MANAGEMENT OF GREEN PEACH APHID, *MYZUS PERSICAE* (SULZER) (HEMIPTERA: APHIDIDAE), IN POTATO CROP

BY

MUHAMMAD ANWAR KHAN

A thesis submitted to Khyber Pakhtunkhwa Agricultural University Peshawar in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY (PhD) IN AGRICULTURE
(PLANT PROTECTION)

DEPARTMENT OF PLANT PROTECTION
FACULTY OF CROP PROTECTION SCIENCES
KHYBER PAKHTUNKHWA AGRICULTURAL UNIVERSITY
PESHAWAR-PAKISTAN
JULY, 2010

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ABBREVIATIONS

Adr(R)	Reduced dose of Admire 2F ‘imidacloprid as a soil routed insecticide’
Adr(R)+Yp	Adr(R) + yellow water pan traps
FR*A*	Fecundity rates of the mature female of *Aphidius spp*
GLW	Green lacewing; *Chrysoperla spp*
GPA	Green Peach Aphid “*Myzus persicae* (Sulzer) (Hemiptera: Aphididae)”
IPM	Integrated Pest Management
LBB	Ladybird beetles; Coccinellids
NE	Natural Enemies ‘naturally occurring biological control agents’.
PER*A*	Percent emergence rates of the parasitoid ‘*Aphidius*’ from parasitized *M. persicae* mummies
Pgs	Plant Growth Stages (days after seeds germination)
PPA*A*	Percent parasitism of GPA by its parasitoids ‘*Aphidius spp*’
Pr(R)	Reduced dose of Provado 1.6F ‘imidacloprid as a foliar insecticide’
Pr(R)+Yp	Pr(R) + and yellow water pan traps
Yp	Yellow water Pan trap (used to attract and trap *M. persicae*)

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ACKNOWLEDGEMENTS

Thanks are extended to Professor Dr. Naseer Husssain (Rtd) Ex-Dean Faculty of Crop Protection and Ex-Chairman/founder of the Department of Plant Protection with whom I got through my first theory course and thus laid the foundation of my PhD. Moreover, even after his retirement, he continuously motivated me and edited my thesis. The second brick of my PhD foundation was honored by Professor Dr. Ahmad-Ur-Rahman Saljoqi Chairman Department of Plant Protection who shouldered the responsibility of my Supervisor-ship when I was about to quit this course for domestic reasons. His patience and technical guidance in conducting experiments and thesis writing are highly appreciated.

Statistical guidance/learning provided by Professor Dr. Zahid Hussain Chairman Department of Mathematics/Statistics/Computer-Science and Associate Professor Dr. Yousaf Hayat of the same Department can't be forgotten. Professor Dr. Jamal Khan Department of Soil Science, Professor Dr. Iftikhar Khalil Department of Plant Breeding and Genetics, Dr. Sanaullah Khattak Ex-Director Nuclear Institute for Food and Agriculture (NIFA) and Professor Dr. Imtiaz Ali Khan Department of Entomology also extended technical guidance in thesis writing/editing.

Gratitude is expressed to all sitting and Ex-personnel of administrative organs especially Director Advanced and Research Studies, Dean Faculty of Crop Protection and Chairman Department of Plant Protection for their cooperation and giving me enough time without which I might not have succeeded to complete this course.

I am grateful to all my friends, colleagues and relatives who were regularly motivating and praying from the core of their hearts for my success in getting this degree. I am also grateful to my wife for her untiring patience and constant motivation.

Muhammad Anwar Khan

ABSTRACT

Research experiments were conducted in Khyber Pakhtunkhwa province of Pakistan during 2007-09 to develop an IPM package for green peach aphid, *Myzus persicae* (Sulzer), in potato crop, having minimum adverse/detrimental effects on its natural enemies including ladybird beetle, syrphidfly and green lacewing. Parasitized *M. persicae* mummies, percent parasitism of *M. persicae* by the *Aphidius* (PPA*A*), percent emergence rate of the *Aphidius* from *M. persicae* mummies (PER*A*), and fecundity rate of the *Aphidius* (FR*A*) were explored. Initially, impact of three different agro-climatic locations/zones, seasons and nine potato varieties were compared for abundance of *M. persicae* and its natural enemies. Varietal resistance to *M. persicae* was re-confirmed through antibiosis test. Later, two foliar [Provado 1.6F (imidacloprid) and Actara 25WG (thiamethoxam) and two soil routed insecticides [Admire 2F (imidacloprid) and Platinum 2SC (thiamethoxam)], in separate experiments, were tested at labeled and reduced doses (by 20%) on resistant Kuroda and susceptible Desiree varieties for their impact on the corresponding parameters and yield. Lastly, yellow water pan traps and reduced doses of Provado and Admire were compared alone and in combinations on Kuroda and Desiree with same objectives.

The mean populations of *M. persicae* and its natural enemies during spring were much higher than fall, in all the locations. During spring, the mean population of *M. persicae* was highest at Mingora and lowest at Malakandair. During fall, it was highest at Malakandair while at Mingora and Abbottabad it was statistically equal. During spring, the ladybird beetle population at Abbottabad was higher than Malakandair while at Mingora it was statistically equal to both the locations. During fall, it was significantly higher at Malakandair than Abbottabad and Mingora that were statistically equal. Averaged over seasons, syrphidfly population was significantly high at Abbottabad and low at Malakandair; green lacewing population at Abbottabad was higher than Malakandair while at Mingora it was statistically equal to both the locations. Population of parasitized *M. persicae* mummies during each season was statistically equal at Abbottabad and Mingora but higher than Malakandair. In each location; the populations of *M. persicae* and its natural enemies were gradually building up till Day 60 during spring and Day 45 of the seeds germination during fall, thereafter they started decreasing up to Day 75 i.e. crop maturity. Among the potato varieties, in each location during spring, Kuroda and Desiree responded as the most resistant and susceptible to *M. persicae* population build up, respectively. During fall; the varieties did not differ for this parameter at Abbottabad and Mingora while at Malakandair both varieties responded similar to spring. Antibiosis test, during spring at Malakandair, gave similar results wherein the r_m value for *M. persicae* was highest on Desiree and lowest on Kuroda.

Taking into account all the experiments; the mean populations of *M. persicae* on Kuroda control plants was lesser than Desiree by 49.9-45.8% while the ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A* were higher 13-4.4, 61.6-35.4, 32.1-19.8, 46.9-39.6, 54.1-17.8, 9.0-4.3 and 27.9-13.2%, respectively. Considering the population difference as a parameter, in foliar experiments the imidacloprid reduced dose was less toxic to *M. persicae* than its labeled dose but significantly more toxic than both the doses of thiamethoxam. At the same time its reduced doses were significantly less toxic to natural enemies than its labeled dose and both the doses of thiamethoxam. Soil routed experiment gave similar results except that for *M. persicae* and FR*A* this interaction was not significant. Excluding the difference among control plants; the foliar and soil routed insecticides (at an average) reduced *M. persicae* on

Kuroda more than Desiree by 0.5 and -7.3%, respectively, while the corresponding natural enemies were observed at reduced number by 4.9 and 9.3, 10.6 and 26.5, 12.6 and 29.0, -0.4 and 3.3, 1.0 and -3.0, 5.8 and 5.8, 0.0 and -11-6%, respectively. The difference between labeled and reduced doses of foliar insecticides, to reduce *M. persicae* population, on Kuroda was 5.7% and for De it was 4.8%; while for soil routed insecticide this interaction was not significant. Kuroda vs Desiree comparison (on each formulation) showed that Kuroda treated with reduced doses was next to Kuroda treated with labeled doses; however, had smaller mean population of *M. persicae* than the Desiree treated with labeled doses.

In foliar experiment; Kuroda treated with reduced doses was the least toxic, Kuroda treated with labeled and Desiree with reduced doses were nearly equally toxic whereas Desiree with labeled doses was the most toxic to natural enemies. In soil routed experiment; Kuroda treated with Admire reduced dose had significantly highest population of ladybird beetle than all other treatments except Kuroda and Desiree control plants. Kuroda treated with reduced dose of Admire and Control (being statistically equal) had significantly highest populations of syrphidfly and green lacewing than other treatments including Desiree control plants. Minimum numbers of ladybird beetle, syrphidfly and green lacewing were recorded on Desiree treated with labeled dose of Platinum. Population of parasitized *M. persicae* mummies on Kuroda treated with reduced doses was statistically smaller than Kuroda control but significantly highest than all other treatments including Desiree control. Kuroda control and Desiree treated with reduced doses (being statistically equal) had significantly higher PPA*A* and PER*A* than Kuroda and Desiree plants treated with labeled doses; however, maximum were recorded on Kuroda control followed by Desiree control plants. Highest yield in both the experiments was obtained from plant treated with labeled and reduced doses (being statistically equal) of imidacloprid than thiamethoxam and lowest from control plants. At an average; Kuroda delivered significantly higher yield than Desiree.

The last experiment; as per significant interactions, showed that Kuroda treated jointly with Provado reduced dose and yellow water pan traps was the most effective to reduce *M. persicae* as compared to least effective treatment that was Desiree Control. Highest population means of ladybird beetle next to yellow water pan trap and Control (being statistically equal) was recorded on plants treated with Provado reduced dose + yellow water pan and reduced doses of Provado or Admire (being statistically equal). Yellow water pan traps, Control, and plants treated with reduced dose of Provado + yellow water pan traps (being statistically equal) had significantly highest populations of syrphidfly and green lacewing than other treatments. Highest means of parasitized *M. persicae* mummies, PER*A* and FR*A* were recorded on Kuroda treated with Provado reduced dose or jointly with yellow water pan traps (being statistically equal); except Kuroda control with or without yellow water pan trap. Kuroda plants treated with Provado reduced dose + yellow water pan, and Kuroda control had significantly highest PPA*A* than all other treatments except Kuroda plants treated with yellow water pan traps. Minimum numbers of the natural enemies were recorded on Desiree plants treated with Admire reduced dose or carrying yellow water pan traps. Maximum yield was obtained from Kuroda treated with Provado reduced dose + yellow water pan traps and minimum from Desiree control plants.

These findings indicated that resistant potato variety ‘Kuroda’, treated with yellow water pan traps and Provado 1.6F reduced dose was the better IPM package to manage *M. persicae* with minimum adverse/detrimental impact on its associated natural and enhancing tuber yield significantly.

Chapter 1

GENERAL INTRODUCTION

1.1 POTATO IMPORTANCE

Pakistan is self-sufficient in potato (*Solanum tuberosum* L) production and relies more than 99% on local produce. It is the fourth most important crop by volume of production and high returns to farmers. In Pakistan it is grown on area of 133,400 hectares with total production of 2.6 million tons at an average yield of 20 tons/hectare. Pakistan has three main growing seasons of potato i.e. spring (Jan-Feb), summer (March-May) and autumn (Sep-Oct). Climatic conditions in Khyber Pakhtunkhwa Province are conducive to growth of all three crops of potatoes and is cultivated on 96,000 hectares with an average yield of 13.5 tons/hectare that lead to a total productions of 1,29,600 tons (MINFAL, 2008).

Several factors hinder potato production that includes lack of certified pest/virus free and quality seeds, multi-cropping techniques, land preparation, irrigation, crop rotation etc. High cost of production and meager credit facilities to purchase the costly inputs like fertilizers and seeds are other constraints. As, only seeds procurement contributes to about 35-40% of the total cost of production. Poor post harvest handling, high cost of transportation/marketing, and price fluctuations as the production moves from glut to shortage, continuously disparage the farmers. All these obstacles lead the farmers to rely on poor quality management techniques, especially related to pests (PARC, 2009).

Pest related issues include many diseases like late blight, mycoplasma, rhizoctonia, verticillium, scab, softrot and nematode diseases that are common. Up to 70% and 45% yield losses have been reported due to late blight and mycoplasma, respectively, in Punjab (PARC, 2009). Among insects, the Colorado potato beetle and the green peach aphid are the serious pests that produce heavy losses to potatoes (Mowry, 2001).

1.2 *MYZUS PERSICAE* (SULZER)

The green peach aphid (GPA), *M. persicae* (Sulzer) (Hemiptera; Aphididae), is worldwide pest with wide host range that includes plant species of about 40 plant families, especially the Brassicaceae, Solanaceae and Asteraceae (Blackman and Eastop, 2000). The *M. persicae* infests plants in fields and greenhouses that allows its high levels of survival in areas with inclement weather, and favors ready transport on plant material. It is common on seedlings, young plants, and lower leaves of older plants.

The aphid infestation leads to a reduction of the phloem sap appetency and that a first infestation may influence further aphid colonization (Brunissen *et al.,* 2006). The *M. persicae* can attain high densities on young plant tissue, causing water stress, wilting, and reduced growth rate of the plant. Lengthened aphid infestation can cause reduction in yield of root and foliage crops. Early season infestation is particularly damaging to potato, even if the aphids are subsequently removed (Petitt and Smilowitz, 1982). Extensive feeding by *M. persicae* causes distortion of young leaves and shoots, premature dropping of fruit and subsequently yield losses (Mau and Kessing, 1991; Karimullah *et al*. 1995a; Karimullah *et al.* 1995b, Saljoqi and van Emden, 2003b; Saljoqi, 2009).

The *M. persicae* is found as virus vector, spreading diseases among many crops throughout the world (Blackman and Eastop, 2000). Nymphs and adults are equally capable of virus transmission, but adults by virtue of being mobile probably have greater opportunity for transmission (Namba and Sylvester, 1981). The main viruses infecting the potato crop are; Potato Virus A (PVA), Potato Virus X (PVX), Potato Virus Y (PVY), Potato Virus S (PVS), Potato Leaf roll Virus (PLRV). Amongst these PVY and PLRV are the most destructive. Yield losses in potato due to PVY and PLRV ranged 13.9-20.1 and 7.5-15.7 percent in autumn season and 44.0-52.2 and 38.8-60 percent in spring, respectively. As such, the proper variety and virus free seed stock is essential, failing which crop yield is reduced by more than 50 percent (Sjekhawat, 1990; Capinera, 2001).

1.3 INTEGRATED PEST MANAGEMENT (IPM) OF *M. PERSICAE*

In IPM more than one control techniques are integrated that include using pest resistant varieties, encouraging naturally occurring biological control agents i.e. natural enemies (NE), cultural management techniques, mechanical and physical devices, changing the habitat to make it incompatible with pest development and selecting pesticides with a lower toxicity to humans and non-target organisms (Hapter, 2007).

Virus free seed stock and resistant variety, to insects and pathogens, play a vital role in economical IPM (Edward, 2008). For example, the combination of pest control and resistant potato cv. Diamant give the highest yield (Abdalla *et al.,* 1995). Potato lines appeared to show potential, moderate and no resistance to *M. persicae* (Tobias and Olson, 2006). Resistance to

M. persicae exist among various genotypes due to various mechanisms/components like antixenosis, antibiosis and tolerance that involve physical and chemical barriers like trichomes, leaf surface/plant tissues, lectins, glycoalkaloids etc. Antixenosis incorporate the avoidance of plant species by the pests either due to color or hairiness/trichomes or olfactory/visual cues etc; antibiosis include the adverse effect of plant specie on the pests survival, development time, fecundity and slowing down the intrinsic rate of population increase (r_m) of the insects; while tolerance involve the ability of the plant to withstand and/or repair damage from insect infestation (Kogan and Ortman, 1978; van Emden, 1987; van Emden, 1989; Kanrar *et al.,* 2002; Goundoudaki *et al.,* 2003; Saljoqi *et al*., 2003; Sauvion *et al.,* 2004; Vargas *et al.,* 2005; Alvarez *et al.,* 2006; Agarwala *et al.,* 2009).

Genetic transformation to enhance crop resistance or tolerance against biotic constraints have potential for more sustainable food production in less-developed areas where agrochemicals are frequently inaccessible or unaffordable to farmers (Sharma and Ortiz, 2000; Sharma *et al.,* 2001). Genetically modified (GM) crops do have the potential to augment biological control and reduce pesticide use but its compatibility with natural enemies needs careful examination, as some traits affect the natural enemies (Sutherland and Poppy, 2004; (Simmons and Gurr, 2006).

