.01 %) and Chlorpyrifos 20 % EC (T_6) (36.58 %) were at par, followed by Imidacloprid 17.8 % SL (T_9) (32.58 %) and Dichlorvos 76 % EC (T_5) (32.01 %) were at par. Further, effective treatments were Lambda cyhalothrin 5 % EC (T_4) (25.15 %), Buprofezin 25 % SC (T_7) (21.15 %), *L. lecanii* 1.15 % WP (T_1) (16.01 %) and *M. anisopliae* 1.15 % WP (T_2) (13.15 %). However, *L. lecanii* 1.15 % WP (T_1) and *M. anisopliae* 1.15 % WP (T_2) were at par with each other. Comparatively less per cent mortality of (nymphs + adults) was observed in Azadirachtin 1 % EC (T_3) (8.58 %).

$T_{10} > T_8 \geq T_6 > T_9 \geq T_5 > T_4 > T_7 > T_1 \geq T_2 > T_3$ was the order of efficacy.

At 7 DAS

The treatment Spirotetramat 15.31 % OD (T_8) (59.56 %) was found promising treatment in recording the highest per mortality of (nymphs + adults) and it was at par with Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (57.92 %) and Chlorpyrifos 20 % EC (T_6) (54.10 %). The next best treatments in the order of preference were, Dichlorvos 76 % EC (T_5) (46.45 %) and Imidacloprid 17.8 % SL (T_9) (42.08 %) were at par. Further, non significant differences were observed between Buprofezin 25 % SC (T_7) (93.34 %), *L. lecanii* 1.15 % WP (T_1) (38.80 %) and Lambda cyhalothrin 5 % EC (T_4) (35.52 %), followed by *M. anisopliae* 1.15 % WP (T_2) (24.59 %) and Azadirachtin 1 % EC (T_3) (19.67 %). However, *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) were at par with each other.

$T_8 \geq T_{10} \geq T_6 > T_5 \geq T_9 > T_7 \geq T_1 \geq T_4 > T_2 \geq T_3$ was the order of efficacy.

Table. 4.28. Bio-efficacy of insecticides against (nymphs + adults) grape mealybug, *M. hirsutus* after second spray, 2018-19

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality				
			3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	16.01 (23.59)*	38.80 (38.53)	51.79 (46.03)	57.43 (49.27)	41.01 (39.82)
2	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	13.15 (21.26)	24.59 (29.73)	36.41 (37.11)	44.56 (41.88)	29.68 (33.01)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	8.58 (17.03)	19.67 (26.33)	30.77 (33.69)	39.11 (38.71)	24.53 (29.69)
4	Lambda cyhalothrin 5 % EC	0.5 ml	25.15 (30.10)	35.52 (36.58)	54.36 (47.50)	49.51 (44.72)	41.14 (39.90)
5	Dichlorvos 76 % EC	2 ml	32.01 (34.46)	46.45 (42.96)	63.59 (52.89)	60.40 (51.00)	50.61 (45.35)
6	Chlorpyrifos 20 % EC	2 ml	36.58 (37.22)	54.10 (47.35)	66.15 (54.42)	61.39 (51.58)	54.56 (47.62)
7	Buprofezin 25 % SC	1.5 ml	21.15 (27.38)	39.34 (38.85)	52.31 (46.32)	60.40 (51.00)	43.30 (41.15)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	40.01 (39.24)	59.56 (50.51)	71.28 (57.59)	78.22 (62.18)	62.27 (52.10)
9	Imidacloprid 17.8 % SL	0.45 ml	32.58 (34.81)	42.08 (40.44)	70.77 (57.27)	77.72 (61.83)	55.79 (48.32)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	47.43 (43.53)	57.92 (49.56)	72.82 (58.58)	80.20 (63.58)	64.59 (53.48)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	0.88	1.22	1.78	2.04	1.38
	CD at 5%	-	2.60	3.60	5.25	6.03	4.08

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (72.82 %) was found to be the most promising treatment in registering the highest per cent mortality of mealybug (nymphs + adults) this was followed by treatments Spirotetramat 15.31 % OD (T_8) (71.28 %), Imidacloprid 17.8 % SL (T_9) (70.77 %) and Chlorpyrifos 20 % EC (T_6) (66.15 %) and all they were at par with each other. The next best treatments in the order of efficacy were Dichlorvos 76 % EC (T_5) (63.59 %), followed by Lambda cyhalothrin 5 % EC (T_4) (54.36 %), Buprofezin 25 % SC (T_7) (52.31 %) and *L. lecanii* 1.15 % WP (T_1) (51.79 %) and all them were at par. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (36.41 %) and Azadirachtin 1 % EC (T_3) (30.77 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 > T_5 > T_4 \geq T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (80.20 %) was found to be the most superior treatment in recording the highest per cent mortality of (nymphs + adults) but remained at par with the treatments Spirotetramat 15.31 % OD (T_8) (78.22 %) and Imidacloprid 17.8 % SL (T_9) (77.72 %). The next best treatments in the order of preference were Chlorpyrifos 20 % EC (T_6) (61.39 %), Dichlorvos 76 % EC (T_5) (60.40 %), Buprofezin 25 % SC (T_7) (60.40 %) and *L. lecanii* 1.15 % WP (T_1) (57.43 %) however all they were at par with each other. Further, non significant differences were observed between the treatments, Lambda cyhalothrin 5 % EC (T_4) (49.51 %), *M. anisopliae* 1.15 % WP (T_2) (44.56 %) and Azadirachtin 1 % EC (T_3) (39.11 %).

$T_{10} \geq T_8 \geq T_9 > T_6 \geq T_5 \geq T_7 \geq T_1 > T_4 \geq T_2 \geq T_3$ was the order of efficacy.

Mean

From the mean data of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (64.59 %) remained to be superior treatment in keeping the highest per cent mortality of (nymphs + adults) and it was at par with the Spirotetramat 15.31 % OD (T_8) (62.27 %). The next best treatments in the order of hierarchy were Imidacloprid 17.8 % SL (T_9) (55.79 %), Chlorpyrifos 20 % EC (T_6) (54.56 %) and Dichlorvos 76 % EC (T_5) (50.61 %) which were at par. Further, non significant diferences were observed between the treatments Buprofezin 25 % SC (T_7), Lambda cyhalothrin 5 % EC (T_4) and *L. lecanii* 1.15 % WP (T_1) which were recorded (43.30 %), (41.14 %) and (41.01 %) mortality, respectively. (29.68 %) and (24.53 %) mortality of (nymphs + adults) were observed within the treatments *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3), respectively and they were at par with each other.

$T_{10} \geq T_8 > T_9 \geq T_6 \geq T_5 > T_7 \geq T_4 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

4.4.5.3 After third spray

The data on per cent mortality of (nymphs + adults) have been presented in Table 4.29 and Fig. 4.19. The statistical analysis of the data reveals that all test insecticides were found to be statistically superior in mortality of mealybug (nymphs + adults) on vines at all four intervals of observations (3, 7, 10 and 14 days).

At 3 DAS

The treatment Spirotetramat 15.31% OD (T_8) (56.59 %) was found to be the most superior treatment in recording the highest per cent mortality of (nymphs + adults) but remained at par with the treatments, Dichlorvos 76 % EC (T_5) (55.13 %), Chlorpyrifos 20 % EC (T_6) (53.18 %), Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (51.22 %) and Imidacloprid 17.8 % SL (T_9) (50.74 %). The next best treatment in the order of preference was Lambda cyhalothrin 5 % EC (T_4) (38.05 %). Further, non significant differences were observed between Buprofezin 25 % SC (T_7) (28.30 %), *L. lecanii* 1.15% WP (T_1) (23.32 %) and *M. anisopliae* 1.15 % WP (T_2) (23.42 %). The least mortality (15.55 %) was recorded in Azadirachtin 1 % EC (T_3).

$T_8 \geq T_5 \geq T_6 \geq T_{10} \geq T_9 > T_4 > T_7 \geq T_1 \geq T_2 > T_3$ was the order of efficacy.

At 7 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (74.76 %) was found to be the most best in reporting the highest per cent mortality of mealybug (nymphs + adults) and was at par with the treatments Spirotetramat 15.31 % OD (T_8) (70.95 %), Chlorpyrifos 20 % EC (T_6) (69.05 %) and Dichlorvos 76 % EC (T_5) (67.14 %). The next best treatments in the order of effectiveness were Imidacloprid 17.8 % SL (T_9) (66.19 %) and Lambda cyhalothrin 5 % EC (T_4) (58.57 %) were at par, followed by *L. lecanii* 1.15 % WP (T_1) (51.90 %) and Buprofezin 25 % SC (T_7) (51.43 %) were at par. Further, *M. anisopliae* 1.15 % WP (T_2) and Azadirachtin 1 % EC (T_3) were recorded (42.86 %) and (32.38 %) of mortality of (nymphs + adults) of grape mealybug.

$T_{10} \geq T_8 \geq T_6 \geq T_5 > T_9 \geq T_4 > T_1 \geq T_7 > T_2 > T_3$ was the order of efficacy.