Purposefully enhancing the activities of natural enemies to manage pests is the foundation point for sound IPM. The IPM strategy, in which natural enemies (parasites, predators and pathogens) and other alternative measures are included, can contribute to a more sustainable management approach (Boiteau *et al.,* 1995; Cloutier *et al.,* 1995). The natural enemies like syrphidfly, parasitoids, coccinellids, chrysopids and entomopathogenic fungi reduce aphid numbers by up to 68% (Karley *et al.,* 2003). Several species of genera *Aphidius, Diaeretiella, Ephedrus, Lysiphlebus,* and *Praon* are parasitoids of *M. persicae* (Pike *et al.,* 2000). Each wasp is suited to a particular type of aphid and greenhouse situation (Moschetti, 2003). The predators are lesser efficient than parasitoids against *M. persicae*, however, their combined utilization gives extra protection (Wieth-off *et al.,* 2002). However, natural enemies rarely control high field populations of aphid in spring or fall crops (Natwick *et al.,* 2002).

Most of the management tools to control aphids, especially the insecticides, are highly disruptive to natural enemies (Godfrey and Haviland, 2003); consequently, its usage may be regarded as the last resort in IPM. The empirically established threshold for *M. persicae* on potato in New Brunswick is 25 aphids per 3 compound leaves per plant (Edward, 2008);

however, it is varied in literature depending on the related parameters and cost benefit ratio. Pesticides, no matter how good it is, have non-target adverse effects and are thus extremely important in predator/prey systems for IPM (Dent, 2000). Dramatic increase in the aphid population is noted in potato following an insecticide application that leads to the aphid management primarily by insecticides (Radcliffe, 1998). However, selective insecticides allowed conventional growers to achieve predator densities similar to those seen in organic fields (Koss *et al.,* 2005).

Yellow sticky strings/boards or yellow water pans that attract and trap *M. persicae* are generally used to monitor its flights time, dispersal and redistribution. In general, decision for control is based on the occurrence of sudden and significant increases in the abundance of *M. persicae* on potato plants or in monitoring traps. As an indication of when leaf roll may begin to spread within the crop, New Brunswick uses a threshold of five cumulative catches in any yellow water-pan trap during the season (County, 2007; Edward, 2008). No information regarding direct impact of these traps on management of *M. persicae* has been traced. However, in this study an attempt is being made to explore the efficacy of these traps in this direction were assessed.

1.4 THE RESEARCH AIMS

It is manifest that the application of appropriate integrated pursuit of management tactics includes pest/virus free seeds, cultivation of resistant varieties and traps (trap crops or yellow water-pan or yellow sticky strings/cards/boards) being compatible with the natural enemies. The IPM is associated with close monitoring of pest population and decision rules based on pest density. Since IPM considers natural enemies as the fundamental sources of mortality to insect pests, therefore, the last remedy i.e. the prioritization and application of insecticides needs extra care. The selective pesticides are comparatively less damaging to natural enemies (Follas and Bland, 1994; Kogan, 1998; Bates *et al.,* 2005; Bernal, 2008). Moreover, selective insecticides at lower doses on resistant varieties are more effective against pests/*M. persicae* development than on susceptible varieties and encourage the development of natural enemies (Shean and Ranshaw, 1991; Saljoqi and van Emden, 2003a; Saljoqi and van Emden, 2003b, Moschetti, 2003; Galvan *et al.,* 2005; Koss *et al.,* 2005; Felsot, 2001). In light of these facts, the research study in hand was an attempt to analyze integration of various techniques against *M. persicae* in potato crop that have minimum adverse effects on its natural enemies and may be readily acceptable, pickable, affordable and implementable for the poor farmer community to achieve goals with precision and sustainability.

To achieve this goal, series of experiments were conducted during 2007-09. Initially, the impact of different agro-ecological and agro-climatic locations, seasons and potato varieties was assessed on development of *M. persicae* population. The varieties were re-evaluated through antibiotic test for relative resistance to *M. persicae*. Thereafter, two foliar and two soil routed insecticides (in separate experiments) were tested at labeled and reduced doses (labeled dose reduced by 20%) against *M. persicae* on two potato varieties, evaluated as the comparatively resistant and susceptible in the initial two experiments. Finally, based on findings of these experiments; the foliar insecticide, soil routed insecticide (at favorable doses) and yellow water pan traps (Yp-traps) as individual treatments and in combinations were compared on the same two potato varieties. The results were based on objectives of the concerned experiments; on maximum reduction of *M. persicae* population, development time of aphid from birth to reproduction, the number of nymphs reproduced by aphid, the intrinsic rate of multiplication 'population increase' (r_m); and minimum adverse impact on its natural enemies {predators (ladybird beetle, syrphidfly, green lacewing) and parasitoid (parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A*)}.

The research study envisaged the following **objectives**:

1) To study the impact of different agro-climatic zones, seasons, and potato varieties on the population trends of *M. persicae* and its associated natural enemies.
2) To evaluate potato varieties for resistance to *M. persicae*, using antibiosis test.
3) To investigate the interaction effect of resistant and susceptible potato varieties treated with labeled and reduced doses of foliar insecticides in management of *M. persicae* with minimum adverse impact on natural enemies and its impact on tubers yield.
4) To study the interaction effect of resistant and susceptible potato varieties treated with labeled and reduced doses of soil routed insecticides in management of *M. persicae* with minimum adverse impact on natural enemies and its impact on tubers yield.
5) To analyze the interaction effect of foliar insecticides, soil routed insecticides, yellow water pan and their combinations on partially resistant and susceptible potato varieties, to mark the best IPM strategy against *M. persicae* with minimum adverse impact on natural enemies and its impact in enhancing potato yield.

Chapter 2

RIVIEW OF LITERATURE

2.1 *MYZUS PERSICAE* (SULZER)

M. persicae eggs are elliptical, initially yellow or green that soon turns black and measure about 0.6 mm in length and 0.3 mm in width. The nymphs are pale yellowish-green in color with three dark lines on the back of abdomen that are not present on the adult. Stem mothers that appear in the spring and fall are deep pink. The developing adult of *M. persicae* is 1.2 to 2.5 mm in length and egg-shaped. The cornicles are moderately long, unevenly swollen along their length, and match the body in color. The appendages are pale. The bases of the antennae have prominent, inwardly directed tubercles. Wingless (apterous) adults vary in color from light green to pale yellow with a medial and lateral green stripes and are almost translucent. Winged (alate) adults have a black or dark brown head and thorax, and yellowish green abdomen with a dark dorsal patch in its center **(**Toba, 1964; Howitt, 1993; Edward, 2008). Keys to identification of *M. persicae* and many other common aphids are published by Blackman and Eastop (1984) and Stoetzel *et al.* (1996).

M. persicae has two main life cycle; anholocycly and holocycly. Anholocyclic *M. persicae* are female and continuously reproduce parthenogenetically. Adults may be winged or wingless. Winged form increases with degree of crowding and lowering of nutritional host's quality and facilitate escape from deteriorating hosts to other host plants of the same or related species. Holocyclic *M. persicae* break the sequence of parthenogenetic generations once a year in response to increasing length of night in autumn. This results in winged females that fly from summer host plants in search of *Prunus persica* (peach) on which sexual females are produced. These mate with winged males arriving from summer host and produce eggs that are much more tolerant of low temperature than the active forms. Eggs hatch in spring. After a generation or two following egg hatch, winged forms are produced on winter host plants and these winged forms return to summer host plants. On summer hosts, wingless and winged forms are produced as in case of anholocyclic aphids. Thus, there are potentially three migratory events in a year. The first in spring, as aphids move from winter to summer host plants, the second as aphids redistribute on summer host plants and the third as aphids return to the winter host plants. The prevalence of two life cycle types varies geographically. Anholocycly dominates where winters are warm and is the only option where peach is absent. Holocycly is the only option where winters are very cold, but it also occurs in areas that have warm winters but an abundance of peach. Thus, depending on location; one, two or three migratory periods may usually be discernible when viewing the overall flight curves for a year (Blackman and Eastop, 2000). Length of the *M. persicae* life cycle varies from 18 to 50 days depending on geographical location, climate, temperature, life cycle and plant host (Toba, 1964).

2.2 IMPACT OF ENVIRONMENT AND NUTRIENTS ON *M. PERSICAE*

Climate, season, temperature, land use and geographical location determine the range, development, survival, abundance and phenology of *M. persicae*. Numerous interactions between these factors make it difficult to identify and relate the processes involved in such relationships (Bale *et al.,* 2002; Karley *et al.,* 2003; Cocu *et al.,* 2005). The impact of these factors is further realized while reviewing/comparing the varied population trend of *M. persicae* in various locations during different parts of the year as reported by Bhadauria *et al.,* 1998; Misra and Agrawal, 1998b; Pinto *et al.,* 2000; Karley *et al.,* 2003; Kabaluk *et al.,* 2006. Elevated ozone levels (250 ppm) result in higher fecundity, and an earlier and larger reproduction rate of *M. persicae* (Schutz and Hummel, 1997). Elevated temperature decreases final plant biomass while leaf nitrogen concentrations are increased. Aphid abundance is enhanced by CO_2 and temperature. As such, *M. persicae* abundance may increase under conditions of climate change (Bezemer *et al.,* 1998). Alate aphids population (of 25 different species, *M. persicae* being the most common) on potato cultivar found during summer is 14 times more as compared to winter (Lauderdale, 2005).

The population of *M. persicae* shows a correlation with rainfall and the plant phenology i.e. number of leaflets/leaf (Pinto *et al.*, 2000). The absence of rain contributes to regulate the number of aphids on winter potato crop. An increase of 0.4 °C in temperature advance the flight of the aphid species by 5–6 days (Fleming and Tatchell, 1995) where as according to Harrington *et al.* (1995) an increase of 1 °C in mean temperature of January–February advanced the timing of the spring migration of *M. persicae* by 2 weeks. In short, global change affect the insect pests status by increasing pest abundance, changing pest interactions with natural enemies, increasing the number of generations in a year, affecting the temporal synchrony of the pests and their hosts or by modifying the geographical range of individual pest (or host) species. Such effects change the impact of pests on crop yields and consequently response strategies such as pesticide use etc (Lawton, 1995).

Appearance of the *M. persicae* may also be associated with plant growth stages (Suarez *et al.,* 1991). *M. persicae* alate females and nymphs appear during the 2nd and 3rd weeks after planting, and adult apterae 1-2 weeks later. Alate adults in traps and nymphs increase during the reproductive stage of the crop and decrease during senescence. In the 2nd generation, winged female population peaks at the beginning of senescence while nymph at the beginning of the reproductive stage. Alatoid nymphs are detected one week after the population peak and two weeks after the onset of tuber development (Narvaez and Notz, 1994).

Cell sap nutrients also influence the aphid population. The *M. persicae* number tends to be higher when plants are fertilized liberally with nitrogen fertilizers (Jansson and Smilowitz, 1986). The combination of lower N and K, and medium P is disadvantageous to its population growth. The nitrogen content of shoots and roots is increased by earthworms that consequently enhances *M. persicae* population, but only in the more enriched nutrient soil (Wurst and Jones, 2003). The soluble carbohydrates, potassium and moisture in rape plants affect significantly the population of *M. persicae* (Zou *et al.,* 1993). Before the *M. persicae* infestation, manure-treated plants of potato produce decreased amounts of foliar glycoalkaloids 'GAs' (the naturally occurring defensive chemicals) compare to the amounts produced by fertilizer-treated plants. During and after the aphid infestation, the manure and fertilizer treated plants do not differ statistically for foliar GAs. The source of available nitrogen to the potato plant does not affect foliar GAs synthesis, and as a consequence, does not affect its endogenous chemical defense against insect herbivory (Fragoyiannis *et al.,* 2000; Fragoyiannis *et al.,* 2001). The onset of crash in aphid numbers is consistently associated with changes in the phloem amino acid composition of potato leaflets (Karley *et al.,* 2003).

The β-glucuronidase expression in potato plants may cause probiotic effect on aphids whereas alteration of the foliage odour results from a pleiotropic effect. The transgenic event may alter aphid physiology or behavior. A probiotic effect of potato cultivar Desiree (DG5 line) reduce pre-reproductive period and mortality, increase daily fecundity and thus a greater population growth potential ($r_m = 0.215$ vs. $r_m = 0.174$ of the control). In contrast, aphids fed with the cultivar DG18 line reduce adult survival and reproductive period but no alteration of their demographic parameters ($r_m = 0.176$). Finally, no physiological alteration is induced in aphids fed on a DG20 ($r_m = 0.170$). Insects are significantly more attracted by the odor of transgenic DG18 potato plant than that of Désirée non-transformed plant, spending twice as much time in the DG18 plant odor. The two other transformed clones (DG5 and DG20) are as attractive as the non-transformed cultivar (Alla *et al.*, 2003).

2.3 VARIETAL/HOST PLANT RESISTANCE IMPACT ON *M. PERSICAE*

The role of varieties/host plant resistance in the management of aphid can't be ignored. Some varieties are comparatively more resistant due to certain inherited or induced traits, for example, the glandular trichomes. Two types of glandular trichomes on foliage of potato cultivars *S. tuberosum* and Dejima are involved in development of resistance. Type A is long hooked trichome with a 4-lobed membrane-bound gland at its apex that exudes an adhesive coating into the tarsi of insects. The insects thus trapped by these trichomes in struggle to free themselves rupture the shorter glandular trichomes (Type B) having an ovoid gland at its tip that results in release of two epoxy components: a resin (chlorogenic acid) and a catalyst (polyphenol oxidase). Insect trapped in the hardening resin die to starvation. Moreover, acetone extracts of glandular trichomes to nymphs and adults highly increase mortality of the *M. persicae*, peaking at 88.3%, 48 and 60 hours after treatment. The foliage of a wild potato species *Solanum berthaultii* Hawkes is protected from *M. persicae* by glandular trichomes. The insect eggs, larvae, or adult mortality occur after contact with plant trichomes (Tingey and Laubengayer, 1981; Lee *et al.,* 1999). Antixenotic stimuli to *M. persicae* on clones of the wild potato *S. berthaultii* show that clones with glandular trichomes are the least preferred and host selection behavior is probably influenced by volatile compounds present in the exudates of trichomes (Moraes *et al.,* 1995).

Host specialization in aphids may involve not only different performances on potential hosts, but also different strategies for host selection and acceptance. The subspecies *M. persicae nicotianae* shows a preference for tobacco, while *M. persicae sensu stricto* for other herbaceous plants. The winged colonizers aphids play an important role in selecting host plants. During outdoor choice tests 77% of spring migrants of *M. persicae n* chose tobacco, whereas equal proportions of *M. persicae s. str.* select tobacco and pepper. In no-choice tests studies, winged aphids distinguished their host through cues located on the plant surface or in subcutaneous tissues perceived prior to the initiation of feeding. Host recognition is evident before phloem tissues are contacted (Margaritopoulos *et al.,* 2005; Vargas *et al.,* 2005). The study on settling behavior and bionomics of the *M. persicae* show that nymphs placed on resistant peach cultivars leave the plants or die within 4 days while the susceptible or less favorable are accepted as host-plants (Sauge and Monet, 1998).

Some potato varieties significantly reduce the longevity and reproductive capacity, post-reproduction periods, gonad embryos, fecundity rate, and the intrinsic rate of natural increase (r_m) of *M. persicae* (Narvaez and Notz, 1993; Sauge and Monet, 1998; Saljoqi *et al.,* 2003) that result in minimum mean population of *M. persicae* per 50 leaves, e.g. 22.7 and 46.3 on Dejima and Superior potato cultivars, respectively (Min *et al.,* 1997). The duration of the nymphal phase is significantly longer on potato than on sesame. In pre-flowering plants, the duration of total lifespan is significantly longer on the upper strata; while in flowering plants the duration of the nymphal stage is significantly longer in the lower strata. The pre-reproduction period is 1.4±1 days on both food plants. The reproduction, post-reproduction periods, longevity and fecundity is significantly smaller on potato (Narvaez and Notz, 1993). The aphid probing behavior shows that resistance is linked to difficulties either in reaching the phloem, in initiating sap uptake or in sustaining food ingestion (Sauge and Monet, 1998).

Some genotypes develop small colonies of *M. persicae* and others develop large ones. Also, in a few genotypes, resistance in mature plants is different for leaves of different ages; young leaves are resistant to aphids whereas old senescent leaves are susceptible. Electrical penetration graph (EPG) show large differences among the genotypes, indicating resistance at the leaf surface and at three different levels of plant tissue including epidermis, mesophyll, and phloem (Alvarez *et al.,* 2006). The *M. persicae* clones performed better on Oriental than on Virginia varieties. Aphids on Virginia varieties showed longer developmental time (9.1-9.6 days), a lower intrinsic rate of increase (0.23-0.26) and higher nymphal mortality (27.9-52.5%) than on Oriental varieties (Goundoudaki *et al.,* 2003).

2.4 IMPACT OF PREDATORS ON *M. PERSICAE*

The management techniques in which preservation of natural enemies are given due importance may contribute to a more sustainable approach in potato production (Boiteau *et al.,* 1995; Cloutier *et al.,* 1995). NE like *Cycloneda sanguinea* Linnaeus and *Condylostylus erectus* Becker, Coccinellids, Syrphidae and Braconidae are quite effective against *M. persicae* (Miranda *et al.,* 1998). In some cases potato cultivation without the application of insecticides is possible. For example, in insecticides treated plots the resurgence of *Aphis gossypii* Glover was recorded due to the elimination of its natural enemies, as in the control plot no outbreak of *A. gossypii* (or any other aphid species) occurred due to its suppression by indigenous predators (like ladybirds, lacewings, Orius bugs). Consequently, the tuber yield and the starch value were comparable to the treated plants (Ito *et al.,* 2005).

Manipulating diversity, both within a guild of predatory insects (one versus four predator species) and among their herbivore prey (one versus two aphid species), showed that the aphid suppression increase with greater predator biodiversity. But, independent of prey species diversity or identity, and no niche differentiation by aphid species is visible among the predator species. It suggests that either niche partitioning among predators occur without based on prey species identity or benefits of predator diversity; for biological control are mediated by interactions within the predator community, such that a diverse resource base is not necessary to yield a positive relationship between predator biodiversity and effective herbivore suppression (Snyder *et al.,* 2008).

2.4.1 IMPORTANCE OF LADYBIRD BEETLE IN IPM OF *M. PERSICAE*

The family Coccinellidae contains over 4000 species and almost all are predators that feed on different kinds of soft-bodied insects (Hodek and Honek, 1996). The seven spotted ladybird beetle (*Coccinella septempunctata* Linnaeus), the twelve spotted lady beetle [*Coleomegilla maculate* (DeGeer)], the convergent lady beetle (*Hippodamia convergens* Guérin-Méneville) and the two-spotted lady beetle [*Adalia bipunctata* (Linnaeus)] are examples of coccinellids. Ladybird beetles are attracted to and feed heavily on aphids, but many species also feed opportunistically on other prey that they encounter. In potatoes coccinellids feed on *M. persicae* and eggs of the Colorado potato beetle *Leptinotarsa decemlineata* Say “CPB” (Moschetti, 2003). Hibernating and reproductive ladybird beetle adults simultaneously coexist in the same habitat in winter. Even though natural substrates are available, the beetle preferred to use artificial substrates such as metal cans, papers, and woods (as thermal microhabitats) to oviposit and pupate, as these are relatively easily warmed by solar radiation. These thermal microhabitats enabled them to complete their development at low ambient winter temperature and to complete an additional generation in winter where prey aphids are abundant (Ohashi *et al.,* 2005).

Peak population development of ladybird beetle occurs at different times during the growing season, depending on the year (Kabaluk *et al.,* 2006). Corn leaf aphid and ladybird beetle populations (*Harmonia axyridis* Pallas, *C. maculata*, and *C. septempunctata*) are aggregated during the peak population period and randomly distributed early and late in the season. Map-correlation analysis, however, shows that the distributions of ladybird beetle do not always coincide with that of corn leaf aphids. None of the environmental factors sampled are significantly correlated with corn leaf aphid and beetles distributions (Park and Obrycki, 2004).

Host types have direct impact on ladybird beetle populations. Presence of variety of crops may influence activity ladybird beetle by providing several types of prey, nectar and pollen sources (Moschetti, 2003). The incubation period, larval and pupal period, male and female longevity, pre-oviposition and oviposition period, eggs laid per female and hatching percentage of ladybird beetle *Micraspis discolour* (Fabricius) fed on different aphids species and rice pollen show that the suitability of different foods (taking total life time into consideration) is: wheat aphid > maize aphid > bean aphid > rice pollen. The fecundity of *M. discolor* is highest when it is fed with bean aphid although the hatching (%) is better in those eggs that come from the beetles fed on wheat aphid (Hannan *et al.,* 1999). *Brevicoryne brassicae* L. and *Megoura viciae* Buckton are comparatively either toxic to *H. axyridis* or unsuitable hosts for their development as compared to *A. gossypii* (Tsaganou *et al.,* 2004). *Aphis fabae* Scopoli and *M. persicae* are essential prey and support the development and reproduction of ladybird beetle whereas *Aleyrodes proletella* L. (being alternate prey) do not. *M. persicae* significantly decreases the pre-oviposition period and increase adult longevity, fecundity and fertility compared to *A. fabae*. Moreover, *A. fabae* represents a suitable diet for larval development, but is not a suitable food source for adult reproduction. The predator's population growth parameters, R_0, r_m and λ are increased with *M. persicae*, whereas T decreases. The 4th instar larvae are the most voracious, particularly when fed on *M. persicae* (Cabral *et al.,* 2006).

The mustard aphid consumption by ladybird beetle is affected significantly ($P<0.05$) by host density. Aphid consumption increase significantly with increasing host density. Searching distance of ladybird beetle decreases with increase in host density while under field conditions is significantly greater as compared to those under laboratory conditions, because the beetles has unlimited area in the field to move and search freely for their food (Solangi *et al.,* 2007a). Predation on natural populations of soybean aphid (*Aphis glycines* Matsumura) show that transient ladybird beetle, despite relatively short residence time in the observed patches, respond positively to increase in *A. glycines* field densities, exert most of the mortality and have the potential to rapidly respond to changes in aphid density with high per capita rates of predation (Costamagna and Landis, 2007).

Behaviors of ladybird beetle are modified in response to spatial complexity, prey quality, and the host plants. Starved ladybird beetle feed for longer and consume more aphids than the non-starved ones. Both larvae and adults feed on infected aphids and in some cases entirely consume them that may be due to the ease in capture of infected (dead) aphids, the feeding stimuli provided by the presence of the host plant and uninfected aphids (where there was a choice of prey) in the environment. Both larvae and adults spend majority of the time foraging in the upper regions of the plants and visit more plants when they are not starved or when less suitable/infected aphid prey is abundant (Roy *et al.,* 2003). Food specificity affects the effectiveness of ladybird beetle in an aphid infested crop. All the aphid species [*Acyrthosiphon pisum* Harris, *Eucallipterus tiliae*, *Euceraphis betulae* (Koch), *Phorodon humuli* (Schrank) and *M. persicae*) cultured on transgenic Bt and conventional (non-Bt) potatoes are found suitable food for the most abundant ladybird beetle based on the rate of larval development, larval mortality and adult fresh weight. Females of ladybird beetle fed with *M. persicae* cultured on Bt potato, or on non-Bt potato or on a mixture of *M. persicae* from Bt potatoes and *Aphis craccivora* Koch, lay a little more eggs than those fed only with *A. craccivora* (Kalushkov and Hodek, 2005).

Comparison of larval development of native ladybird beetle (*H. convergens* and *Coccinella transversoguttata* Brown) and exotic species (*C. septempunctata* and *H. axyridis*) on a monotypic diet of *M. persicae*, a monotypic diet of CPB eggs, or a mixed diet of both *M. persicae* and CPB eggs show that no larva of any species complete development on a pure diet of CPB eggs, and survivorship is highest for all species when they feed on a pure diet of *M. persicae*. *H. convergens* and *H. axyridis* exhibit significantly lower survivorship on a mixed diet of both CPB eggs and *M. persicae*, compared to a pure *M. persicae* diet. The two *Coccinella* species respond similarly to the inclusion of CPB eggs, and so one may not expect any difference following the replacement of one by another. Overall, no ladybird beetle species benefit from the inclusion of CPB eggs in its diet. However, an introduced species, *C. septempunctata* has invaded and apparently displaced its native congener. A second exotic *H. axyridi* has colonized the area and is becoming more abundant (Snyder and Clevenger, 2004).

2.4.2 IMPORTANCE OF SYRPHIDFLY IN IPM OF *M. PERSICAE*

The syrphidflies also called hover-flies and flower flies (Diptera: Syrphidae) are common and important NE with a significant impact on aphid populations and other small slow-moving insects. Hoverflies have high reproductive rates and voracities, allowing them to efficiently exploit short-lived aphid colonies. Each larva completes its development in two to three weeks by consuming up to 400 aphids. They exhibit high mobility, enabling them to distribute eggs over large areas and to locate aphid colonies earlier in the season than other aphidophaga (Dixon, 2000). The adults feed on pollen and nectar for which they prefer wild carrot or Queen Anne's lace, wild mustard, sweet alyssum, coriander, dill, and other small-flowered herbs. They are attracted to weedy borders or mixed garden plantings that are infested with aphids. They are most noticeable in later half of the growing season, usually when aphid infestations get established. Adults oviposit close to aphid colonies and at relatively low aphid densities (Sadeghi and Gilbert, 2000). No peak in ovipostion relative to aphid is observed. Within individual plants that are colonized by aphids, there are some ovipositions on individual leaves without aphids, and no hoverfly eggs are seen on leaves that have more than 400 aphids. The presence of hoverfly eggs is positively correlated with numbers of aphid species and sampling date (Ambrosino, 2006).

2.4.3 IMPORTANCE OF GREEN LACEWING IN IPM OF *M. PERSICAE*

Several species of Chrysoperla and Chrysopa [Green lacewings 'GLW' *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae)] are voracious predators of aphids, mites and a wide variety of soft-bodied insects, including insect eggs, thrips, mealybugs, immature whiteflies, and small caterpillars. They are slow-flying, nocturnal insect that feeds on nectar and pollen and emits a foul-smelling fluid from special glands if captured. Green lacewing larva (aphidlion) is the actual predator that resembles a green-gray alligator with mouthparts like ice tongs. Later stages of the larvae eat up to 50 aphids per day. Each larva may eat up to 600 aphids until it pupates. They are more effective in low growing crops. The larvae of the green lacewing are extremely efficient and greedy against aphids. The aphidlions travel 80-100 feet in search of prey. Once their food source is exhausted they leave the area. The adults must have a source of nectar, pollen, or honeydew to feed on in the general vicinity of the pest area to stimulate egg laying, or they will leave. An adequate food supply and suitable adult habitat can contribute to green lacewing existence and reproduction in the crop (Mahr, 2000).

Host/food has impact on green lacewing, for example, development of *Chrysoperla rufilabris* (Burmeister) larvae is longer when sweet potato whitefly (SPW), aphids, or an artificial diet alone is provided. However, with a combination of eggs and first instars of SPW and an artificial diet or *Sitotroga cerealella* Olivier eggs, development of larvae is shortened with increased survivorship, adult emergence, and body weight. Larvae of *C. rufilabris* prefer *S. cerealella* eggs over *Helicoverpa zea* Boddie and *Manduca sexta* (Linnaeus) eggs or *Bemisia tabaci* Gennadius (Legaspi *et al.,* 1994). The pre-oviposition, oviposition and post-oviposition period of *C. carnea* is 6.55, 21.10 and 7.95 days respectively when its larvae are reared on *A. gossypii* and 9.25, 21.85 and 11.20 days respectively when reared on *M. persicae*. The fecundity is 84.70 and 103 when *A. gossypii* and *M. persicae*, respectively, serve as larval food and the respective values of incubation period are 2.25 and 3.68 days. The duration of first, second and third instar larva is 2.60, 2.25, 2.38 and 3.75, 2.78 and 3.35 days when reared on *A. gossypii* and *M. persicae*. The pupal period is 9.43 and 11.40 days on *A. gossypii* and *M. persicae,* respectively. The females live longer (35.70 & 38.80 days) than males (32.20 & 35.80 days) on the two respective hosts (Mannan *et al.,* 1997).

2.4.4 INTRAGUILD AND EXTRAGUILD PREDATIONS

The presence of multiple prey species might distract generalists from feeding on any single target pest (Koss *et al.,* 2004). Aphidophagous predators compete for the same prey species. During their foraging activity they frequently encounter heterospecific aphid predators. These situations lead to intraguild predation (Hindayana *et al.,* 2001). The *H. axyridis* is a strong intraguild competitor and have negative impact on other Coccinellids. Egg cannibalism by larvae or adults is most often while the remaining predation events upon Coccinellids eggs are done by other species of Coccinellidae. When *C. maculata* and *Olla v-nigrum* (Mulsant) are grouped as 'native' and compared with the exotic *H. axyridis*, more native eggs are attacked than exotic eggs and a higher percentage of eggs are attacked by *H. axyridis* larvae. Native and exotic larvae attack a similar percentage of native eggs but native larvae attack significantly fewer exotic eggs than did exotic larvae. Therefore, eggs of the native species *C. maculata* and *O. v-nigrum* may continue to be subjected to cannibalism and also to possible predation by other native species and exotic *H. axyridis* (Cottrell, 2004). The addition of an alternative food source reduces egg cannibalism and predation. In the absence of an alternative food source, native coccinellid eggs suffer from both cannibalism and predation whereas, cannibalism is the larger threat to *H. axyridis* eggs (Cottrell, 2005). Introduced specie, *C. septempunctata* has apparently displaced its native congener *H. convergens* and *C. transversoguttata*. A second exotic, *H. axyridis*, has colonized the area and is becoming more abundant (Snyder and Clevenger, 2004).

Interaction of the hoverfly *Episyrphus balteatus* De Geer with three other aphid predators: *C. septempunctata*, *C. carnea*, and *Aphidoletes aphidimyza* (Rondani) shows that the interactions between *E. balteatus* larvae and the other predators depend predominantly on the relative body size of the competitors. Relatively large individuals act as intraguild predators, while smaller individuals became intraguild prey. Moreover, the same species can be both intraguild predator and intraguild prey (Hindayana *et al.,* 2001).

Aphidlions (GLW larvae) consume each other if no other prey is available (Mahr, 2000). *C. carnea* and *C. maculata* larvae while feeding on eggs of leaf beetle *Galerucella pusilla* (Duft), an introduced NE of *Lythrum salicaria* L, have lower survival rates, longer developmental times, and reduced adult weight. *G. pusilla* eggs are not suitable prey for 95% of *C. maculata* larvae, but 37% of *C. carnea* larvae complete development on *G. pusilla* eggs. Utilization of *G. pusilla* eggs by these predators as alternative prey during low availability of prey affect the biological control of *L. salicaria* (Wiebe and Obrycki, 2002). Investigation whether the honeydew-feeding females of the *C. rufilabris* 'GLW' avoid laying eggs in the presence of conspecific eggs, the potential risk associated to cannibalism, show that females are not reluctant to oviposit in the presence of conspecific eggs. However, the larvae show no preference for kin or non-kin eggs that indicates that the risk of egg cannibalism by neonate in the field may be low (Fréchette *et al.,* 2006).