At 10 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (89.59 %) proved to be the most superior treatment in recording the highest per cent mortality of (nymphs + adults) and was at par with the Spirotetramat 15.31 % OD (T_8) (88.69 %), Imidacloprid 17.8 % SL (T_9) (87.78 %), Chlorpyrifos 20 % EC (T_6) (86.42 %), Dichlorvos 76 % EC (T_5) (84.61 %) and Lambda cyhalothrin 5 % EC (T_4) (84.16 %). The next best treatments in the order of preference were Buprofezin 25 % SC (T_7) (73.30 %) and *L. lecanii* 1.15 % WP (T_1) (70.13 %) were at par. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (51.13 %) and Azadirachtin 1 % EC (T_3) (45.24 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 \geq T_4 > T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

Table 4.29. Bio-efficacy of insecticides against (nymphs + adults) grape mealybug, *M. hirsutus* after third spray, 2018-19

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality				
			3 DAS	7 DAS	10 DAS	14 DAS	Mean
1	*L. lecanii* 1.15 % WP (1×10^8 CFU/g)	5 g	24.89 (29.93)*	51.90 (46.09)	70.13 (56.87)	84.00 (66.42)	57.73 (49.45)
2	*M. anisopliae* 1.15 % WP (1×10^8 CFU/g)	5 g	23.42 (28.94)	42.86 (40.90)	51.13 (45.65)	61.78 (51.81)	44.80 (42.02)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	16.11 (23.66)	32.38 (34.68)	45.24 (42.27)	67.56 (55.28)	40.32 (39.42)
4	Lambda cyhalothrin 5 % EC	0.5 ml	38.05 (38.09)	58.57 (49.93)	84.16 (66.55)	74.22 (59.49)	63.75 (52.98)
5	Dichlorvos 76 % EC	2 ml	55.13 (47.94)	67.14 (55.02)	84.61 (66.90)	76.00 (60.67)	70.72 (57.24)
6	Chlorpyrifos 20 % EC	2 ml	53.18 (46.82)	69.05 (56.20)	86.42 (68.38)	77.78 (61.88)	71.61 (57.80)
7	Buprofezin 25 % SC	1.5 ml	28.30 (32.14)	51.43 (45.82)	73.30 (58.89)	88.44 (70.12)	60.37 (50.99)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	56.59 (48.79)	70.95 (57.39)	88.69 (70.35)	98.22 (82.33)	78.61 (62.45)
9	Imidacloprid 17.8 % SL	0.45 ml	50.74 (45.42)	66.19 (54.45)	87.78 (69.54)	96.89 (79.84)	75.40 (60.27)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	51.22 (45.70)	74.76 (59.84)	89.59 (71.18)	99.56 (86.20)	78.78 (62.57)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig	Sig
	SE (M) ±	-	1.27	1.75	2.18	1.73	2.09
	CD at 5%	-	3.74	5.17	6.44	5.10	6.16

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 14 DAS

The treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (99.56 %) remained to be the most superior treatment and registered the highest per cent mortality of (nymphs + adults) and at par with the treatment Spirotetramat 15.31 % OD (T_8) (98.22 %). The next best treatments in the order of preference were Imidacloprid 17.8 % SL (T_9) (96.89 %), followed by Buprofezin 25 % SC (T_7) (88.44 %) and *L. lecanii* 1.15 % WP (T_1) (84.00 %) were at par with each other. Further, non significant differences were observed between Chlorpyrifos 20 % EC (T_6) (77.78 %), Dichlorvos 76

% EC (T_5) (76.00 %) and Lambda cyhalothrin 5 % EC (T_4) (74.22 %). Whereas, Azadirachtin 1 % EC (T_3) (67.56 %) and *M. anisopliae* 1.15 % WP (T_2) (61.78 %) were at par.

$T_{10} \geq T_8 > T_9 > T_7 \geq T_1 > T_6 \geq T_5 \geq T_4 > T_3 \geq T_2$ was the order of efficacy.

Mean

From the mean resultus of the 3, 7, 10 and 14 DAS it was clearly observed that the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (78.78 %) remained to be the most superior treatment in keeping the highest per cent mortality of (nymphs + adults) and it was at par with the treatments Spirotetramat 15.31 % OD (T_8) (78.61 %), Imidacloprid 17.8 % SL (T_9) (75.40 %), Chlorpyrifos 20 % EC (T_6) (71.61 %) and Dichlorvos 76 % EC (T_5) (70.72 %). The next best treatments in the order of preference were, Lambda cyhalothrin 5 % EC (T_4) (63.75 %), Buprofezin 25 % SC (T_7) (60.37 %) and *L. lecanii* 1.15 % WP (T_1) (57.73 %) and all they were at par. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (44.80 %) and Azadirachtin 1 % EC (T_3) (40.32 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 > T_4 \geq T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

4.4.6 Bio-efficacy of insecticides against (nymphs + adults) of grape mealybug, *M. hirsutus* during 2017-18 and 2018-19 (Pooled)

The pooled data on the efficacy of various insecticides during 2017 - 2018 and 2018 - 2019 are presented in Table 4.30 and Fig.4.20. The mean per cent mortality of (nymphs + adults) during 2017 - 2018 and 2018 - 2019 (Pooled) computed in subsequent intervals of 3, 7, 10 and 14 days after spraying (DAS) indicated that all the insecticidal treatments were significantly superior in mortality of (nymphs + adults) on vines.

At 3 DAS

The treatment with Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (42.82 %) remained to be the most superior treatment in recording the highest per cent mortality of (nymphs + adults) which was at par with the treatments Spirotetramat 15.31 % OD (T_8) (42.06 %), Chlorpyrifos 20 % EC (T_6) (40.31 %), Dichlorvos 76 % EC (T_5) (39.27 %) and Imidacloprid 17.8 % SL (T_9) (36.71 %). The next best treatments in the order of preference were Lambda cyhalothrin 5 % EC (T_4) (28.58 %), followed by Buprofezin 25 % SC (T_7) (20.42 %) and *L. lecanii* 1.15 % WP (T_1) (15.67 %) were at par with it. Whereas, *M. anisopliae* 1.15 % WP (T_2) (14.17 %) and Azadirachtin 1 % EC (T_3) (9.70 %) were found at par with each other.

$T_{10} \geq T_8 \geq T_6 \geq T_5 \geq T_9 > T_4 > T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

Table. 4.30. Bio-efficacy of insecticides against (nymphs + adults) of grape mealybug, *M. hirsutus* during 2017-18 and 2018-19 (Pooled)

Tr. No.	Treatments	Dose (ml or g/L)	Per cent mortality			
			3 DAS	7 DAS	10 DAS	14 DAS
1	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	15.67 (23.32)*	36.36 (37.08)	52.92 (46.67)	65.17 (53.83)
2	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	14.17 (22.11)	27.72 (31.77)	40.73 (39.66)	49.80 (44.89)
3	Azadirachtin 1 % EC (10000 ppm)	3 ml	9.70 (18.15)	20.34 (26.81)	31.09 (33.89)	44.96 (42.11)
4	Lambda cyhalothrin 5 % EC	0.5 ml	28.58 (32.32)	43.12 (41.05)	60.02 (50.78)	53.99 (47.29)
5	Dichlorvos 76 % EC	2 ml	39.27 (38.80)	50.05 (45.03)	65.44 (53.99)	59.81 (50.66)
6	Chlorpyrifos 20 % EC	2 ml	40.31 (39.41)	53.68 (47.11)	68.51 (55.86)	62.49 (52.23)
7	Buprofezin 25 % SC	1.5 ml	20.42 (26.86)	37.03 (37.48)	56.26 (48.60)	69.27 (56.33)
8	Spirotetramat 15.31 % w/w OD	0.7 ml	42.06 (40.43)	57.60 (49.37)	70.72 (57.24)	81.30 (64.38)
9	Imidacloprid 17.8 % SL	0.45 ml	36.71 (37.29)	49.26 (44.58)	69.76 (56.64)	80.19 (63.57)
10	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	42.82 (40.87)	58.01 (49.61)	73.56 (59.06)	83.25 (65.84)
11	Untreated control	-	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)	0.01 (0.57)
	F test	-	Sig	Sig	Sig	Sig
	SE (M) ±	-	1.53	1.88	2.17	2.54
	CD at 5%	-	4.52	5.53	6.39	7.48

*Figures in parentheses are arc sin transformed values, DAS : Days after spraying

At 7 DAS

The treatment, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (58.01 %) remained to be the most superior treatment in registering the highest per cent mortality of (nymphs + adults) was found at par with the treatments Spirotetramat 15.31 % OD (T_8) (57.60 %) and Chlorpyrifos 20 % EC (T_6) (53.68 %), Dichlorvos 76 % EC (T_5) (50.05 %) and Imidacloprid 17.8 % SL (T_9) (49.26 %). The next best treatments in the order of preference were Lambda cyhalothrin 5 % EC (T_4) (43.12 %), Buprofezin

25 % SC (T_7) (37.03 %) and *L. lecanii* 1.15 % WP (T_1) (36.36 %) and they were at par with each other. Further, *M. anisopliae* 1.15 % WP (T_2) (27.72 %) and Azadirachtin 1 % EC (T_3) (20.34 %) were at par and recorded minimum mortality.

$T_{10} \geq T_8 \geq T_6 \geq T_5 \geq T_9 > T_4 \geq T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

At 10 DAS

The treatment with Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (73.56 %) remained to be the most superior treatment in recording the highest per cent mortality of (nymphs + adults) that was at par with the treatments Spirotetramat 15.31 % OD (T_8) (70.72 %), Imidacloprid 17.8 % SL (T_9) (69.76 %), Chlorpyrifos 20 % EC (T_6) (68.51 %) and Dichlorvos 76 % EC (T_5) (65.44 %). The next best treatments in the order of efficacy were Lambda cyhalothrin 5 % EC (T_4) (60.02 %), Buprofezin 25 % SC (T_7) (56.26 %) and *L. lecanii* 1.15 % WP (T_1) (52.92 %) and all of they were at par. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (40.73 %) and Azadirachtin 1 % EC (T_3) (31.09 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 > T_4 \geq T_7 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

At 14 DAS

The treatment with Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (83.25 %) was found to be the most superior treatment in keeping the highest per cent mortality of (nymphs + adults) but was at par with the treatments Spirotetramat 15.31 % OD (T_8) (81.30 %) and Imidacloprid 17.8 % SL (T_9) (80.19 %). The next best treatments in the order of preference were, Buprofezin 25 % SC (T_7) (69.27 %), *L. lecanii* 1.15 % WP (T_1) (65.17 %), Chlorpyrifos 20 % EC (T_6) (62.49 %) and Dichlorvos 76 % EC (T_5) (59.81 %) and all they were at par. Further, non significant differences were observed between Lambda cyhalothrin 5 % EC (T_4) (53.99 %), *M. anisopliae* 1.15 % WP (T_2) (49.80 %) and Azadirachtin 1 % EC (T_3) (44.96 %).

$T_{10} \geq T_8 \geq T_9 > T_7 \geq T_1 \geq T_6 \geq T_5 > T_4 \geq T_2 \geq T_3$ was the order of efficacy.

It can be inferred from the results of present investigation that the field evaluation of insecticides against grape mealybug exerted variable efficacy over untreated control during both the years 2017-18 and 2018-19. The cumulative bio-efficacy of the test insecticides studied on egg sacs represented that all the test insecticides were found promising in reducing the egg sacs over untrated control. Among all the treatments spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) was found the most superior treatment followed by Spirotetramat 15.31% OD. The next best tratments in order of preference were Imidacloprid 17.8 % SL followed by Chlorpyrifos 20 % EC and Dichlorvos 76 % EC, respectively. Wheareas, Buprofezin 25 % SC, Lambda cyhalothrin 5 % EC and *L. lecanii* 1.15 % WP remain at par with each other. *M. anisopliae* 1.15% WP and Azadirachtin 1% EC recorded comparatively less mortality of egg sacs and more or less similar trend was exhibited at all the four interval of observations. The present findings will certainly help in planning IPM strategies against mealybugs at it's vulnerable stage as available literature on this aspect is scanty hence the outcomes of the present study was not comparable.

The pooled data of three spray applications administered on grapevines on both the years reaveled more or less similar trend of efficacy of insecticides in mortality of mealybugs (nymph + adult) at all the four dates of observations. Amongest ten test insecticides, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) appered to be equally promising with Spirotetramat 15.31% OD and Imidacloprid 17.8 % SL, respectively followed by Chlorpyrifos 20 % EC, Dichlorvos 76 % EC, Lambda cyhalothrin 5 % EC, Buprofezin 25 % SC, *L. lecanii* 1.15% WP, *M. anisopliae* 1.15% WP, Azadirachtin 1% EC in the decending order of the bio efficacy.

The findings of the many previous workers are in line with above findings. Agarwal *et al.* (2009) reported that Spirotetamat 12 % + Imidacloprid 36 % 480 SC was recorded 85.09 % mortality of cotton mealybug and equally effective with the check Profenophos 50 % EC. Kumar *et al.* (2008) reported that after the three spray of spirotetamat 150 OD @ 75 g a.i/ha reduces the cotton mealybug, *P. solenopsis* population from 368 to 62/plant. Similar findings given by Mansour *et al.* (2018) and reported that spirotetramat was found efficient to control mealybugs, *viz.,*, *P. ficus* and *P. citri* on grape and citurs, respectively. Sequeria *et al.* (2020) also identified spirotetramat as key insecticide in integrated pest management strategies on cotton mealybug. Tanwar *et al.* (2007), Sunitha *et al.* (2009) reported that Imidacloprid was found effective insecticide in reducing the mealybug infestation both in lab and field. According to Ghorpade and Khilari (2010) two spray applications of Imidacloprid 17.8 SL @ 0.3 ml/L reduces the pink malybug on grapevines and bunches. In respect of Imidacloprid, the findings are in corroboration with that reported by Castle and Prabhakar (2011), Lo and Walker (2011), Seni and Sahoo (2015) and Kaur and Banu (2019).

According to Marcano *et al.* (2006) Chlorpyrifos 35.2 %, @ 1.5 L/ha was the most effective insecticide for control of *M. hirsutus* (Green). Narasimha Rao *et al.* (1977) and Mani (1990) reported that Dichlorvos with combination of fish oil rosin soap effectively control mealybugs. Patil and Sathe (2011) reported that Dichlorvos (0.15 %) was found promising in cent per cent mortality of *M. hirsutus* after thirteen days of insecticidal spray at NRC - Grapes, Pune. Similar findings in corroborration by Naik *et al.* (2017) who reported that, Dichlorvos was found effective in reducing the population of *M. hirsutus*.

Seni and Sahoo (2015) reported that Lamda - cyhalothrin 5 EC and Buprofezin 25 SC were found promising treatments against papaya mealybug in field. Similar findings corroborated by Shinde *et al*. (2016) who opined that, lambda - cyhalothrin 5 EC @ 1 ml/L effective in controlling cotton mealybugs. Balikai (2002) and Balikai (2005) reported that, Buprofezin 25 SC @ 1500 ml/ha and Buprofezin 25 SC @ 2250 ml/ha recorded the least number of mealybug colonies on grapevines. Similarly Kumar *et al.* (2014) reported that Buprofezin 0.025% was effective against papaya mealybug. Kulkarni *et al.* (2003) reported that *V. lecanni* at concentrations ranging from 2 to 6 g/L was effective against mealy bug, *Ferrisia virgata* and *Planococcus citri*. According to Banu *et al*. (2010) *L. lecanii* was found to be highly pathogenic to *Phenacoccus solenopsis* under laboratory condition. Similar findings with respect to *L. lecanni* corroborated by Chavan and Kadam (2010), Surulivelu *et al.* (2012), Kulkarni and Patil (2013) and Amala *et al.* (2014) against mealybugs on grape, cotton and custerd apple. Kharbade *et al*. (2009) reported that *M. anisopliae* @ 2000 g/ha was most effective by recording minimum of 87.46 mealybugs/5 cm shoot tip and was found statistically on par with neem oil @ 2000 ml/ha. Sunitha *et al.* (2009) reported that azadirachtin 0.03 % @ 5 ml/L was effective in reducing the grapevine mealy bug, *M. hirsutus* infestation (86.72 %) this findings contradicts the present findings may be due to the differences in climatic conditions of spray sites.

4.4.7 Bio-efficacy of insecticides against per cent infested bunches

Mealybug infested grape bunches were worked out at harvest by counting the total number of bunches and infested bunches on a number basis and weight basis during 2017 -18 and 2018 -19 (Plate 4.7 and Plate 4.8).

4.4.7.1. Bio-efficacy of insecticides against per cent infested bunches during 2017-18

The data on per cent infested bunches due to mealybug have been presented in Table 4.31. and Fig. 4.21. The results revealed that the entire test insecticides were found to be statistically superior on reduction of per cent infestation of bunches in both numbers and weight basis.

Number basis

The data on the bunch damage on a number basis revealed that, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (0.49 %) was found to be the most superior treatment in keeping the lowest per cent damage that was at par with the treatments Spirotetramat 15.31 % OD (T_8) (0.73 %), Imidacloprid 17.8 % SL (T_9) (0.81 %), Chlorpyrifos 20 % EC (T_6) (1.24 %) and Dichlorvos 76 % EC (T_5) (1.67 %). The next best treatments in the order of preference were Buprofezin 25 % SC (T_7) (2.53 %), Lambda cyhalothrin 5 % EC (T_4) (2.88 %) and *L. lecanii* 1.15 % WP (T_1) (5.43 %), and all they were at par with each other. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (7.07 %) and Azadirachtin 1 % EC (T_3) (7.67 %). Whereas, the highest per cent damaged bunches were evident in untreated control (T_{11}) (16.32 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 > T_7 \geq T_4 \geq T_1 > T_2 \geq T_3$ was the order of efficacy.

Weight basis

The data on the bunch damage on a weight basis revealed that, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (0.49 %) was found to be the most superior treatment in recording the lowest per cent damage that was at par with the treatments Spirotetramat 15.31 % OD (T_8) (0.56 %), Imidacloprid 17.8 % SL (T_9) (0.63 %), Chlorpyrifos 20 % EC (T_6) (0.69 %), Dichlorvos 76 % EC (T_5) (0.94 %), Buprofezin 25 % SC (T_7) (1.42 %) and Lambda cyhalothrin 5 % EC (T_4) (1.61 %) respectively. The next best treatments in the order of preference were *L. lecanii* 1.15 % WP (T_1) (3.96 %), *M. anisopliae* 1.15 % WP (T_2) (3.96 %) and Azadirachtin 1 % EC (T_3) (4.29 %) and all of they were at par. Whereas, the highest per cent damaged bunches were evident in Untreated control (T_{11}) (9.14 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 \geq T_7 \geq T_4 > T_1 \geq T_2 \geq T_3$ was the order of efficacy.