2.5 IMPACT OF PARASITOIDS ON *M. PERSICAE*

Several species of genera *Aphidius, Diaeretiella, Ephedrus, Lysiphlebus,* and *Praon* are parasitoids of *M. persicae* (Pike *et al.,* 2000). Parasitism of aphids by hymenopterans occur at low to moderate levels throughout the growing season (13% of total aphids in visual samples, on average), with peak parasitism appearing toward the end of the growing season in each year (Kabaluk *et al.,* 2006). The parasitoids have significant impact on aphid populations. Each wasp is suited to a particular type of aphid and situation. The aphid parasitoids can also be used in combination with predators, such as GLW lacewings or aphid midges. However, they may not be compatible with entomopathogenic fungi (e.g. *Beauveria bassiana*) that kill the parasite larvae inside the aphid. In general these wasps are sensitive to most insecticides, however many non-residual contact insecticides can be used when aphids are in the "mummy" stage (Moschetti, 2003).

2.5.1 IMPORTANCE OF *APHIDIUS SPP* IN IPM OF *M. PERSICAE*

Aphidius species and their preferred hosts are: *Aphidius matricariae* Haliday (*M. persicae* and related aphids); *Aphidius colemani* Viereck (Melon aphid *A. gossypii*); *Aphidius ervi* (Haliday) [Potato aphid *M. euphorbiae* (Thomas)]. *A. matricariae* parasitizes about 40 aphid species. *Aphidius* is a good searcher, and can locate new aphid colonies even when aphid populations are low. In addition to killing aphids directly, mechanical disturbance of aphid colonies by the searching behavior of the adult wasps causes many aphids to fall off the plants and die. Optimum conditions for its development are daytime temperatures of 18-25 ºC (64-77 ºF) and relative humidity 60-80%. *Aphidius* are not affected by short-day induced diapause, so it can be used year-round. *Aphidius* alone can not provide control when aphid populations are high, but may be used with Aphiloletes to provide control. Effectiveness may be reduced in late summer when *Aphidius* itself are attacked by naturally occurring hyperparasites (Moschetti, 2003).

Females exposed to short day-lengths and low temperatures during their adult life produce more diapausing offspring than those at long-day, high-temperature conditions. Furthermore, maternal age also influence the incidence of diapause in the progeny. A higher proportion of parasitoids developing in first-instar aphid nymphs enter diapause as compared to those developing in fourth-instar hosts. The multiplicity of the factors and the involvement of two generations in diapause initiation of *Aphidius nigripes* Ashmead are considered as adaptations of a multivoltine species with a short developmental time permitting the parasitoid to adequately assess seasonal changes in the environment (Brodeur and McNeil, 1989). In *A. ervi* the incidence of diapause around the critical photoperiod is dependent on temperature. At a photoperiod of 12 hours light:12 hours dark, a significantly higher proportion of diapausing individuals is found at 12°C than at 15°C. The second larval stage of the parasitoid is most sensitive to photoperiod. Experiments show that the parasitoid responds independently of the aphid host. The sex ratio of the population that emerges after rearing in short-days and/or after diapause is male biased (Christiansen-Weniger and Hardie, 1999).

Oviposition of *A. ervi* females ranges between one and four eggs laid per aphid colony (colony size 10 aphids). On isolated host plants, the foraging success of *A. ervi* females is not influenced by simulated “rain” compared to standard conditions. In contrast, simulated “wind” increases the number of oviposition and the oviposition rate because fewer aphids drop off plants during parasitoid attack. Parasitoid dispersal is not prevented by adverse weather conditions. Within a patch of host plants, *A. ervi* females visit most host plants under standard conditions. Only parasitoids that have oviposition experience on the release plant successfully find new hosts after dispersal. In contrast to isolated plants, simulated “wind” and “rain” reduce both parasitoid dispersal and the oviposition rate, demonstrating the importance of habitat structure for the parasitoid's foraging behavior (Schwörer and

Völkl, 2001). Parasitoids move at least 16 m within 24 h after release. Released *A. colemani* remain at the experimental site for at least 3 days. In most cases dispersal is random with regard to compass direction. Prevailing light to moderate wind speed don't influence dispersal of parasitoids (Langhof *et al.,* 2005).

The effect of parasitism by *A. ervi* on the thermoregulatory behavior of *A. pisum* in alfalfa fields shows that mummies are found exclusively on the adaxial surface of the upper leaves, and aphids in the mid canopy. The adaxial surface of the upper leaves is ca. 2°C hotter than the mid-canopy. The thermal effect (selected minus exposure temperature) is found higher in magnitude in non-parasitized than in parasitized aphids; the thermal effects on both types of aphids are linearly and negatively correlated with exposure temperature (i.e. aphids showed negative thermal sensitivity). The thermal sensitivity of parasitized aphids is lower than that of non-parasitized aphids (Lagos *et al.,* 2001).

Soil type affects the dynamics of *A. colemani*; the number of parasitized aphids is increased on plants growing in the enriched soil. Larger parasitoids also emerge from mummies of plants growing in this soil (Wurst and Jones, 2003)**.** The fitness of females of *A. ervi,* the most prevalent primary parasitoid, and the sex ratio of their progeny are not affected when developed while feeding on GM (genetically modified) potato plants (Cowgill *et al.,* 2004). *A. colemani* successfully parasitizes and completes development in *M. persicae* however it could not complete development in five other common aphid species. In host-choice tests, a cohort of a Brazilian *A. colemani* reared on *M. persicae* or on *A. gossypii* both prefer to oviposit on *A. gossypii*, indicating an innate genetic preference for this host. However, the cohort reared on *M. persicae* show a lower degree of preference for *A. gossypii* than the one reared on *A. gossypii*, indicating that epigenetic (conditioning) factors can alter the genetic predisposition to some extent (Messing and Rabasse, 1995). The influence of different morphs of the black bean aphid *A. fabae* on diapause induction in two species *A. matricariae* and *Praon volucre* (Haliday) show that diapause in the parasitoid larvae is initiated by hormonal differences between the tested aphid morphs, independent of environmental cues and maternal effects (Polgár *et al.,* 1991).

Whilst foraging on insect-resistant transgenic plants, aphid parasitoids are at risk from direct and indirect effects of the expression of a transgene used to control the pest species. Lectin (*Galanthus nivalis agglutinin*; GNA) delivered via artificial diet to *M. persicae* has a dose-dependent effect on parasitoid development. Although *A. ervi* development is not affected when developing within hosts feeding on transgenic potato leaves, this probably reflects sub-optimal expression of the toxin in the transgenic potato line used (Couty *et al.,* 2001). Honeydews collected from the various aphid species feeding on potato, wheat, or artificial diet are found to be relatively suitable food sources for adult *A. ervi*, although not always as suitable as a 2 M sucrose solution. The differences in parasitoid longevity can to some extent be explained by carbohydrate composition. The sucrose and its hexode components (glucose and fructose) are very suitable carbohydrate sources for hymenopteran parasitoids (Petra *et al*., 2007).

2.5.2 HYPER PARASITISM AND PREDATION OF PARASITOIDS

The hyper-parasitism has negative impact on primary parasitoids as it reduces their numbers and is detrimental in biological control efforts. *Diaeretiella rapae* MacIntosh while parasitizing *M. persicae* are itself parasitized, up to 90%, mostly by *Asaphes lucens*, *Aphidencytrus aphidivirous*, and/or *Alloxysta spp*. Secondary parasitism is intensified in aphid populations of highest density, not under biological control by Aphidiidae or predators (Horn, 1989). *H. axyridis* could complement aphid biological control by the parasitoid *Aphelinus asychis* Walker rather than disrupting control through intraguild predation (Snyder *et al.,* 2004). The joint presence of aphidophagous predator (*E. balteatus*) and the aphid parasitoid (*A. colemani*) in the fields could be complementary for the control of *M. persicae*, since the *E. balteatus* that act as an intraguild predator avoid to lay eggs in aphid colonies parasitized by *A. colemani* (Pineda *et al.,* 2007).

2.6 IMPACT OF INSECTICIDES ON *M. PERSICAE*

Insecticides chemical classes include chlorinated hydrocarbons, organophosphates, carbamates, synthetic pyrethroids, microbials, neonicotinoids, thiamethoxam, avermectins, naturalyte and others. These insecticides are formulated into emulsifiable liquid concentrates, flowable liquids, wettable powders, soluble powders, dusts, and granules so as to be applied as per required environment (Adkisson and Smith, 2007). Several factors determine the efficacy of insecticides, for example, the selection of correct insecticide, proper timings of its application and good coverage of the crop as aphids particularly the *M. persicae* are frequently most abundant on the undersides of leaves. If the insecticide is applied only to the tops of leaves, control will not be adequate (Adkisson and Smith, 2007). According to Misra and Agrawal (1998a) the application of granular insecticides in soil under rain fed conditions at higher hills is practically ineffective against *M. persicae* (to record greater than or equal to 50 % mortality) due to insufficient uptake and translocation of the insecticides up to the foliage (Misra and Agrawal, 1998a).

Chemical control of certain aphid species including *M. persicae* has become extremely difficult due to resistance to insecticides particularly organophosphates, carbamates and pyrethroids (Ronald, 1991; Ciglari *et al.,* 1997). Even within species of certain aphids, strains may show differences in insecticide susceptibility (Blackman & Eastop 1984), for example red-colored aphids are more resistant to dimethoate and lambda-cyhalothrin, and usually more resistant to endosulfan than green-colored aphids collected from the same field (Kerns *et al.,* 1988).

Extreme elevated carboxylesterases in *M. persicae* grants resistance to carbamates, organophosphates, and pyrethroids; acetylcholinesterase (MACE) gives strong resistance to the di-methyl carbamates, pirimicarb and triazamate; mutation reduced nervous system sensitivity, termed knockdown resistance L1014F (kdr) grants resistance to pyrethroids; mutation M918T (super-*kdr*) favors enhanced resistance to pyrethroids (Anstead *et al.,* 2005; van Toor *et al.,* 2008). Clones homozygous for the *kdr* mutation document high resistance to the pyrethroids (deltamethrin, cypermethrin, cyhalothrin and bifenthrin). Those diagnosed as heterozygous for the *kdr* allele show variant response, some proving as resistant as *kdr* homozygotes, and others fully susceptible to pyrethroids. These indicate the presence of a second or a secondary gene capable of modifying the dominance of the primary *kdr* allele (Boughton *et al.,* 2006). Most of the strains of *M. persicae* have high or extremely high production of an esterase enzyme which sequester and detoxify insecticides with esteric group. Both MACE and *kdr* phenotypes are associated with high levels of esterase activity. MACE and *kdr* resistance mechanisms result in linkage disequilibrium. The efficacy of a pyrethroid insecticide against a strain possessing a F979S mutation within its para-type sodium channel gene suggests that this amino acid substitution could affect the sodium channel responsively to pyrethroids (Criniti *et al.,* 2008).

Insecticides may cause dramatic increase in aphid/pest population due to destruction of the natural enemies, stimulating the production of nymphs, failure to control the target pest and development of resistance. For example, Cypermethrin with oil greatly decrease spread of PLRV probably because of better early season control of *M. persicae*. Although, there is no evidence of stimulation of growth or reproduction of *M. persicae* by the cypermethrin and oil, either acting directly or indirectly via changes in the plants yet, insecticide-resistant forms of *M. persicae* increase in numbers at the end of the season, which may have serious consequences for their control in the future (Harrington *et al.,* 1989). Therefore, pesticides may be used as a last resort when all the other IPM strategies failed to suppress the pest population below economic threshold level and careful monitoring indicates that they are needed. Moreover, the least toxic and most target specific pesticides must be chosen (Oetting 1985; ffrench-Constant, 1998; Adkisson and Smith, 2007)

Oxydemeton-methyl 25 EC at 200 g a.i./ha and Dimethoate 30 EC at 200 g a.i./ha either alone or in combination with Mancozeb 75 WP at 1500 g a.i./ha and Ziram 27 SC at 1600 g a.i./ha are effective against *M. persicae* on potato (Nagia *et al.,* 1994). Frequencies of insecticide-resistant variants shows that *M. persicae* is more abundant at the end of the season on plants sprayed alternately with a mixture of pyrethroid with oil and pirimicarb as compared to those treated with pirimicarb alone (ffrench-Constant, 1998). The neem (*Azadirachta indica*) seed kernel extracts (NSKE) and azadirachtin offered to one-day-*old M. persicae* nymphs via a membrane feeding system show that the neem metabolites display 100% mortality at doses higher than 2560 ppm. At intermediate doses, ranging between 320 and 2560 ppm, larval growth and mortality are influenced in a dose-dependent manner (Heuvel *et al.,* 1998).

Evaluation of cadmium @ 200 or 400 mg/ kg dry weight soil and imidacloprid @ 4 or 40 g a.i./ ha on the pea aphid (*A. pisum*) show that cadmium at both concentrations reduce the population buildup of the pea aphid. Imidacloprid also reduce aphid growth rate, but only at the highest concentration while combinations of cadmium and imidacloprid have the greatest impact on aphid growth rate (Kramarz and Stark, 2003). Slight susceptibility in aphids to imidacloprid suggests that development of resistance is a possibility and justifies close resistance monitoring. Little/no differences in susceptibility to acephate, mevinphos or bifenthrin are detected (Kerns *et al.,* 1988). Virtually no resistance to imidacloprid in *M. persicae* and *A. gossypii* (well-known for resistance problems to conventional insecticides) is detected. In contrast, strong resistance is found to oxydemeton-methyl and pirimicarb, and to some extent to cyfluthrin. Two strains of *A. gossypii* exhibited reduced susceptibility to imidacloprid when tested directly after collection. However, after maintaining them for six weeks in the laboratory, the aphids were as susceptible as the reference strain. The diagnostic concentrations of methamidophos don't reveal any resistance in *M. persicae*, but do so in four strains of *A. gossypii* (Nauen and Elbert, 2003).

The effects of sub-lethal imidacloprid concentrations on acquisition and inoculation of PLRV by *M. persicae* from infected potatoes show that virus transmission decline significantly with increasing concentrations of imidacloprid. Sub-lethal concentrations of imidacloprid clearly inhibit both acquisition and inoculation of PLRV by *M. persicae*, either through poisoning, temporary intoxication, and/or antifeedant effects (Mowry and John, 2002). Esfenvalerate, imidacloprid, oxamyl, pymetrozine, methamidophos and thiamethoxam testing showed that exposing virus-free *M. persicae* to insecticide residues on virus source plants (during a 2-day acquisition access period), the subsequent transmission of PLRV to untreated indicator plants declined significantly with increasing dosage for all insecticides. Reduction of PLRV transmission by imidacloprid and thiamethoxam appeared to be largely related to their toxic effects, but antifeedant properties also might play a role, especially in inoculation experiments. Reduced PLRV transmission due to pymetrozine reflects its antifeedant properties (Mowry, 2005).

2.7 IMPACT OF INSECTICIDES ON PREDATORS

Reduced concentrations and selective insecticides may encourage activity of lady beetles (Moschetti, 2003). Evaluation of Confidor, Talstar, Sumialpha, Polo, Danitol, Steward, Tracer and Proclaim show that all the insecticides cause higher mortality of the 4th instar grubs of *C. septempunctata*) when applied at high concentrations. However, Denitol is comparatively more toxic while Tracer is the least toxic (Solangi *et al.,* 2007b). Etofenprox and acetamiprid are highly toxic to most developmental stages and adult of the *H. axyridis* at recommended dosages for aphid control. Thiamethoxam cause knockdown of larvae, pupae, and adults; however, most recover within 24 h. Imidacloprid, at 50 mg a.i./L, produce LC_{50} values of 30.3 and 190.2 mg a.i./L for 3rd and 4th instars, respectively. Abamectin is highly toxic to eggs, larvae, pupae, and adult ladybird beetles at rates under 18.4 mg a.i./L. Generally, the 1st and 2nd instars of *H. axyridis* are very sensitive to most of the tested insecticides (Youn *et al.,* 2003).