Table 4.31. Bio-efficacy of insecticides against per cent infested bunches during 2017-18

Tr. No.	Treatments	Dose (ml or g/L)	Per cent infested bunches	
			Number basis	Weight basis
1.	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	5.43 (13.47)*	3.04 (10.04)
2.	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	7.07 (15.42)	3.96 (11.48)
3.	Azadirachtin 1 % EC (10000 ppm)	3 ml	7.67 (16.07)	4.29 (11.96)
4.	Lambda cyhalothrin 5 % EC	0.5 ml	2.88 (9.77)	1.61 (7.30)
5.	Dichlorvos 76 % EC	2 ml	1.67 (7.43)	0.94 (5.55)
6.	Chlorpyrifos 20 % EC	2 ml	1.24 (6.39)	0.69 (4.78)
7.	Buprofezin 25 % SC	1.5 ml	2.53 (9.16)	1.42 (6.84)
8.	Spirotetramat 15.31 % w/w OD	0.7 ml	0.73 (4.91)	0.56 (4.28)
9.	Imidacloprid 17.8 % SL	0.45 ml	0.81 (5.17)	0.63 (4.57)
10.	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	0.56 (4.27)	0.49 (4.01)
11.	Untreated control	-	16.32 (23.83)	9.14 (17.6)
	F test	-	Sig	Sig
	SE (M) ±	-	1.60	1.33
	CD at 5%	-	4.72	3.92

*Figures in parentheses are arc sin transformed values

4.4.7.2 Bio-efficacy of insecticides against per cent infested bunches during 2018-19

The data on per cent infested bunches due to mealybug have been presented in Table 4.32 and Fig.4.22. The statistical analysis of the data reveals that the entire test insecticides were found to be statistically superior on reduction of per cent infestation of bunches in both numbers and weight basis.

Table 4.32. Bio-efficacy of insecticides against per cent infested bunches during 2018-19

Tr. No.	Treatments	Dose (ml or g/L)	Per cent infested bunches	
			Number basis	Weight basis
1.	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	5.34 (13.36)*	2.99 (9.96)
2.	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	6.95 (15.29)	3.89 (11.38)
3.	Azadirachtin 1 % EC (10000 ppm)	3 ml	7.40 (15.79)	4.15 (11.75)
4.	Lambda cyhalothrin 5 % EC	0.5 ml	2.82 (9.67)	1.58 (7.22)
5.	Dichlorvos 76 % EC	2 ml	1.65 (7.38)	0.92 (5.51)
6.	Chlorpyrifos 20 % EC	2 ml	1.20 (6.29)	0.67 (4.70)
7.	Buprofezin 25 % SC	1.5 ml	2.51 (9.12)	1.41 (6.81)
8.	Spirotetramat 15.31 % w/w OD	0.7 ml	0.70 (4.78)	0.55 (4.25)
9.	Imidacloprid 17.8 % SL	0.45 ml	0.79 (5.09)	0.61 (4.49)
10.	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	0.54 (4.20)	0.47 (3.94)
11.	Untreated control	-	15.89 (23.49)	8.90 (17.36)
	F test	-	Sig	Sig
	SE (M) ±	-	1.59	1.32
	CD at 5%	-	4.69	3.90

*Figures in parentheses are arc sin transformed values

Number basis

The data on the bunch damage on a number basis revealed that, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (0.54 %) was found to be the most superior treatment in recording the lowest per cent damage that was at par with the treatments Spirotetramat 15.31 % OD (T_8) (0.70 %), Imidacloprid 17.8 % SL (T_9) (0.79 %), Chlorpyrifos 20 % EC (T_6) (1.20 %) and Dichlorvos 76 % EC (T_5) (1.65 %). The next best treatments in the order of preference were Buprofezin 25 % SC (T_7) (2.51 %), Lambda cyhalothrin 5 % EC (T_4) (2.82 %) and *L. lecanii* 1.15 % WP (T_1) (5.34 %), and they were at par with each other. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (6.95 %) and Azadirachtin 1 % EC (T_3) (7.40 %). Whereas, the highest per cent damaged bunches were evident in untreated control (T_{11}) (15.89 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 > T_7 \geq T_4 > T_1 > T_2 \geq T_3$ was the order of efficacy.

Weight basis

The data on the bunch damage on a weight basis revealed that, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (0.47 %) was found to be the most superior treatment in keeping the lowest per cent damage that was at par with the treatments Spirotetramat 15.31 % OD (T_8) (0.55 %), Imidacloprid 17.8 % SL (T_9) (0.61 %), Chlorpyrifos 20 % EC (T_6) (0.67 %), Dichlorvos 76 % EC (T_5) (0.92 %), Buprofezin 25 % SC (T_7) (1.41 %) and Lambda cyhalothrin 5 % EC (T_4) (1.58 %). The next best treatments in the order of preference were *L. lecanii* 1.15 % WP (T_1) (2.99 %), *M. anisopliae* 1.15 % WP (T_2) (3.89 %) and Azadirachtin 1 % EC (T_3) (4.15 %) and all of they were at par with each other. Whereas, the highest per cent damaged bunches were evident in untreated control (T_{11}) (8.90 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 \geq T_7 \geq T_4 > T_1 \geq T_2 \geq T_3$ was the order of efficacy.

4.4.7.3 Bio-efficacy of insecticides against per cent infested bunches during 2017-18 and 2018-19 (Pooled)

The data on per cent infested bunches due to mealybug have been presented in Table 4.33 and Fig. 4.23. The statistical analysis of the data revealed that all test insecticides were found to be statistically superior on reduction of per cent infested of bunches in both numbers and weight basis.

Number basis

The data on the bunch damage on a number basis revealed that, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (0.55 %) was found to be the most superior treatment in keeping the lowest per cent damage that was at par with the treatments Spirotetramat 15.31 % OD (T_8) (0.71 %), Imidacloprid 17.8 % SL (T_9) (0.80 %), Chlorpyrifos 20 % EC (T_6) (1.22 %) and Dichlorvos 76 % EC (T_5) (1.66 %). The next best treatments in the order of efficacy were Buprofezin 25 % SC (T_7) (2.52 %), Lambda cyhalothrin 5 % EC (T_4) (2.85 %) and *L. lecanii* 1.15 % WP (T_1) (5.38 %), but all they were at par. Further, a non significant difference was observed between *M.*

anisopliae 1.15 % WP (T_2) (7.01 %) and Azadirachtin 1 % EC (T_3) (7.54 %). Whereas, the highest per cent damaged bunches were evident in untreated control (T_{11}) (16.11 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 > T_7 \geq T_4 > T_1 > T_2 \geq T_3$ was the order of efficacy.

Table. 4.33. Bio-efficacy of insecticides against per cent infested bunches during 2017-18 and 2018-19 (Pooled)

Tr. No.	Treatments	Dose (ml or g/L)	Per cent infested bunches	
			Number basis	Weight basis
1.	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	5.38 (13.42)*	3.01 (10.00)
2.	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	7.01 (15.35)	3.93 (11.43)
3.	Azadirachtin 1 % EC (10000 ppm)	3 ml	7.54 (15.93)	4.22 (11.85)
4.	Lambda cyhalothrin 5 % EC	0.5 ml	2.85 (9.72)	1.60 (7.26)
5.	Dichlorvos 76 % EC	2 ml	1.66 (7.40)	0.93 (5.53)
6.	Chlorpyrifos 20 % EC	2 ml	1.22 (6.34)	0.68 (4.74)
7.	Buprofezin 25 % SC	1.5 ml	2.52 (9.14)	1.41 (6.83)
8.	Spirotetramat 15.31 % w/w OD	0.7 ml	0.71 (4.85)	0.55 (4.27)
9.	Imidacloprid 17.8 % SL	0.45 ml	0.80 (5.13)	0.62 (4.53)
10.	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	0.55 (4.24)	0.48 (3.98)
11.	Untreated control	-	16.11 (23.66)	9.02 (17.48)
	F test	-	Sig	Sig
	SE (M) ±	-	1.59	1.33
	CD at 5%	-	4.70	3.91

*Figures in parentheses are arc sin transformed values

Weight basis

The data on the bunch damage on a weight basis revealed that, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (0.48 %) was found to be the most superior treatment in keeping the lowest per cent damage that was at par with the treatments Spirotetramat 15.31 % OD (T_8) (0.55 %), Imidacloprid 17.8 % SL (T_9)

(0.62 %), Chlorpyrifos 20 % EC (T_6) (0.68 %), Dichlorvos 76 % EC (T_5) (0.93 %), Buprofezin 25 % SC (T_7) (1.41 %) and Lambda cyhalothrin 5 % EC (T_4) (1.60 %). The next best treatments in the order of hierarchy were *L. lecanii* 1.15 % WP (T_1) (3.01 %), *M. anisopliae* 1.15 % WP (T_2) (3.93 %) and Azadirachtin 1 % EC (T_3) (4.22 %) and all they were at par with each other. Whereas, the highest per cent damaged bunches were evident in untreated control (T_{11}) (9.02 %).

$T_{10} \geq T_8 \geq T_9 \geq T_6 \geq T_5 \geq T_7 \geq T_4 > T_1 \geq T_2 \geq T_3$ was the order of efficacy.

It can be inferred from the results of present investigation that all the test insecticides were effective in reducing infestation of mealynugs on bunches and thereby save the marketable produce in both the years. The per cent infestation observed was significantly low; ranged from 0.55 to 7.54 per cent and 0.48 to 4.22 per cent on number and weight basis, respectively. Whereas, maximum infested bunches 16.11 and 9.02 per cent on number and weight basis was observed in untreated control plots, respectively. The present findings are in corroboration with Sanap (2011) who reported that the 0.83 to 6.18 per cent and 0.58 to 4.90 per cent infested bunches on number and weight basis as againt 8.72 and 7.65 per cent in untreated control.

4.4.8 Bio-efficacy of insecticides on yield of grape with per cent increase over control and per cent avoidable losses

The data on the yield of grapes recorded during 2017-18 and 2018-19 and pooled mean for both years are presented in Table 4.34 and depicted in Fig. 4.24, Fig. 4.25 and Fig. 4.26, respectively.

4.4.8.1 Yield, 2017-18

The yield of grapes in all the treatments varied from 11.47 to 21.54 t ha^{-1}. The highest yield was obtained in the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (21.54 t ha^{-1}) that was at par with Spirotetramat 15.31 % OD (T_8) (21.10 t ha^{-1}), Imidacloprid 17.8 % SL (T_9) (20.18 t ha^{-1}) and Chlorpyrifos 20 % EC (T_6) (19.70 t ha^{-1}). The next best treatments in the order of effectiveness were Dichlorvos 76 % EC (T_5) (18.72 t ha^{-1}), Lambda cyhalothrin 5 % EC (T_4) (18.10 t ha^{-1}) and Buprofezin 25 % SC (T_7) (18.72 t ha^{-1}), but all they were at par with each other. Further, non significant differences were observed between *L. lecanii* 1.15 % WP (T_1) (15.78 t ha^{-1}), *M. anisopliae* 1.15 % WP (T_2) (14.22 t ha^{-1}) and Azadirachtin 1 % EC (T_3) (13.36 t ha^{-1}). Whereas, the lowest yield was recorded in untreated control (T_{11}) (11.47 t ha^{-1}).

Table 4.34. Bio-efficacy of insecticides on yield of grape with per cent increase over control and per cent avoidable losses

Tr. No.	Treatments	Dose (ml or g/L)	2017-18			2018-19			Pooled Mean 2017-18 and 2018-19		
			Yield (t/ha)	% increase over control	% Avoidable losses	Yield (t/ha)	% increase over control	% Avoidable losses	Yield (t/ha)	% increase over control	% Avoidable losses
1.	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	15.78	37.58	27.31	15.84	36.79	26.89	15.81	37.12	27.07
2.	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	14.22	23.98	19.34	14.23	22.88	18.62	14.23	23.42	18.97
3.	Azadirachtin 1 % EC (10000 ppm)	3 ml	13.36	16.48	14.15	13.54	16.93	14.48	13.45	16.65	14.28
4.	Lambda cyhalothrin 5 % EC	0.5 ml	18.1	57.80	36.63	18.65	61.05	37.91	18.38	59.41	37.27
5.	Dichlorvos 76 % EC	2 ml	18.72	63.21	38.73	19.87	71.59	41.72	19.3	67.39	40.26
6.	Chlorpyrifos 20 % EC	2 ml	19.7	71.75	41.78	20.15	74.01	42.53	19.93	72.85	42.15
7.	Buprofezin 25 % SC	1.5 ml	17.85	55.62	35.74	18.14	56.65	36.16	18	56.11	35.94
8.	Spirotetramat 15.31 % w/w OD	0.7 ml	21.1	83.96	45.64	21.65	86.96	46.51	21.38	85.43	46.07
9.	Imidacloprid 17.8 % SL	0.45 ml	20.18	75.94	43.16	20.57	77.63	43.70	20.38	76.76	43.42
10.	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	21.54	87.79	46.75	21.67	87.13	46.56	21.61	87.42	46.65
11.	Untreated control	-	11.47	0.00	0.00	11.58	0.00	0.00	11.53	0.00	0.00
	SE (M) ±	-	0.88	--	--	0.91	--	--	0.89	--	--
	CD at 5%	-	2.60	--	--	2.67	--	--	2.64	--	--

The per cent increase in yield over control in all the treatments varied from 16.48 to 87.79 per cent. Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (87.79 %) was recorded as the highest per cent increase in yield over control (46.75 % avoidable losses) over control.

4.4.8.2 Yield, 2018-19

The yield of grapes in all the treatments varied from 11.58 to 21.67 t ha^{-1}. The highest yield obtained in the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (21.67 t ha^{-1}) that was at par with Spirotetramat 15.31 % OD (T_8) (21.65 t ha^{-1}), Imidacloprid 17.8 % SL (T_9) (20.57 t ha^{-1}), Chlorpyrifos 20 % EC (T_6) (20.15 t ha^{-1}) and Dichlorvos 76 % EC (T_5) (19.87 t ha^{-1}). The next best treatments in the order of preference were Lambda cyhalothrin 5 % EC (T_4) (18.65 t ha^{-1}) and Buprofezin 25 % SC (T_7) (18.14 t ha^{-1}) were at par with each other. Further, non significant differences were observed between *L. lecanii* 1.15% WP (T_1) (15.84 t ha^{-1}), *M. anisopliae* 1.15 % WP (T_2) (14.23 t ha^{-1}) and Azadirachtin 1 % EC (T_3) (13.54 t ha^{-1}). Whereas, the lowest yield was recorded in untreated control (T_{11}) (11.58 t ha^{-1}).

The per cent increase in yield over control in all the treatments varied from 16.93 to 87.13 per cent. Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (87.13 %) was recorded as the highest per cent increase in yield over control with (46.56 % avoidable losses).

4.4.8.3 Pooled mean of grape yield 2017-18 and 2018-19

The yield of grapes in all the treatments varied from 11.53 to 21.61 t ha^{-1}. The highest yield obtained in the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (21.61 t ha^{-1}) that was at par with Spirotetramat 15.31 % OD (T_8) (21.38 t ha^{-1}), Imidacloprid 17.8 % SL (T_9) (20.38 t ha^{-1}), Chlorpyrifos 20 % EC (T_6) (19.93 t ha^{-1}) and Dichlorvos 76 % EC (T_5) (19.30 t ha^{-1}). The next best treatments in the order of hierarchy were Lambda cyhalothrin 5 % EC (T_4) (18.38 t ha^{-1}), Buprofezin 25 % SC (T_7) (18.00 t ha^{-1}) and *L. lecanii* 1.15% WP (T_1) (15.81 t ha^{-1}) all these were at par. Further, a non significant difference was observed between *M. anisopliae* 1.15 % WP (T_2) (14.23 t ha^{-1}) and Azadirachtin 1 % EC (T_3) (13.45 t ha^{-1}). Whereas, the lowest yield was recorded in untreated control (T_{11}) (11.53 t ha^{-1}).

The per cent increase in yield over control in all the treatments varied from 16.65 to 87.42 per cent. Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC)

(T_{10}) (87.42 %) recorded as the highest per cent increase in yield over control with (46.65 % avoidable losses)

4.4.9 Cost economics of insecticides treatments

The economics of test insecticides were worked out based on fruit yield during 2017-18 and 2018-19 tabulated in Table 4.35. The data were then computed for gross income, expenditure incurred towards plant protection, increase in yield over control, net income from marketable fruit and Incremental Cost-Benefit Ratio (ICBR).

Gross income (Rs.) was worked out based on mean fruit yield of two years (2017-18 and 2018-19). Among the evaluated insecticides the highest gross income was obtained in the plot protected with three sprays of Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (Rs. 6.48 lakh ha^{-1}). It was followed by Spirotetramat 15.31 % OD (T_8) (Rs. 6.41 lakh ha^{-1}), Imidacloprid 17.8 % SL (T_9) (Rs. 6.11 lakh ha^{-1}), Chlorpyrifos 20 % EC (T_6) (Rs. 5.97 lakh ha^{-1}), Dichlorvos 76 % EC (T_5) (Rs. 5.78 lakh ha^{-1}), Lambda cyhalothrin 5 % EC (T_4) (Rs. 5.51 lakh ha^{-1}), Buprofezin 25 % SC (T_7) (Rs. 5.39 lakh ha^{-1}), *L. lecanii* 1.15% WP (T_1) (Rs. 4.74 lakh ha^{-1}), *M. anisopliae* 1.15 % WP (T_2) (Rs. 4.26 lakh ha^{-1}), Azadirachtin 1 % EC (T_3) (Rs. 4. 03 lakh ha^{-1}).

A similar trend was observed in the data regarding additional income over control (Rs. ha^{-1}). It was revealed that the highest income was recorded in the treatment Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (Rs. 3,02,400 ha^{-1}). It was followed by Spirotetramat 15.31 % OD (T_8) (Rs. 2,95,500 ha^{-1}), Imidacloprid 17.8 % SL (T_9) (Rs. 2,65,500 ha^{-1}), Chlorpyrifos 20 % EC (T_6) (Rs. 2,52,000 ha^{-1}), Dichlorvos 76 % EC (T_5) (Rs. 2,33,100 ha^{-1}), Lambda cyhalothrin 5 % EC (T_4) (Rs. 2,05,500 ha^{-1}), Buprofezin 25 % SC (T_7) (Rs. 1,94,100 ha^{-1}), *L. lecanii* 1.15% WP (T_1) (Rs. 1,28,550 ha^{-1}), *M. anisopliae* 1.15 % WP (T_2) (Rs. 81,000 ha^{-1}), Azadirachtin 1 % EC (T_3) (Rs. 57,750 ha^{-1}).

The highest Incremental Cost-Benefit Ratio (ICBR) was registered by Chlorpyrifos 20 % EC (T_6) (1:46.19), Lambda cyhalothrin 5 % EC (1:45.92), Imidacloprid 17.8 % SL (T_9) (1:42.66), Spirotetramat 15.31 % OD (T_8) (1:29.25), Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) (1:29.09), Dichlorvos 76 % EC (T_5) (1:22.83), Buprofezin 25 % SC (T_7) (1:20.86), *L. lecanii* 1.15% WP (T_1) (1:19.40), *M. anisopliae* 1.15 % WP (T_2) (1:11.86) and Azadirachtin 1 % EC (T_3) (1:2.10).