The spinosad and indoxacarb reduce *H. axyridis* population growth by affecting its survival, development, and reproduction. Indoxacarb at 10% FR, have more lethal and sub lethal effects on *H. axyridis* than spinosad at 10, 25 or 50% FR (Galvan *et al.,* 2005). Predatory efficiency of the adults and larvae of *C. septempunctata* is significantly reduced when encounter with dimethoate residues and treated prey. Prey-choice experiments reveal that adult coccinellids consume significantly fewer treated than untreated aphids over the 5-h experimental period. Fourth instar larvae preferentially consume untreated aphids when given the choice of full rate dimethoate treated aphids or untreated aphids (Singh *et al.,* 2004). Voracity of ladybird beetle is not significantly affected by pirimicarb; therefore, it can constitute a complementary component for the IPM of *A. fabae* (Moura *et al.,* 2006). According Harrington *et al.* (1989), the numbers of predacious carabid beetles on the cypermethrin/oil treated plots decrease at about the time numbers of aphids, yet signs of the resurgence begin earlier and evidence for the role of reduced carabids is not conclusive.

The behavior and distribution pattern of adult ladybird beetle in the crop canopy of winter wheat infested with the cereal aphids showed that no ladybird beetle were killed or knocked down as a result deltamethrin residues. Deltamethrin residues forced ladybird beetle to walk and groom significantly more frequently and rest significantly less frequently up to three days of the post treatment than those in the unsprayed plot. Similarly, in treated plots as compared to control, higher numbers of ladybird beetle were observed on ground and in the bottom crop canopy during the 1^{st} two days of post treatment. Upon the foliage, ladybird beetle were significantly more on the abaxial leaf surface in the treated crop (Wiles and Jepson, 1994).

Study on the foraging behavior of ladybird beetle larvae on dead *A. pisum* aphids, either infected with the entomopathogenic fungus *Erynia neoaphidis* (sporulating) or uninfected, shows that larvae search for longer and feed less when presented with infected rather than uninfected *A. pisum.* Although no sporulating infected aphids are completely consumed, both adult and larval ladybird beetle can still be considered as intraguild predators. Preliminary studies to assess the potential of other aphid natural enemies as intraguild predators illustrate that adults of the carabid, *Pterostichus madidus* (Fabricius), entirely consume sporulating cadavers. Third instar *C. carnea* and hoverfly *E. balteatus* larvae never feed on sporulating cadavers (Roy *et al.,* 1998).

Survival of green lacewing adults is reduced after feeding on flowers from plants treated with a soil application of imidacloprid (Marathon 1% G at labeled rate and twice labeled rate). Percent survival for green lacewing at 10 d show statistical difference between treatments and controls: 79% for untreated flowers, 14% for labeled rate, and 6% for twice labeled rate. Trembling is observed in imidacloprid treatments, but not controls. A cold enthrone test shows that green lacewing do not starve to avoid feeding on treated flowers. In support of these data, a previous demonstrates that soil-applied imidacloprid is translocated to flower nectar. Consequently, plants treated with imidacloprid reduce populations of *C. carnea* and lower their efficacy as biological control agents (Rogers *et al.,* 2007). The indirect effects of insecticides on green lacewing, *Micromus tasmaniae* Walker, populations feeding on lettuce aphid *Nasonovia ribisnigri* (Mosley) show that pirimicarb cause 30–40%, pymetrozine less than 20% while imidacloprid cause over 96% mortality. A dose-response bioassay of imidacloprid (1/6 field rate or less) show delayed development rate from 3rd instar larvae into pupae from day 3-8 of the post treatments (Walker *et al.,* 2007).

2.8 THE IMPACT OF INSECTICIDES ON PARASITOIDS

The sensitivity of nine non-target arthropod families to 95 plant protection products 'PPP' (including herbicides, fungicides, insecticides and plant growth regulators) reveal that *Typhlodromus pyri* Scheuten and *Aphidius* have highest sensitivity to PPP. Ranking of the species tested, in order of decreasing sensitivity and based on a combination of both lethal and sub-lethal endpoints, follows: *T. pyri, Aphidius* spp, *C. septempunctata, Orius* spp, *Pardosa* spp, *E. balteatus, C. carnea, P. cupreus* and *Aleochara bilineata*. It shows that the potential of insects to be adversely affected can be predicted by determining the lethal and sub-lethal effects of the pesticides on the two sensitive species, *T. pyri* and *Aphidius spp* (Candolfi *et al.,* 1999).

Behaviors of parasitoids such as flight activity and foraging may be altered by even relatively non-toxic insecticides, thus potentially modifying the effectiveness of NE. Exposure of adult of *Microplitis croceipes* (Cresson) (parasitoid of *Heliothis*) to fenvalerate/chlordimeform (pyrethroid/formamidine) mixture result in significantly higher mortality rates than in controls. Carbamate (thiodicarb) causes similar rates of mortality whereas methomyl (a type of carbamate different from thiodicarb) cause significantly higher mortality (about 70%). Females sprayed directly with a fenvalerate/chlordimeform mixture significantly decrease flight activity up to 20 h post-treatment. Alternatively, attraction to cotton sprayed with either the fenvalerate/chlordimeform mixture or with methomyl to unsprayed females is significantly decreased (Elzen *et al.,* 1989). The parasitoid *M. croceipes* host foraging ability is severely affected for periods ranging from 2 days (imidacloprid) to 18 days (aldicarb) after insecticide application (Stapel *et al.,* 2000). Thiodicarb (application 5 days after parasitoid oviposition) allow the highest rates of adult emergence of *Eretmocerus tejanus* Rose and Zolnerowich (65.9%) and *Eretmocerus mundus* Mercet (35.8%). Endosulfan is the next least-toxic material, followed by the organophosphates (azinphos-methyl and methyl parathion) and the insect growth regulator buprofezin. The pyrethroid bifenthrin is the most toxic to both parasitoids. When applied just before the expected emergence of adults, survival ranges from 47.2 to 92.2% with buprofezin, thiodicarb, and endosulfan. It means that *Bemisia* parasitoids respond differently to various chemicals, and that sub-lethal effects on the subsequent longevity and reproductive ability among survivors of the least-toxic chemicals are not severe. Adult parasitoids (that survive pesticides applied to immature stages within their host) do not necessarily suffer latent detrimental effects on important biological parameters (Jones *et al.,* 1998).

Negative impacts on parasitoids may occur in areas where cadmium contamination is present and imidacloprid is used to control aphids. Imidacloprid alone have no effect on population growth rate of the parasitoid (*A. ervi*). However, cadmium alone or in combination with imidacloprid has a negative impact on *A. ervi* by reducing 77% the population growth rate (Kramarz and Stark, 2003).

The relationship between the insecticide doses and the subsequent ability of parasitoids to respond to host-related cues shows that none of the doses of carbamate (pirimicarb), pyrethroid (lambda-cyhalothrin), organophosphate (chlorpyrifos), and a carbamyltriazole (triazamate) have any effect on *A. ervi* responses to the odor from the aphid-infested plant (*M. persicae* on oilseed rape). But, a significant dose-behavioral quantified for triazamate show that attraction to the odor is no longer significant in females surviving the LD_{50} (Desneux *et al.,* 2004). The effects of deltamethrin on *A. ervi* show that field rate dosage reduces the adult longevity but not the rate of emergence from mummies, however, effects vary between the insecticide exposure methods. Two indices i.e. the population survival index and the reproductive potential predict effects of deltamethrin on *A. ervi* in terms of mortality and reduction of recolonization capacities. The adults that survive residual exposure to deltamethrin retain their ability to orient to host odors (Desneux *et al.,* 2006).

2.9. ROLE OF YELLOW WATER PAN TRAPS IN MANAGEMENT OF *M. PERSICAE*

Several trapping methods including suction traps, yellow water pan traps (Yp) and sticky string traps are compared for studies of aphid species diversity and population dynamics (Halbert *et al,* 1986; Labonne *et al,* 1989; Boiteau, 1990; Avinent *et al.,* 1991). Usage of yellow sticky plastic sheet enhances effectiveness of the other management techniques against *M. persicae* in potato crop (Saljoqi and van Emden, 2003c). Yp traps located within a crop more accurately indicate those species landing in the crop (Halbert *et* *al,* 1986; Seif, 1988; Avinent *et al.,* 1991). Yp traps are used to provide weekly aphid (*M. persicae*), potato aphid, pea aphids, spotted alfalfa aphids and other aphids) population information to potato growers in Union, Baker, Morrow, and Umatilla Counties (Hamm, 2001). Monitoring flight activity and species composition of alate aphids by Yp traps for 20 years show that *M. persicae* dominates among the species that damage potatoes. A significant relationship (R2=0.77) between the relative number of species caught and those living on the plants is recorded proving a reliable forecast. There is significant relationship between number of flying and potato colonizing aphids and the mild temperature values (R2=0.52 and 0.45), respectively. Strong relationship is seen between the effective heat sum, calculated from the temperature data (1^{st} May-31^{st} August), and the number of aphids caught in traps and those of feeding on the plants R2=0.88 and 0.92, respectively (Kuroli and Lantos, 2006).

In general, *Aphis spiraecola* Patch*, M. persicae, and Rhopalosiphum maidis* (Fitch) are attracted to Yp-traps where as *A. gossypii, Lipaphis erysimi* (Kaltenbach), *M. euphorbiae, and R. padi* (Fitch) are more attracted to green pan traps (Difonzo *et al,* 1997; Boiteau, 1990). Comparisons are based by the different trap compositions used resulting in variations of reflected light quality. However, regardless of the exact reflection spectra, Yp tend to collect greater numbers of aphids compared with green traps (Irwin, 1980). Yp traps prove as an appropriate sampling device in trial on 'Evaluation of reflective and cover crop mulches for insect, disease and weed control in fresh market tomato production systems' and effectively trap *M. persicae*, cotton/melon aphid, potato/tomato aphid, bean aphid, cowpea aphid, thrips, whiteflies, and leafhoppers (Mitchell *et al,* 2001). It is assumed that critical levels of GPA are reached when more than 5 winged aphids are caught per trap (Yp trap or Moericke's traps) per week. Other assumptions are for 5-10 aphids, mostly wingless, detected per 100 leaves (Alan *et al,* 2003).

Chapter 3

GENERAL MATERIALS AND METHODS

3.1 Geographical position of experimental zones/locations

The experiments related to Chapter 4 were conducted at Malakandair Research Farm of Khyber Pakhtunkhwa Agricultural University Peshawar, and two farmer's field (leased/ subsidized) at Mingora and Abbottabad in spring and fall during 2007; the locations situated in Khyber Pakhtunkhwa Province of Pakistan with different agro-ecological and agro-climatic conditions. All the other experiments (Chapter 5 to 8) were conducted during 2007 to 2009 at Malakandair. The Malakandair is location in District Peshawar that lies between 33^{o} $44^{/}$ to 34^{o} $15^{/}$ north latitudes and 71^{o} $22^{/}$ to 71^{o} $42^{/}$ east longitudes with an altitude of 510 meters above sea level. Mingora is located in District Swat that lies between 34^{o} $34^{/}$ to 35^{o} $55^{/}$ north latitudes and 72^{o} $08^{/}$ to 72^{o} $50^{/}$ east longitudes with an altitude of 984 meters. District Abbottabad lies between 33^{o} $50^{/}$ to 34^{o} $23^{/}$ north latitudes and 72^{o} $35^{/}$ to 73^{o} $31^{/}$ east longitudes with an altitude of 1300 meters above sea level.

3.2 SEEDS COLLECTION

The seeds of the following potato varieties were obtained from the Potato Research Center (PRC) Abbottabad, Potato Seed Dealers Gujranwala and from Local market of Pabbi, Nowshera.

V1 = Cardinal	V4 = Kuroda (Kr)	V7 = Ajax
V2 = Desiree (De)	V5 = Santee	V8 = Raja
V3 = Diamant	V6 = Ultimus	V9 = Multa

3.3 EXPERIMENTAL LAYOUTS AND AGRONOMIC MEASURES

Experimental plot size and number of treatments were different in various experiments as mentioned in the relevant chapters. However, in all experiments each experimental unit was nine square meters in size and kept three meters apart from one another. Plant-to-plant and row-to-row distance was kept constant at 20 cm and 75 cm, respectively. Treatments were replicated thrice in all experiments. Di-ammonium phosphate (DAP) and farmyard manure were applied at recommended rate during land preparation for sowing while urea was supplemented after a month. Other agronomic measures like irrigation, hoeing, weeding and earthen-up were applied when required and kept constant throughout the experiment.

3.4 DATA COLLECTION /POPULATION ESTIMATES

3.4.1 Green Peach Aphid (*Myzus persicae*)

Twelve plants per experimental unit were randomly selected while walking in a predetermined pattern (X) through field, avoiding the border rows. *M. persicae* (winged and wingless) were counted on three compound leaves per plant (top, middle and bottom) on the dates mentioned in material and methods sections of the concerned experiments (chapters) and was averaged over nine compound leaves for analysis and presentation. Data was recorded on the same leaves through out the experiment (Saljoqi and van Emden, 2003a; Edward, 2008).

3.4.2 Natural Enemies

Populations of ladybird beetle (LBB), syrphidfly, green lacewing (GLW) and parasitized *M. persicae* mummies were recorded on ten plants per experimental unit while walking in a predetermined pattern (X) through field and data was analyzed.

3.4.3 Percent parasitism of the *M. persicae* by its parasitoids '*Aphidius*' (PPA*A*)

Infested potato leaves with sufficient quantity of GPA were collected from each experimental unit. The mummies were removed while known number of aphids, leaves and two filter papers were filled in polythene bags (32 x 46 cm). Filter papers were meant to reduce the condensation in polythene bags. After five days, parasitoids developed into 4th and 5th instars nymphs and adult aphids to mummies. The mummies were counted and percent parasitism was calculated (Saljoqi and van Emden, 2003a) by using equation (3.1).

$$PPA\mathit{A} = \frac{\text{Number of mummies formed at the end}}{\text{Total initial number of nymphs and adult aphids}} \times 100 \quad \text{----------} \ (3.1)$$

3.4.4 Percent emergence rates of the *Aphidius* from the parasitized *M. persicae* mummies (PER*A*)

Fifty aphid mummies from each experimental unit were collected and placed in Petri dishes lined with filter papers. Each Petri dish was covered and kept in laboratory for ten days. After ten days the emerged parasitoids (*Aphidius spp*.) were counted for each replicate and the percent emergence was calculated (Saljoqi and van Emden, 2003a) by using equation (3.2):

$$PERA = \frac{\text{Number of adults emerged}}{\text{Total number of mummies}} \times 100 \text{ ---------------------------------- } (3.2)$$

3.4.5 Fecundity rates of the mature female of *Aphidius spp* (FR*A*)

Ovaries of newly emerged female were studied for number of mature eggs to determine the FR*A* of female parasitoids. To get fresh adults, mummies were collected from each experimental unit and kept in Petri dishes for emergence. Newly emerged adult parasitoids were served with 30% honey/water solution presented in cotton pieces. Female parasitoids collected from Petri dishes, using battery-operated aspirator, were killed in 70% ethyl alcohol and their abdomens were placed in glycerol on a microscopic slide. Using an insect mounting pin, the ovaries were extracted and placed in 1% acid fuchsine for 30 seconds. To explore eggs, the ovaries were punctured under low power stereo binocular microscope. Numbers of eggs were then counted using a tally counter under high power microscope (Saljoqi and van Emden, 2003a).

3.5 Yield

Crop was harvested manually. The yield obtained for each treatment was measured in Kilograms and converted into tons per hectare for analysis.

3.6 Data analysis

The data was analyzed using MSTATC package by analysis of variance as per design used in the concerned experiment. The means were compared using LSD at 5% level of significance ($P< 0.05$).

Chapter 4

IMPACT OF LOCATIONS, SEASONS AND POTATO VARIETIES ON GREEN PEACH APHID, *M. PERSICAE* (SULZER), AND NATURAL ENEMIES

4.1 INTRODUCTION

Climate, land use and geographical location are linked and can interact in complex ways in determining patterns of *M. persicae* annual numbers and phenology (Cocu *et al.*, 2005; Thomas *et al.,* 2004). Natural biological control (natural enemies) is another factor that influence *M. persicae* population (Ito *et al.,* 2005). However, the population of natural enemies in itself is also regulated by all the factors described for *M. persicae*. For example, the percent parasitism of *M. persicae* is regulated by temperature (Kassem *et al.,* 2005); Ladybird beetles may have more generations and best survival rates in warmer/more favorable climatic conditions (Moschetti, 2003; Ohashi *et al.*, 2005; Kabaluk *et al.*, 2006); Green lacewing larvae are more effective in low growing crops. Syrphidfly are most noticeable in later half of the growing season, when aphid infestations get established (Sadeghi and Gilbert, 2000). Overall, the phenology models predict time of events in an organism's development (Dufour, 2003).