Table 4.35. Incremental cost benefit ratio and net gain by insecticides against grape mealybug, *M. hirsutus*

Tr. No.	Treatments	Dose (ml or g/L)	Quantity of insecticide required/ ha (ml or g)	Cost of insecticide (3 Sprays) (Rs/ha)	Cost of spraying operation (3 Sprays) (Rs/ha)	Total cost on plant protection (Rs/ha) (A)	Yield (t/ha)	Gross realization (Rs/ha)	Increase yield over control (t/ha)	Net realization over control (Rs/ha) (B)	Net Gain (Rs/ha) (B-A) (C)	Net ICBR (C/A) (D) (1:00)
1.	*L. lecanii* 1.15 % WP (1 x 10^8 CFU/g)	5 g	5000	3000	3300	6300	15.81	474300	4.28	128550	122250	1:19.40
2.	*M. anisopliae* 1.15 % WP (1 x 10^8 CFU/g)	5 g	5000	3000	3300	6300	14.23	426750	2.70	81000	74700	1:11.86
3.	Azadirachtin 1 % EC (10000 ppm)	3 ml	3000	15300	3300	18600	13.45	403500	1.92	57750	39150	1:2.10
4.	Lambda cyhalothrin 5 % EC	0.5 ml	500	1080	3300	4380	18.38	551250	6.85	205500	201120	1:45.92
5.	Dichlorvos 76 % EC	2 ml	2000	6480	3300	9780	19.30	578850	7.77	233100	223320	1:22.83
6.	Chlorpyrifos 20 % EC	2 ml	2000	2040	3300	5340	19.93	597750	8.40	252000	246660	1:46.19
7.	Buprofezin 25 % SC	1.5 ml	1500	5580	3300	8880	18.00	539850	6.47	194100	185220	1:20.86
8.	Spirotetramat 15.31 % w/w OD	0.7 ml	700	6468	3300	9768	21.38	641250	9.85	295500	285732	1:29.25
9.	Imidacloprid 17.8 % SL	0.45 ml	450	2781	3300	6081	20.38	611250	8.85	265500	259419	1:42.66
10.	Spirotetramat 11.1 % + Imidacloprid 11.01 % w/w (240 SC)	0.75 ml	750	6750	3300	10050	21.61	648150	10.08	302400	292350	1:29.09
11.	Untreated control	-	---	---	---	---	11.53	345750	---	---	---	---

L. lecanii 1.15% WP (1X10^8 CFU/g)	- Rs.200/Kg	Chlorpyrifos 20% EC	- Rs.340/L
M. anisopliae 1.15% WP (1X10^8 CFU/g)	- Rs.200/Kg	Buprofezin 25% SC	- Rs.1240/L
Azadirachtin 1% (10000 ppm)	- Rs.1700/L	Spirotetramat 15.31% OD	- Rs.3080/L
Lambda cyhalothrin 5% EC	- Rs.720/L	Imidacloprid 17.8% SL	- Rs.2060/L
Dichlorvos 76% EC	- Rs.1080/L	Spirotetramat 11.01% + Imidacloprid 11.01% w/w (240 SC)	- Rs.3000/L
Market sale price of grape	- Rs.30,000/t	Cost of spraying operation (1000 L Water/ha)	- Rs.1100/ha

More or less similar observations were also reported by Katke and Balikai (2008) who reported that Dimethoate 30 EC @ 1.7 ml+ fish oil rosin soap @ 5g/l and dimethoate 30 EC @ 1.7 ml/ were most promising treatments for controlling grapevine mealybugs and recorded bunch yield was 31.7 t/ha and 32.3 t/ha, respectively. However, highest incremental cost benefit ratio of 1:58 was observed in Dimethoate 30 EC @ 1.7 ml/l. According to Angu (2015) in the order of preference buprofezin 0.04 % was the most effective treatment in reducing the population of mealybug and recorded highest yield (37340 kg ha^{-1}) and incremental benefit cost ratio of 169.3, respectively followed by acetamiprid 0.02 % (33081 kg ha^{-1} and IBCR 131.2). Similarly, Shinde (2012) studied the efficacy of seven new insecticides, buprofezin 25 SC @ 1.5 ml/l was found most effective in reducing number of mealy bug colonies per plant and per bunch. Whereas, highest ICBR was found in acetamiprid 20 SP @ 0.3 g/L (1:40.9) and lambda cyhalothrin 5 EC @ 1 ml/L (1.36.4). Karanjekar (2019) reported that the highest marketable fruit yield (67.26 q ha^{-1}), net profit (Rs. 68720 ha^{-1}) was recorded with buprofezin 25 % SC @ 1.5 ml/lit. But highest ICBR recorded in Imidacloprid 17.8 % SL @ 0.2 ml/lit (1: 15.58) against mealybug on custered apple. The treatment with Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) (T_{10}) recorded highest yield but due to higher cost recorded 1:29.09 ICBR.

5. SUMMARY AND CONCLUSION

The present investigations were carried out for studying the Seasonal incidence, biology and management of grape mealybug at MPKV, Rahuri during the years 2017-18 to 2019-20. The summary of research findings and the conclusions drawn are presented below.

5.1 Summary

5.1.1 Seasonal incidence of grape mealybug, *M. hirsutus* during 2018-19 and 2019-20

Weekly observations on pest incidence were recorded throughout the period of experimentation. Meteorological data during the period was correlated. Present studies revealed that, the number of egg sacs per vine was higher when maximum temperature increased and morning and evening relative humidity decreased. During, 2018-19 highest egg sacs count (7.1/vine) was observed in 13th meteorological week when maximum temperature was 39.29°C and morning and evening relative humidity were 39.57 and 13.14 per cent, respectively. Similarly during 2019-20 highest egg sacs count (7.5/vine) was observed in 14th meteorological week when maximum temperature was 39.71°C and morning and evening relative humidity were 37.71 and 14.14 per cent, respectively. The nymphal population also showed highly significant positive correlation with maximum temperature, highly significant negative correlation with morning and evening relative humidity and significant negative correlation with rainfall. During, 2018-19 maximum nymphal count (28.5/vine) was registered on 13th meteorological week and minimum in third week of August (33rd SMW) when maximum temperature was (39.29 and 27.86 °C), respectively and morning and evening relative humidity were (39.57 and 80.71 %), (13.14 and 72.86 %), respectively. During 2019-20 maximum nymphal count (28.3/vine) was registered on 13th meteorological week and minimum in third week of September (38th SMW) when maximum temperature was (34.20 and 29.83°C), respectively and morning and evening relative humidity were (75.29 and 83.57 %), (32.14 and 71.00 %), respectively. in general both the years the number of egg sacs and nymphal population started decreasing from September to the end of November and went on increasing from December till March. The adults count was highest (13.2/vine) and (28.3/ vine) in the last week of March (13th SMW) observed in both years, respectively.

Wheareas, maximum number of mealybug colonies (11.8/vine) and (12.6/vine) was also recorded in last week of March (13th SMW).

Taking an overall view, it can be summarized that the mealybug population was governed chiefly by the combined effects of three factors i.e. temperature, relative humidity and rainfall. High temperature proved most congenial for its multiplication while high relative humidity and high rainfall were detrimental for survival of mealybug population.

5.1.2 Biology of grape mealybug, *M. hirsutus* (summer and winter season 2018)

Laboratory studies on biology of *M. hirsutus* were carried out during summer season (April, 2018) and winter season (October, 2018) wherein, life stage wise duration was recorded.

During summer season the incubation period was 4.20 ± 0.70 and 3.55 ± 0.76 days, the nymphal period was 23.8 ± 1.15 and 21.5 ± 1.13 days, the adult longevity was 8.80 ± 0.68 and 2.40 ± 0.51 days and the total life span was 36.8 ± 1.52 and 27.5 ± 1.44 days in case of female and male, respectively.

The incubation period, nymphal period and the adult longevity for female was 7.05 ± 0.83, 25.2 ± 1.30 and 14.2 ± 1.57 days and for male 6.40 ± 0.50, 22.6 ± 1.46 and 4.07 ± 0.80 days and thus accounting 46.5 ± 2.20 and 33.1 ± 1.74 days for total life span of mealy bug, respectively during winter season.

The female had three nymphal instars while the male had four. The total life cycle of grape mealy bug took more days during winter than summer. The hatching percentage of eggs varied from 80.00 to 86.67 and 90.00 to 93.33 per cent with an average of 83.33 ± 2.80 and 91.33 ± 1.42 per cent during summer and winter, respectively. During summer the fecundity ranged from 337 to 428 with a mean of 374 ± 40.2 eggs. During winter the fecundity ranged from 352 to 496 with an average of 421 ± 49.7 eggs. It was observed that the nymphal period, adult longevity and fecundity were more during winter than summer.

5.1.3 Pesticide usage pattern for management of grape mealybug in Western Maharashtra

Thirty grape growers each from district *viz.*,Ahmednagar, Pune, Solapur, Sangli and Nashik of Western Maharashtra, were interviewed based on questionnaire by random selection. Results revealed that irrespective of the growing conditions, grape growers relied mainly on novel insecticides (55.83 %) followed by conventional insecticides (27.11 %) and bio-pesticides (17.06 %) for the pest management. Grape growers were able to identify the pest problems (88.66 % respondents). On the basis of incidence, the sucking pests *viz.*,mealybug, thrips and mites were the most commonly occurring insect pests in the region. In addition, other pests like stem borer, flea beetles, defoliators, nematodes etc. were also noticed. Grape growers were aware of natural enemies (19.33 %) and biopesticides (59.33 %). Some grape growers were aware about the use of recommended pesticides (12.00 %) as well as aware about safe wating period (27.33 %). Grape growers knew about effects of pesticide residues (68.00 %), but they did not follow precautionary measures while spraying in the field to avoid toxic effects of pesticides. Majority of the grape growers mainly relied on pesticide retailers followed by neighbours, media, university scientists and agricultural department for selecting insecticides for spraying. Majority of grape growers followed 6 -10 rounds of pesticides application during the fruiting season.

5.1.4 Bio-efficacy of insecticides against grape mealybug, *M. hirsutus*

The field bio-efficacy of ten insecticides was evaluated during 2017-18 and 2018-19. The observations on per cent mortality/reduction of egg sacs and (nymphs + adults) were recorded at 3, 7, 10 and 14 days after spray.

The data pertaining to three foliar applications exhibited more or less similar resultus. Amongst the ten test insecticides, Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) @ 0.75 ml /L appered to be equally promising with Spirotetramat 15.31 % OD @ 0.7 ml/L and Imidacloprid 17.8 % SL @ 0.45 ml/L, respectively followed by Chlorpyrifos 20 % EC @ 2 ml/L, Dichlorvos 76 % EC @ 2 ml/L, Lambda cyhalothrin 5 % EC @ 0.5 ml/L, Buprofezin 25 % SC @ 1.5 ml/L, *L. lecanii* 1.15% WP @ 5 g/L, *M. anisopliae* 1.15% WP @ 5 g/L, Azadirachtin 1% EC @ 3 ml/L in the decending order of the bio efficacy. The Incremental Cost Benefit Ratio (ICBR) of Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) @ 0.75 ml /L was computed as 1: 29.09 and hence may be recommended against the grape mealybug.

The mean per cent increase in yield over control in all the treatments varied from 16.65 to 87.42 per cent. Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) @ 0.75 ml /L recorded the highest per cent increase in yield over control.

Though the insecticides *viz.*,Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) proved superiority in controlling the mealybugs and exhibited relatively higher net realization but failed to meet adequate ICBR due to higher market price. The highest Incremental Cost Benefit Ratio (ICBR) was registered in Chlorpyrifos 20 % EC @ 2 ml/L (1:46.19) followed by Lambda cyhalothrin 5 % EC @ 0.5 ml/L (1:45.92) and Imidacloprid 17.8 % SL @ 0.45 ml/L (1:42.66).

5.2 Conclusions

1. The pest occurred throughout the year. The abiotic factors *viz.*,maximum temperature, bright sunshine and evaporation were found positively correlated indicating that the increase in the mealybug population was synchronized with these factors. The other factors *viz.*,minimum temperature, morning relative humidity, evening relative humidity, wind velocity, rainfall and number of rainy days were found negatively correlated indicating that the decrease in the mealybug population was influenced by these factors. There is a close relationship exists between the aforesaid factors and the new flush for the occurrence of the pest which may be useful for developing the pest forecasting model in changing climatic conditions.
2. The duration of life cycle of the pest was found extended during winter season. Understanding the biology of the pest in the crop was yield valuable information for strategizing the management options of the particular pest. Cognizance of most vulnerable stages of pest reduces overall pest management efforts
3. Pesticide usage pattern for the management of grape mealybug in Western Maharashtra indicates that grape growers relied mainly on synthetic insecticides; many conventional insecticides that are on the verge of ban. Hence insecticides need to exploit scrupulously; novel insecticides including IGRs, Neonicotinoids, Ket-enols (tetramic acid derivatives) and entomopathogenic fungi may serve as the competent alternatives.
4. The field bio-efficacy of Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) and Spirotetramat 15.31 % OD exhibited promising performance. However, the former two formulations are comparatively expensive when computed for ICBR.
5. In suppressing the field prevailing mealybug population, Imidacloprid 17.8 % SL @ 0.45 ml/L appeared to be equally promising with superior treatment *i.e.* Spirotetramat 11.1 % + Imidacloprid 11.01 % (240 SC) @ 0.75 ml /L and may be recommended.

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7. APPENDICES

Appendix-I : Weekly mean weather data during 2018-19

Month	SMW	Temperature (^{0}C)		Relative Humidity (%)		Wind velocity (km/hr)	Sunshine (hr)	Evaporation (mm)	Rainfall (mm)	No of rainy days (days)
		Max.	Min.	Mor RH-I	Eve RH-II					
02 Apr – 08 Apr	14	37.54	19.86	40.14	19.43	1.79	7.93	7.47	0.00	0
09 Apr – 15 Apr	15	37.26	20.04	44.00	19.57	1.64	8.79	8.46	0.00	0
16 Apr – 22 Apr	16	39.31	22.31	41.29	21.29	3.64	9.97	10.46	0.14	1
23 Apr – 29 Apr	17	39.43	19.74	30.14	13.57	2.19	10.84	13.00	0.00	0
30 Apr – 06 May	18	40.66	20.99	36.14	17.00	3.94	10.60	14.34	0.00	0
07 May – 13 May	19	40.20	24.17	32.14	17.71	4.13	10.30	13.83	0.00	0
14 May – 20 May	20	39.77	24.33	36.29	19.00	4.77	9.81	13.66	0.00	0
21 May – 27 May	21	38.86	25.20	40.43	20.57	4.53	7.09	9.47	0.00	0
28 May – 03 Jun	22	38.86	24.76	64.14	34.43	4.43	7.81	7.77	4.94	2
04 Jun – 10 Jun	23	34.20	24.60	71.86	47.29	3.73	3.83	4.83	1.57	2
11 Jun – 17 Jun	24	35.34	25.01	61.86	41.71	11.59	7.80	6.06	0.00	0
18 Jun – 24 Jun	25	34.14	23.37	72.43	54.14	5.46	4.83	5.29	6.14	3
25 Jun – 01 Jul	26	32.09	22.97	72.71	53.29	7.73	4.83	5.00	9.11	2
02 Jul –08 Jul	27	31.71	23.31	76.14	59.43	8.01	3.90	5.29	3.74	1
09 Jul – 15 Jul	28	28.26	22.83	80.00	69.71	5.00	0.30	3.37	1.97	4
16 Jul – 22 Jul	29	29.40	22.99	76.71	64.71	8.67	1.84	4.09	0.63	1
23 Jul – 29 Jul	30	28.66	22.73	75.14	62.29	7.54	1.27	4.14	0.00	0
30 Jul – 05 Aug	31	31.34	23.27	71.71	53.29	7.93	4.01	5.43	0.00	0
06 Aug – 12 Aug	32	30.00	22.99	75.14	62.57	6.81	1.49	5.10	0.00	0
13 Aug – 19 Aug	33	27.86	22.53	80.71	72.86	4.83	0.59	3.63	8.34	3
20 Aug – 26 Aug	34	27.94	21.49	80.00	70.57	5.01	3.06	3.71	3.46	2
27 Aug – 02 Sep	35	29.66	21.14	74.71	61.14	3.47	5.00	4.43	0.91	1
03 Sep – 09 Sep	36	30.09	19.64	70.57	53.14	4.16	5.77	5.14	0.00	0
10 Sep – 16 Sep	37	32.40	19.50	69.14	48.71	0.83	7.60	5.47	0.00	0
17 Sep – 23 Sep	38	31.94	22.11	71.57	45.14	2.71	6.16	5.47	0.54	1
24 Sep – 30 Sep	39	33.83	22.29	71.43	44.43	1.31	8.10	6.34	0.00	0

Appendix-I contd….

Month	SMW	Temperature (^0C)		Relative Humidity (%)		Wind velocity (km/hr)	Sunshine (hr)	Evaporation (mm)	Rainfall (mm)	No of rainy days (days)
		Max.	Min.	Mor RH-I	Eve RH-II					
01 Oct – 07 Oct	40	34.03	21.54	67.29	42.86	1.27	7.80	6.33	0.00	0
08 Oct – 14 Oct	41	34.03	18.37	54.71	30.14	1.57	8.80	7.06	0.00	0
15 Oct – 21 Oct	42	33.49	18.57	50.00	30.29	1.27	8.24	6.63	0.00	0
22 Oct – 28 Oct	43	34.40	16.77	46.00	31.14	0.97	8.49	6.66	0.00	0
29 Oct – 04 Nov	44	31.74	14.41	58.14	38.00	1.89	9.46	6.49	0.29	1
05 Nov – 11 Nov	45	33.11	16.77	58.71	37.29	0.84	8.09	6.36	0.00	0
12 Nov – 18 Nov	46	32.49	12.94	43.43	23.29	0.84	9.96	5.89	0.00	0
19 Nov – 25 Nov	47	31.74	16.30	61.14	46.43	1.27	7.74	5.69	0.00	0
26 Nov – 02 Dec	48	30.14	11.33	54.00	31.71	0.80	9.19	5.63	0.00	0
03 Dec – 09 Dec	49	30.34	15.04	60.43	35.00	0.39	6.63	4.83	0.00	0
10 Dec – 16 Dec	50	28.11	11.33	54.71	31.14	0.69	8.00	4.87	0.00	0
17 Dec – 23 Dec	51	26.51	9.11	64.00	36.00	0.49	9.09	4.43	0.00	0
24 Dec – 31 Dec	52	27.78	8.99	51.38	29.38	0.63	8.78	4.60	0.00	0
01 Jan – 07 Jan	1	29.34	8.86	42.29	23.57	0.34	9.16	4.37	0.00	0
08 Jan – 14 Jan	2	28.49	8.93	56.86	28.14	0.20	8.24	4.36	0.00	0
15 Jan – 21 Jan	3	29.37	11.29	57.71	33.00	0.27	8.29	4.47	0.00	0
22 Jan – 28 Jan	4	27.29	10.36	60.57	42.14	1.07	6.79	4.51	0.00	0
29 Jan – 04 Feb	5	27.74	10.39	53.43	29.43	0.73	7.76	4.69	0.00	0
05 Feb – 11 Feb	6	27.57	9.06	54.00	29.29	0.97	8.30	4.53	0.00	0
12 Feb – 18 Feb	7	31.83	14.14	55.14	27.71	0.74	8.27	5.43	0.00	0
19 Feb – 25 Feb	8	34.66	15.91	49.86	24.43	0.86	9.59	6.01	0.00	0
26 Feb – 04 Mar	9	31.91	12.97	47.29	19.71	1.39	9.67	6.09	0.00	0
05 Mar – 11 Mar	10	33.31	14.09	45.14	19.86	0.89	9.20	6.39	0.00	0
12 Mar – 18 Mar	11	35.50	15.96	51.43	16.14	0.94	8.57	6.66	0.00	0
19 Mar – 25 Mar	12	36.43	16.13	46.14	14.71	1.57	8.94	7.33	0.00	0
26 Mar – 01 Apr	13	39.29	18.77	39.57	13.14	1.57	8.93	8.43	0.00	0