The decreased efficacy of pesticides due to pest adaptation and the concern for environment/health has necessitated the search for insect resistant varieties (Eigenbrode and Trumble, 1994). All plants have some endogenous resistance to insect damage (Gatehouse, 2002). Often, successful crop production is impossible without resistance to pests that otherwise may not be controlled. Basics for an ideal IPM should be cultivation of resistant varieties, which are then integrated with other control measures. In rebuttal to insect attack, plants rely on a variety of defense mechanisms, involving physical barriers, toxic or anti-nutritive secondary metabolites, and/or recruitment of natural enemies (Agrawal, 2007; Heil, 2008; Rasmann and Agrawal, 2009; Wink, 2008). In addition, plant's defense system depends on a variety of genetic, ontogenetic, and environmental factors that cumulatively shape the multivariate defensive phenotype and outcome of the interaction (Duffey and Stout, 1996).

Potato varieties resist the *M. persicae* damage through various traits. The detail review in this regard is described in Section 2.3; however, a little addition about the role of transgenic varieties is described here. Many excellent responses of the economic, environmental and health benefits of insect resistant transgenic crops have been reported (James, 2005; Ferry *et al.,* 2006). For example genetically modified (GM) rice cultivation is beneficial to small and poor farmers as of higher crop yields and reduced pesticide use that has also contributed to improved health, compared with household cultivation of non-GM rice (Huang *et al.,* 2005). Through *Bt* (*Bacillus thuringiensis*) induced resistance in cotton fields in India, the documented benefits are about 70% reduction in insecticide applications that resulted in a saving of up to US$30 per ha in insecticidal costs, and an 80–87% increase in harvested cotton yield (Qaim and Zilberman, 2003). The proportion of farmers with pesticide poisoning has been reduced from 22% to 4.7% in *Bt* cotton fields (Huang *et al.,* 2002). The biotechnology-derived crops reduce the use of pesticides by huge amount of up to 21000 tons (Sankula, *et al.,* 2005). Plant resistance results in reduction of pesticide concentration giving an equivalent kill of the pest on a susceptible variety (Saljoqi and van Emden, 2003a).

Important part of IPM is to preserve natural enemies associated with crop pests (Bates *et al.,* 2005). The effects of insect-resistant crops on non-target insects may also be evaluated (Romeis *et al.,* 2006). Interactions involving crops, insect pests and their natural enemies must all be included while evaluating the environmental impact of transgenic crops (Riddick and Mills, 2004; Vojteck *et al.,* 2005). Although insect-resistant transgenic plants may not have a direct effect on natural enemies of pests, indirect effects are almost inevitable. For example, prey fed on plant material expressing *Bt* proteins affected the growth and development of a carabid beetle (Meissle *et al.,* 2005). Moreover, besides no direct effect, reduction in pest quantity will indirectly reduce the available prey for predators and parasites (Schuler *et al.,* 2003). Finally, all the traits that reduce pest growth rates may synergistically attract natural enemies of herbivores and thus increase the opportunity for predation or parasitism (Thaler, 1999; Kessler and Baldwin, 2004).

IPM is based on cultivation of resistant varieties. As such, in the first instance to establish IPM strategy; various potato varieties were screened on the basis of their response to incidence of *M. persicae*, during spring and fall in 2007 at three different locations viz Malakandair, Mingora and Abbottabad having different geographical locations and climatology (Section 4.3). The role of natural enemies can not be ignored in IPM strategy. Hence data was also collected on natural enemies of *M. persicae* in farmer’s potato crop.

The research study envisaged the following **objectives**:

1) To study the impact of different agro-climatic and agro-ecological locations viz Malakandair, Abbottabad and Mingora on population trends of *M. persicae* and its natural enemies including ladybird beetle, syrphidfly, green lacewing and parasitized *M. persicae* mummies.

2) To investigate the impact of seasons (spring and fall) on population trends of *M. persicae* and its natural enemies.

3) To evaluate the impact of plant growth stages on the population trends of *M. persicae* and its natural enemies.

4) To study the impact of potato varieties on population dynamics of *M. persicae* and its natural enemies.

4.2 MATERIALS AND METHODS

4.2.1 Experimental Design and layout

The nine potato varieties (Section 3.1) were raised in a randomized complete block design of 27 experimental units in each of the above mentioned locality, representing nine treatments and three replicates. Size of experimental unit and other agronomic measures were applied as stated in Section 3.3.

4.2.2 Population Estimates

The *M. persicae* population was studied as per detail given in Section 3.4.1. However, data was recorded fortnightly on various plant growth stages (Pgs) from Day 15 to 75 of seeds germination i.e. crop maturity. In each location (Malakandair, Abbottabad and Mingora) the populations of natural enemies (ladybird beetle, syrphidfly, green lacewing and parasitized aphid mummies) were studied in the experimental plots and two other farmer's plots (regardless of the potato varieties) as replicates. In each replicate, 30 plants were randomly selected while walking in a predetermined pattern (X) through field and data was recorded per plant on same dates as for *M. persicae*. The population was averaged over 10 plants for analysis and presentation.

4.2.3 Data Analysis

The *M. persicae* data were analyzed using MSTATC package by analysis of variance of 'two factors randomized complete clock design with split plots, combined over locations and seasons, using same locations and randomization each season'. The data on population trend of natural enemies were analyzed using analysis of variance of 'randomized complete block design, combined over locations and seasons, using same locations each season but randomized'. Means were compared using LSD Test at 5 % level of significance ($P < 0.05$).

4.3 RESULTS

4.3.1 Climatology of the locations

Since all the three locations had different geographical positions, therefore, the climatology of each location was also different. Data recorded in government agriculture research stations of the concerned locations are presented in Table 4.I.

Table 4.I Mean monthly temperature, precipitation and humidity recorded on various experimental sites during 2007

Months	**Malakandair**				**Abbottabad**				**Mingora**			
	Mean (^{o}C) Temperature		Precipitation (mm)	Humidity (%)	Mean (^{o}C) Temperature		Precipitation (mm)	Humidity (%)	Mean (^{o}C) Temperature		Precipitation (mm)	Humidity (%)
	Maximum	Minimum			Maximum	Minimum			Maximum	Minimum		
January	18.4	4.0	26.0	58.6	12.6	1.8	64.8	59.1	13.2	2.1	50.5	58.7
February	19.5	6.3	42.7	57.5	13.4	2.9	113.6	61.0	14.3	3.3	70.6	51.2
March	23.7	11.2	78.4	58.4	17.8	6.9	142.3	57.0	18.8	8.1	119.3	47.4
April	30.0	16.4	48.9	51.7	23.3	11.4	111.8	51.5	24.4	12.0	105.2	52.4
May	35.9	21.3	27.0	37.4	28.3	15.5	81.6	42.0	29.6	15.6	60.1	40.9
June	40.4	25.7	7.7	36.2	32.4	19.7	85.3	41.2	34.1	21.2	51.3	37.7
July	37.7	26.6	42.3	55.0	29.6	20.1	258.3	66.7	31.4	22.5	145.8	65.3
August	35.7	25.7	67.7	64.6	28.2	19.3	261.3	74.8	30.2	20.2	159.8	72.2
September	35.0	22.7	17.9	58.7	27.8	16.8	96.9	62.3	29.0	17.6	81.8	59.1
October	31.2	16.1	9.7	54.9	24.9	12.0	56.9	51.3	25.1	12.6	50.7	50.5
November	25.6	9.6	12.3	60.1	20.1	7.2	31.9	49.4	21.9	7.8	28.7	45.5
December	20.1	4.9	23.3	63.7	15.0	3.5	61.5	56.0	15.8	4.1	54.7	52.4
Annual Means	**29.4**	**15.9**	**33.7**	**54.7**	**22.8**	**11.4**	**113.8**	**56.0**	**24.0**	**12.3**	**81.5**	**52.8**

4.3.2 Impact of seasons, locations, varieties and plant growth stages (Pgs) on *M. persicae* population

The analysis of variance for the population of *M. persicae* per nine compound leaves of potato plants showed highly significant effect ($P<0.05$) due to seasons, locations, varieties and plant growth stages (Appendix-A Table-A1). All interaction effects were also significant; except for location x variety (L x V) and location x variety x plant growth stages (L x V x Pgs). The results of main factors are shown in Fig 4.1. The mean values for locations showed significant variations with respect to *M. persicae* population, being higher at Mingora and minimum at Malakandair. During spring, *M. persicae* incidence was significantly higher as compared to fall. Among varieties, Desiree was susceptible to *M. persicae* while Kuroda showed significant resistance. The attack of *M. persicae* on various plant growth stages was also significant being severe on Day 60 and minimum on Day 15 of seeds germination.

Interaction between location x season (L x S) for mean number of *M. persicae* population was highly significant (Fig 4.2). During spring, *M. persicae* population was significantly higher than fall at all locations. During spring, all the three locations had significantly different population of *M. persicae* being highest at Mingora and lowest at Malakandair. During fall, the *M. persicae* populations at Abbottabad and Mingora were statistically equal and significantly lower than Malakandair.

The interaction effect between varieties and season (V x S) was significant (Fig 4.3). Significantly higher *M. persicae* population was recorded on all potato varieties during spring as compared to fall. Kuroda and Desiree were detected as the most significant resistant and susceptible varieties, respectively, during both seasons. All the other varieties did not differ significantly for the *M. persicae* development during fall; while during spring they responded variably.

Interaction effect of seasons x locations x varieties (S x L x V) was significant (Table 4.II). The population of *M. persicae* in each location during spring was significantly higher than fall on all varieties. During spring, *M. persicae* development on potato varieties in the various locations was significantly different being maximum on Desiree at Mingora and minimum on Kuroda at Malakandair. However, Kuroda and Desiree were consistently the most resistant and susceptible varieties, respectively, in each location. During fall, *M. persicae* population on potato varieties in all the locations was statistically equal, with few exceptions. At Malakandair, similar to spring, *M. persicae* populations on Kuroda and Desiree were significantly the lowest and highest, respectively.

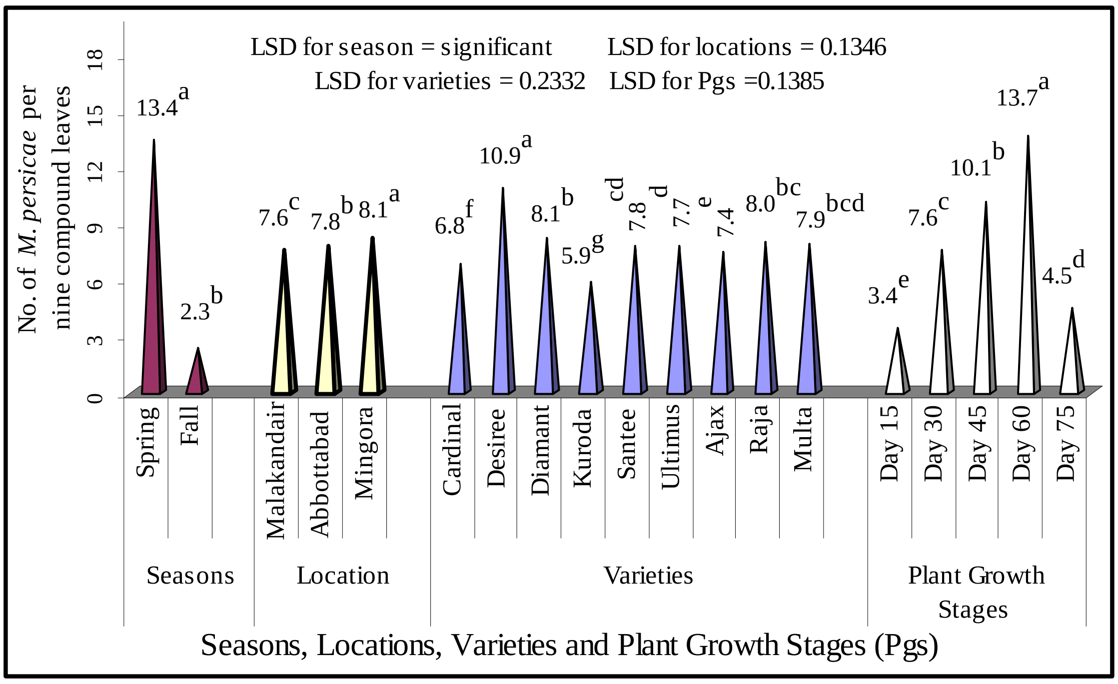


Fig 4.1 Impact of seasons, location, varieties and plant growth stages (days after seeds germination) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop

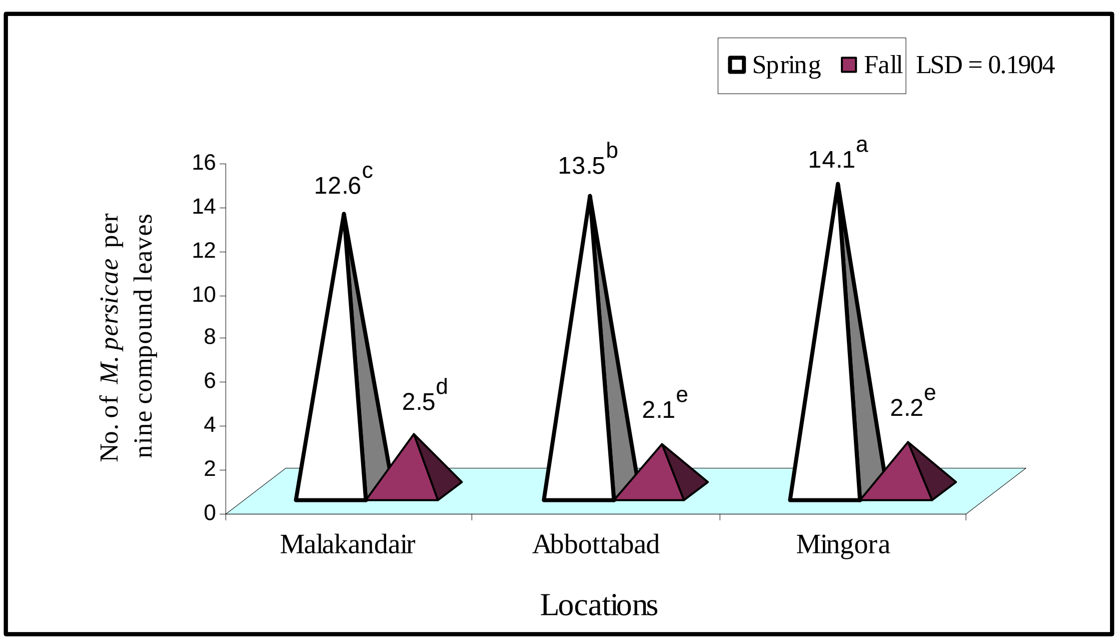


Fig 4.2 Interaction effect of locations x seasons (L x S) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