Appendix-II : Weekly mean weather data during 2019-20

Month	SMW	Temperature (^{0}C)		Relative Humidity (%)		Wind velocity (km/hr)	Sunshine (hr)	Evaporation (mm)	Rainfall (mm)	No of rainy days (days)
		Max.	Min.	Mor RH-I	Eve RH-II					
02 Apr – 08 Apr	14	39.71	19.96	37.71	14.14	2.53	9.17	9.30	0.00	0
09 Apr – 15 Apr	15	40.44	21.19	35.29	13.43	2.10	9.06	9.36	0.00	0
16 Apr – 22 Apr	16	37.14	19.20	45.00	18.57	2.69	9.41	8.91	0.63	1
23 Apr – 29 Apr	17	41.26	23.99	30.57	11.71	2.49	10.53	11.11	0.00	0
30 Apr – 06 May	18	39.09	20.74	37.29	15.86	4.17	10.34	10.49	0.00	0
07 May – 13 May	19	39.29	21.73	44.29	17.57	3.34	10.53	12.14	0.00	0
14 May – 20 May	20	40.00	21.81	34.57	14.00	4.61	10.77	13.74	0.00	0
21 May – 27 May	21	41.26	25.49	38.29	16.29	4.44	10.87	14.69	0.00	0
28 May – 03 Jun	22	41.20	23.47	39.14	19.00	5.43	10.47	13.46	0.00	0
04 Jun – 10 Jun	23	39.17	26.14	51.43	30.29	5.37	6.10	11.91	1.00	1
11 Jun – 17 Jun	24	37.17	24.87	58.71	35.14	8.31	9.41	10.79	0.06	1
18 Jun – 24 Jun	25	36.06	24.33	69.86	40.00	6.23	7.80	10.91	2.60	2
25 Jun – 01 Jul	26	31.43	23.81	80.71	60.29	2.04	2.80	4.60	7.34	5
02 Jul – 08 Jul	27	30.61	23.54	79.00	63.14	4.93	1.30	4.34	5.29	3
09 Jul – 15 Jul	28	32.00	23.60	76.00	56.57	7.37	4.70	5.33	0.54	1
16 Jul – 22 Jul	29	33.83	23.24	71.43	51.29	6.44	7.77	5.87	4.57	2
23 Jul – 29 Jul	30	30.51	23.59	78.43	68.14	4.11	2.31	3.30	2.63	4
30 Jul – 05 Aug	31	27.03	22.86	87.00	77.43	4.79	0.23	1.86	6.80	6
06 Aug – 12 Aug	32	28.03	23.27	80.57	68.14	8.17	1.99	3.60	0.51	3
13 Aug – 19 Aug	33	31.00	22.47	75.14	59.57	6.96	4.29	5.43	0.20	1
20 Aug – 26 Aug	34	32.49	21.29	72.43	47.57	4.13	7.91	6.19	0.00	0
27 Aug – 02 Sep	35	31.97	22.99	75.14	55.71	4.07	5.90	5.74	12.57	4
03 Sep – 09 Sep	36	29.97	23.33	77.57	70.57	3.57	1.86	4.29	0.43	2
10 Sep – 16 Sep	37	28.77	22.47	78.57	68.43	4.64	1.36	3.67	3.09	3
17 Sep – 23 Sep	38	29.83	21.73	83.57	71.00	1.61	4.23	3.69	12.03	4
24 Sep – 30 Sep	39	30.23	21.94	83.43	66.86	0.83	4.96	3.40	5.23	3
01 Oct – 07 Oct	40	31.14	21.11	80.57	58.71	1.10	6.07	5.06	1.11	4
08 Oct – 14 Oct	41	31.69	21.13	77.00	50.29	0.76	7.13	4.83	0.40	2

Appendix-II contd….

Month	SMW	Temperature (^0C)		Relative Humidity (%)		Wind velocity (km/hr)	Sunshine (hr)	Evaporation (mm)	Rainfall (mm)	No of rainy days (days)
		Max.	Min.	Mor RH-I	Eve RH-II					
15 Oct – 21 Oct	42	28.26	18.57	81.57	67.71	1.44	5.03	3.60	7.49	3
22 Oct – 28 Oct	43	25.71	20.80	87.14	79.57	1.36	2.44	1.66	20.26	6
29 Oct – 04 Nov	44	30.43	20.97	84.00	58.57	1.09	6.13	4.97	0.57	2
05 Nov – 11 Nov	45	31.09	18.41	76.14	46.14	0.60	9.03	5.46	3.34	2
12 Nov – 18 Nov	46	29.69	16.74	73.00	48.00	0.86	7.54	5.60	0.00	0
19 Nov – 25 Nov	47	30.04	15.21	74.00	45.29	0.34	7.77	5.44	0.00	0
26 Nov – 02 Dec	48	30.47	15.93	73.86	44.29	0.26	7.29	4.96	0.00	0
03 Dec – 09 Dec	49	28.77	16.41	71.14	46.86	0.27	5.43	4.91	0.00	0
10 Dec – 16 Dec	50	29.66	16.34	74.29	42.00	0.27	7.37	4.89	0.40	1
17 Dec – 23 Dec	51	28.00	15.84	78.57	46.86	0.40	5.10	4.29	0.00	0
24 Dec – 31 Dec	52	27.10	16.65	79.63	48.38	0.83	4.36	4.15	0.18	1
01 Jan – 07 Jan	1	27.00	12.03	80.86	49.00	1.33	6.76	4.66	0.00	0
08 Jan – 14 Jan	2	25.86	13.80	82.86	47.43	0.97	6.71	4.41	0.00	0
15 Jan – 21 Jan	3	25.14	11.89	83.14	43.14	0.77	8.06	4.56	0.00	0
22 Jan – 28 Jan	4	30.20	15.31	83.29	33.14	0.69	8.69	4.89	0.00	0
29 Jan – 04 Feb	5	27.37	12.89	79.57	39.71	1.07	8.89	4.96	0.00	0
05 Feb – 11 Feb	6	28.09	13.93	80.86	43.14	2.20	7.63	4.80	0.00	0
12 Feb – 18 Feb	7	30.34	16.34	81.43	33.71	0.80	7.57	4.64	0.00	0
19 Feb – 25 Feb	8	33.49	16.89	73.00	25.29	0.93	9.30	6.23	0.00	0
26 Feb – 04 Mar	9	32.38	14.11	74.88	22.00	1.71	9.46	5.65	0.00	0
05 Mar – 11 Mar	10	31.03	14.69	73.00	28.29	2.39	8.60	6.07	0.00	0
12 Mar – 18 Mar	11	32.51	15.90	67.71	26.71	1.57	8.51	6.20	0.00	0
19 Mar – 25 Mar	12	34.40	17.41	71.57	25.29	1.36	8.77	7.81	0.00	0
26 Mar – 01 Apr	13	34.20	20.24	75.29	32.14	1.39	7.33	6.69	3.34	3

Appendix-III : Quetionnaire (Format of pesticides usage pattern for management of grape mealybugs in Western Maharashtra)

Department of Agricultural Entomology, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. – Ahmednagar, Maharashtra - 413 722 (India)			
1.	Name of farmer		
2.	Address		
3.	Mobile No. of farmer		
4.	Survey No./Gut No.		
5.	Total cultivable land		
6.	Area under grape crop		
7.	Variety		
8.	Age of orchard		
9.	Yield/ha		
10.	Export/Local market		
11.	Area under other crop/s		
12.	Pest occurrence		
	i.	Mealybug	
	ii.	Thrips	
	iii.	Stem borer	
	iv.	Other	
13.	Insecticides used against mealybug		
14.	Volume of spray		
15.	No. of sprays		
16.	Frequency of interval		
17.	Do you know about recommended insecticides in grape?		
18.	How do you measure pesticides? (bottle top/ approximately)		
19.	How do you mix the pesticides in the water? (bare hands /sticks)		
20.	Which appliances do you use to spray pesticides?		
21.	Do you know about safe waiting period?		
22.	Do you know about label claim?		
23.	Do you know about effects of pesticide residues?		
24.	Do you know about ETL of pests?		
25.	Information on application of bio-pesticides. (if any)		
26.	Do you know about natural enemies		
27.	Do you use any mobile application for getting information on pest management?		
28.	Source of information for recommended pesticides – Agril.Dept/Neighbour/Media/Dealers/Scientists/University		
29.	Signature and name of farmer		Date : Place :
30.	Signature of surveyor and name		

8. VITAE

Mr. PAWAR UDAY ANIL

DOCTOR OF PHILOSOPHY (AGRICULTURE)

IN

AGRICULTURAL ENTOMOLOGY

2023

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