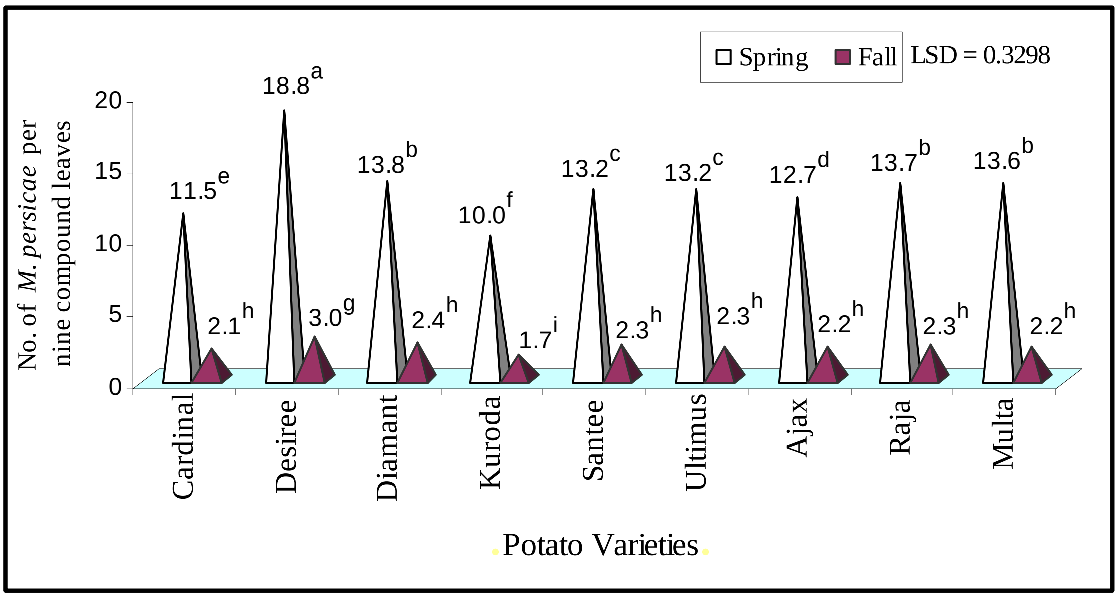


Fig 4.3 Interaction effect of varieties x seasons (V x S) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop

Table 4.II Interaction effect of season x locations x varieties (S x L x V) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), per nine compound leaves of potato plants

Season	Locations	Cardinal	Desiree	Diamant	Kuroda	Santee	Ultimus	Ajax	Raja	Multa
Spring	Malakandair	10.91^{n}	17.82^{c}	13.00^{h-j}	9.18^{p}	12.71^{h-k}	12.51^{j-l}	12.39^{kl}	12.73^{h-k}	12.58^{i-k}
	Abbottabad	11.75^{m}	18.77^{b}	13.71^{fg}	10.17^{o}	13.23^{gh}	13.09^{hi}	13.01^{h-j}	13.73^{fg}	13.83^{f}
	Mingora	11.97^{lm}	19.69^{a}	14.80^{d}	10.76^{n}	13.80^{f}	14.10^{ef}	12.73^{h-k}	14.62^{de}	14.41^{de}
Fall	Malakandair	2.22^{s-u}	3.79^{q}	2.96^{r}	1.75^{t-v}	2.59^{rs}	2.48^{rs}	2.41^{rs}	2.43^{rs}	2.30st
	Abbottabad	2.05^{s-v}	2.55^{rs}	2.15^{s-v}	1.61^{v}	2.18^{s-u}	2.15^{s-v}	2.13^{s-v}	2.23^{s-u}	2.16^{s-v}
	Mingora	2.11^{s-v}	2.58^{rs}	2.23^{s-u}	1.68^{uv}	2.23^{s-u}	2.19^{s-u}	2.15^{s-v}	2.30st	2.20^{s-u}

LSD value for interaction effect = 0.5712
Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

Interaction between seasons and plant growth stages (S x Pgs) was significant, Fig 4.4. The *M. persicae* population during spring was significantly higher than fall on all plant growth stages. During spring, its population was at significant increase till Day 60 and thereafter it crashed significantly on Day 75 of seeds germination i.e. at crop maturity. During fall, the peak *M. persicae* incidence was recorded on Day 30 and thereafter it started decreasing significantly till crop maturity.

Interaction between plants growth stage and location (Pgs x L) was significant, Fig 4.5. In all locations, *M. persicae* population increased significantly from Day 15 to 60 and crashed on Day 75 being highest at Mingora except Day 15 and Day 75 on which it did not differ from Malakandair and both the locations, respectively. Abbottabad had significantly higher populations than Malakandair on Day 45, 60 and 75 while on Day 15 and 30 both the locations did not differ significantly.

Interaction effect of seasons x locations x plant growth stages (S x L x Pgs) was significant, Fig 4.6. *M. persicae* population build up during spring was significantly higher than fall in all the locations. During spring, its population was at significant increase from Day 15 to 60 before it crashed on Day 75; while during fall the peak population of *M. persicae* was recorded on Day 30 and thereafter it started decreasing till Day 75. The *M. persicae* population during spring was significantly highest at Mingora; except Day 15 and 75 on which it was statistically equal to Malakandair while on Day 75 it was significantly lower than Abbottabad. The lowest *M. persicae* population during spring was recorded at Malakandair; except Day 15 on which it was statistically equal to both the locations and on Day 75 it was equal to Mingora. During fall, *M. persicae* population was significantly highest at Malakandair; except Day 15 and 75 on which it was statistically equal in all locations. Abbottabad and Mingora, during fall, did not differ statistically on any plant growth stage in respect of *M. persicae* populations.

Interaction effect between plants growth stages and varieties (Pgs x V) was significant, Fig. 4.7. The *M. persicae* population was at significant increase on all varieties till Day 60 before it crashed significantly on Day 75. Kuroda had consistently the lowest and Desiree had the highest *M. persicae* populations on all plant growth stages as compared to other varieties.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

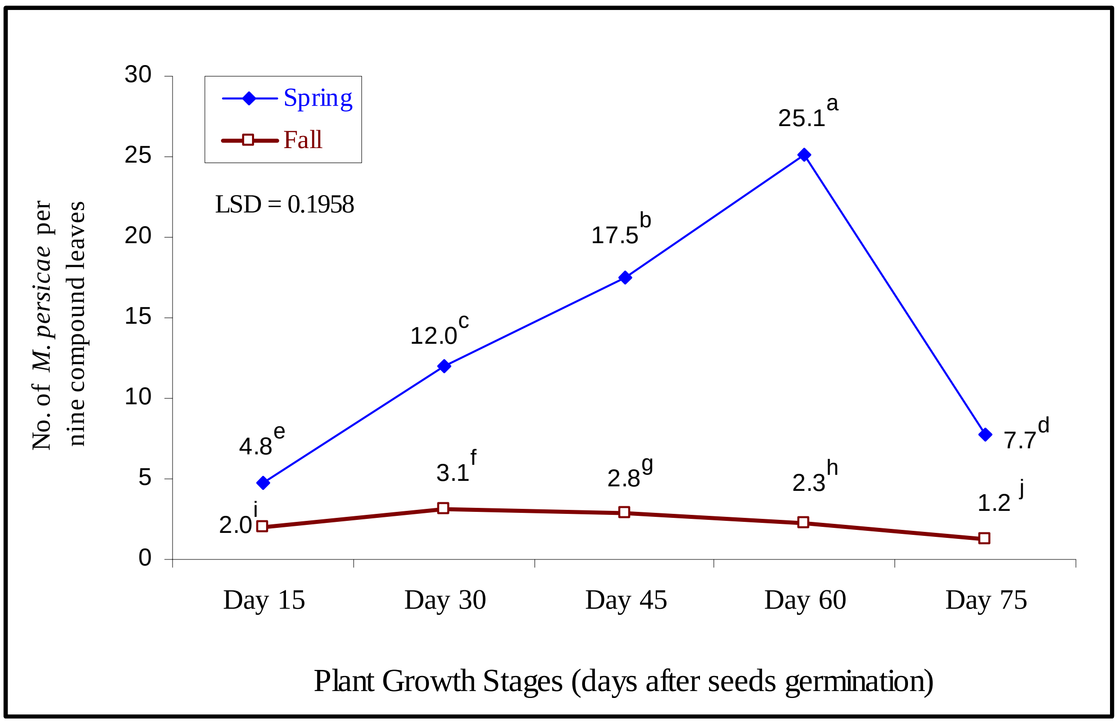


Fig 4.4 Interaction effect of seasons x plant growth stages (S x Pgs) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop

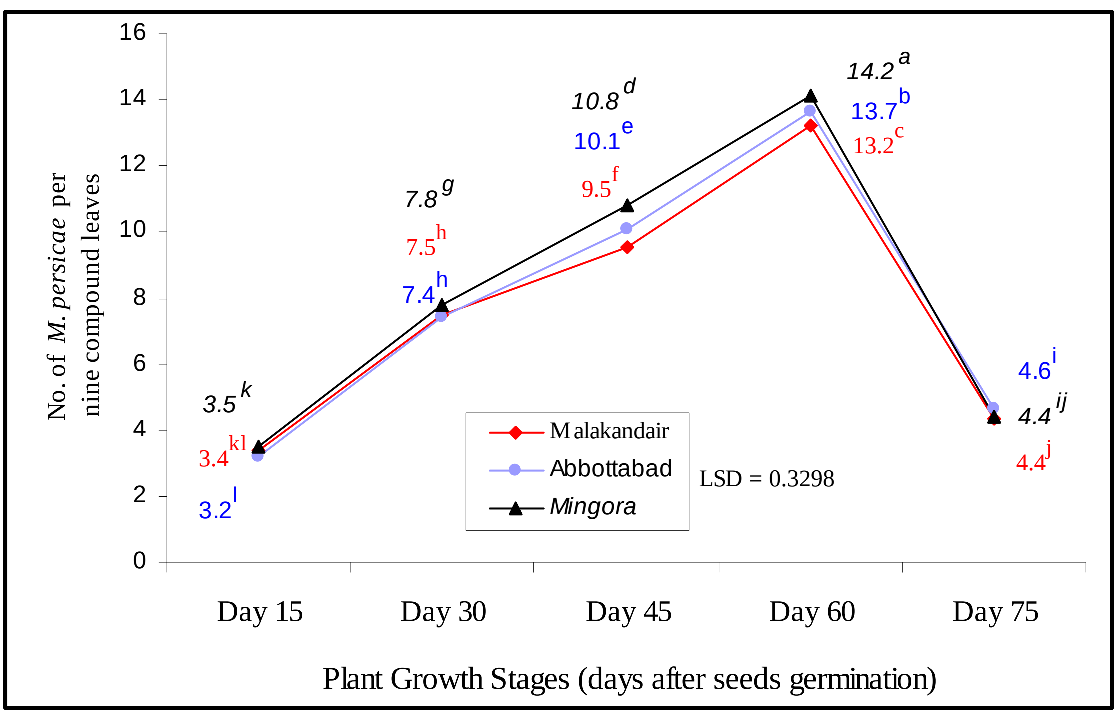


Fig 4.5 Interaction effect of plant growth stages x locations (Pgs x L) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

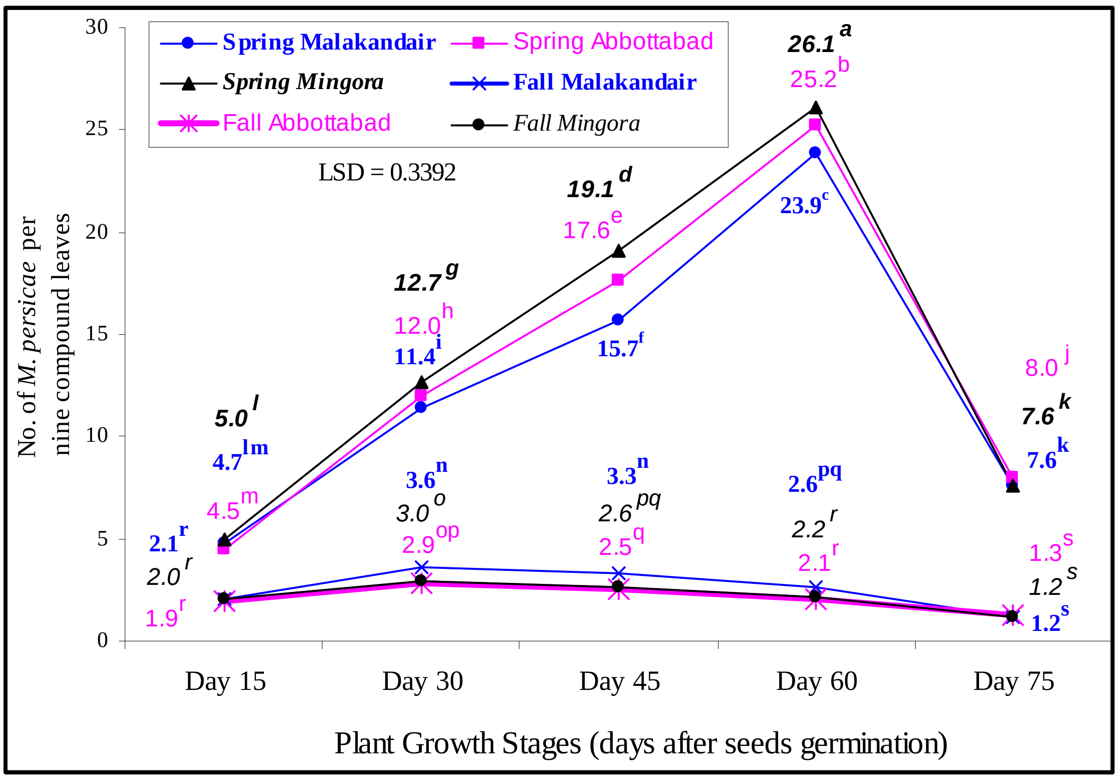
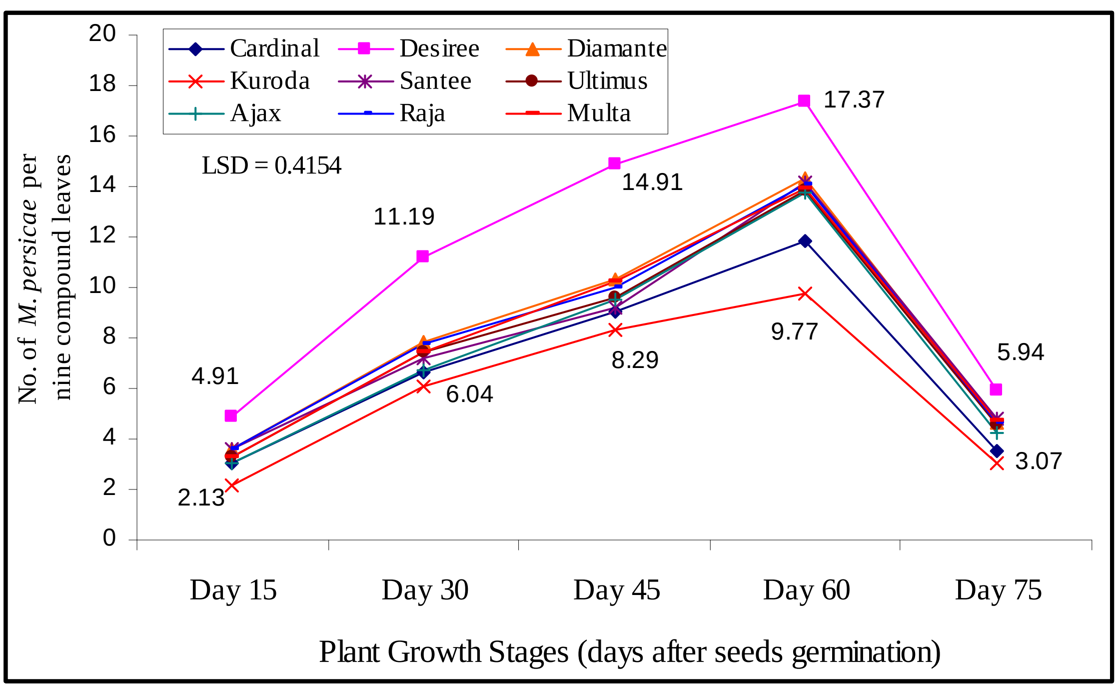


Fig 4.6 Interaction effect of plant growth stages x seasons x locations (Pgs x S x L) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop



'ig 4.7 Interaction effect of plant growth stages x varieties (Pgs x V) on the population ıeans of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop

Interaction effect of seasons x plant growth stages x varieties (S x Pgs x V) was significant, Table 4.III. Population trends of the *M. persicae* on varieties at various plant growth stages regarding this interaction were similar to those presented in Fig 4.7 with the exception that peak *M. persicae* population during fall was observed on Day 30 of seeds germination. The *M. persicae* populations on varieties at each plant growth stage during spring were significantly higher than fall.

Interaction effect of seasons x location x plant growth stages x varieties (S x L x Pgs x V) was significant, Table-4.1V. In all the locations during both seasons and each plant growth stage; varieties Desiree and Kuroda were found significantly susceptible and resistant to *M. persicae* population buildup, respectively. On each variety and location, the *M. persicae* development during spring increased gradually from Day 15 to 60 before it crashed on Day 75 while during fall it was gradually increasing from Day 15 to 30 and thereafter it decreased till the crop maturity.

Table 4.III Interaction effect of seasons x plant growth stages x varieties (S x Pgs x V) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), per nine compound leaves of potato plants

Season	Plant growth stages (Pgs)	Varieties								
		Cardinal	Desiree	Diamant	Kuroda	Santee	Ultimus	Ajax	Raja	Multa
Spring	Day 15	3.98	6.69	4.94	2.87	4.81	4.67	4.45	5.43	4.94
	Day 30	10.42	18.43	12.19	9.78	11.39	11.95	10.42	12.12	11.50
	Day 45	15.29	26.26	17.78	14.48	15.81	16.53	16.19	17.25	17.57
	Day 60	21.71	31.98	26.23	17.82	26.00	25.18	25.27	25.75	25.81
	Day 75	6.30	10.44	8.03	5.23	8.23	7.83	7.21	7.92	8.21
Fall	Day 15	2.13	3.14	2.20	1.38	2.33	1.88	1.70	1.71	1.57
	Day 30	2.82	3.96	3.45	2.30	3.01	2.99	2.98	3.34	3.40
	Day 45	2.87	3.57	2.92	2.10	2.64	2.69	2.83	2.79	2.94
	Day 60	2.01	2.76	2.36	1.71	2.36	2.44	2.32	2.46	2.01
	Day 75	0.79	1.43	1.29	0.91	1.33	1.36	1.32	1.31	1.17

LSD value for interaction effect = 0.4154
Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Table 4.IV Interaction effect of seasons x locations x plant growth stages x varieties (S x L x Pgs x V) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), per nine compound leaves of potato plant

Seasons	Locations	Plant growth stages (Pgs)	Potato Varieties								
			Cardinal	Desiree	Diamant	Kuroda	Santee	Ultimus	Ajax	Raja	Multa
Spring	Malakandair	Day 15	3.88	7.30	5.03	2.85	4.74	4.65	4.60	4.88	4.70
		Day 30	9.66	17.14	11.52	9.21	11.13	10.87	10.77	11.10	10.92
		Day 45	14.83	24.39	15.75	13.01	14.77	14.62	14.43	14.78	14.77
		Day 60	20.43	30.25	24.86	16.24	24.71	24.48	24.35	24.83	24.55
		Day 75	5.74	10.00	7.82	4.60	8.19	7.93	7.78	8.04	7.95
	Abbottabad	Day 15	3.58	6.32	4.53	2.66	4.55	4.40	4.07	5.37	5.25
		Day 30	10.11	18.69	11.84	9.88	11.30	11.92	10.37	12.28	11.72
		Day 45	15.38	26.82	17.17	14.64	15.73	16.17	17.14	17.36	18.19
		Day 60	22.66	31.51	26.99	17.83	25.75	25.30	25.59	25.85	25.76
		Day 75	6.99	10.49	8.02	5.84	8.82	7.65	7.89	7.79	8.21
	Mingora	Day 15	4.47	6.43	5.25	3.12	5.15	4.96	4.67	6.03	4.86
		Day 30	11.50	19.45	13.22	10.26	11.73	13.07	10.13	12.96	11.87
		Day 45	15.65	27.56	20.41	15.79	16.94	18.81	17.00	19.60	19.73
		Day 60	22.04	34.17	26.85	19.39	27.53	25.76	25.87	26.56	27.13
		Day 75	6.16	10.83	8.25	5.26	7.67	7.91	5.95	7.92	8.47
Fall	Malakandair	Day 15	2.28	3.64	2.61	1.51	2.45	1.91	1.28	1.47	1.51
		Day 30	3.04	5.50	4.42	2.38	3.53	3.40	3.34	3.43	3.40
		Day 45	3.12	4.91	3.92	2.26	3.01	3.11	3.29	3.23	3.03
		Day 60	1.93	3.64	2.78	1.71	2.59	2.72	2.75	2.67	2.47
		Day 75	0.73	1.27	1.07	0.91	1.36	1.26	1.40	1.36	1.06
	Abbottabad	Day 15	2.01	2.84	1.93	1.27	2.24	1.84	1.87	1.78	1.58
		Day 30	2.68	3.15	2.87	2.24	2.71	2.75	2.77	3.26	3.37
		Day 45	2.72	2.87	2.40	1.94	2.43	2.44	2.57	2.52	2.84
		Day 60	2.01	2.29	2.11	1.67	2.18	2.27	2.06	2.24	1.74
		Day 75	0.83	1.58	1.43	0.90	1.36	1.43	1.35	1.37	1.29
	Mingora	Day 15	2.12	2.93	2.06	1.35	2.31	1.90	1.96	1.86	1.64
		Day 30	2.75	3.22	3.07	2.28	2.78	2.81	2.82	3.34	3.44
		Day 45	2.78	2.92	2.45	2.09	2.47	2.53	2.62	2.61	2.95
		Day 60	2.10	2.35	2.19	1.76	2.31	2.33	2.14	2.48	1.82
		Day 75	0.80	1.45	1.38	0.91	1.26	1.39	1.21	1.22	1.15

LSD value for interaction effect = 0.4154
Means followed by same letter(s) are non significantly different at 0.05% level of significance using LSD Test

4.3.3 Impact of seasons, locations and plant growth stages (Pgs) on ladybird beetle population

The analysis of variance for population of ladybird beetle per ten potato plants showed significant effect ($P<0.05$) due to seasons, locations and plant growth stages ‘Pgs’ (Appendix-A Table-A2). All interaction effects were also significant ($P<0.05$); except for replication x season x location (R x S x L) and seasons x locations x plant growth stages (V x L x Pgs). The results of main factors are shown in Fig 4.8. The mean values for locations showed significant variation with respect to ladybird beetle population being significantly higher at Malakandair than Mingora; however, Abbottabad did not differ significantly from any of these locations. Ladybird beetle populations on various plant growth stages were also significant being highest on Day 45 and minimum on Day 15 of seeds germination. The population during spring was significantly higher than fall.

Interaction between seasons and locations (S x L) for ladybird beetle per ten potato plants was significant (Fig 4.9). The ladybird beetle population at Abbottabad and Mingora during spring was significantly higher than fall whereas at Malakandair the season effect was not significant. The population during spring was highest at Abbottabad and lowest at Malakandair while Mingora did not differ statistically with both of these locations. The population of ladybird beetle during fall at Malakandair was significantly higher than Abbottabad and Mingora (both of which had statistically equal ladybird beetles).

Interaction between seasons and plant growth stages (S x Pgs) for ladybird beetle per ten potato plants was significant (Fig 4.10). The population during spring was at significant increase till Day 60 and crashed on Day 75. While during fall the population was at increase till Day 45 and thereafter it started decreasing gradually with significant difference till Day 75. Important point to be noted here is that the population during fall was higher than spring on Day 15 and 30 of the seeds germination and thereafter it was consistently lower till Day 75.

Interaction between plants growth stages and locations (Pgs x L) was significant, Fig 4.11. The population of ladybird beetle at Abbottabad and Mingora was at increase till Day 60 and thereafter it crashed on Day 75, however, both the location did not differ statistically on each plant growth stage. The population trend of ladybird beetle at Malakandair was statistically equal to both the locations except that on Day 15 and 30 it was significantly higher than Abbottabad and Mingora.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

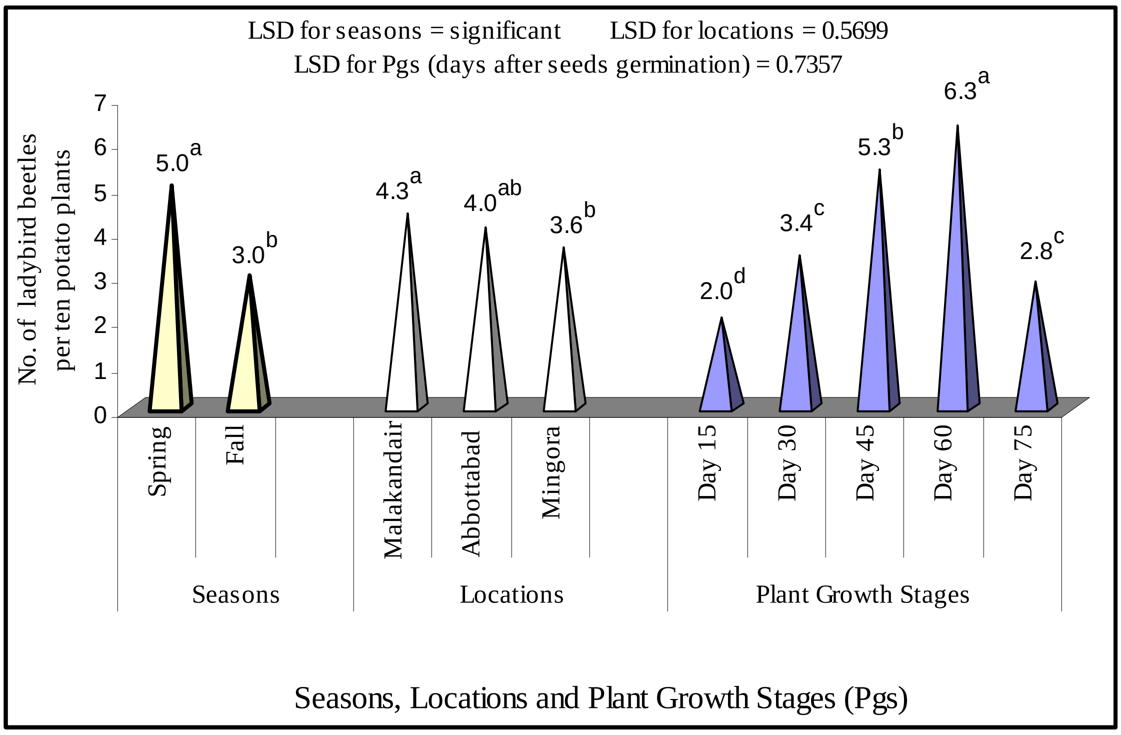


Fig 4.8 Impact of seasons, locations and plant growth stages (days after seeds germination) on the population means of coccinellids "ladybird beetles" in potato crop

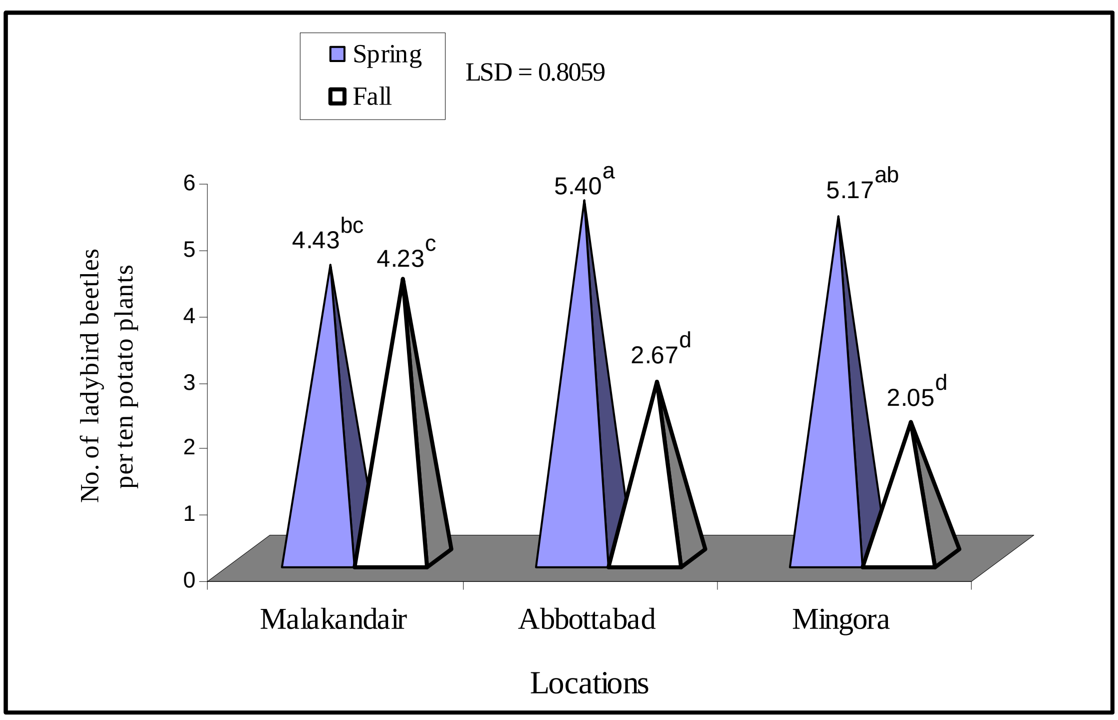


Fig 4.9 Interaction effect of locations x seasons (L x S) on the population means of coccinellids "ladybird beetles" in potato crop

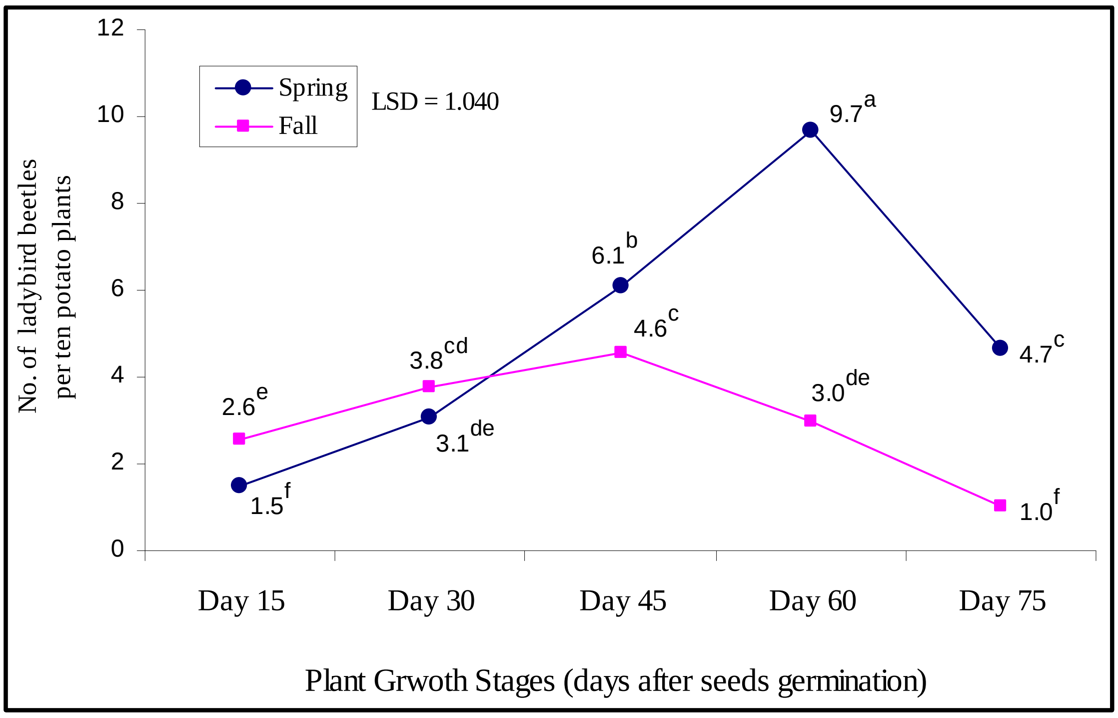


Fig 4.10 Interaction effect of seasons x plant growth stages (S x Pgs) on the population means of coccinellids "ladybird beetles" in potato crop

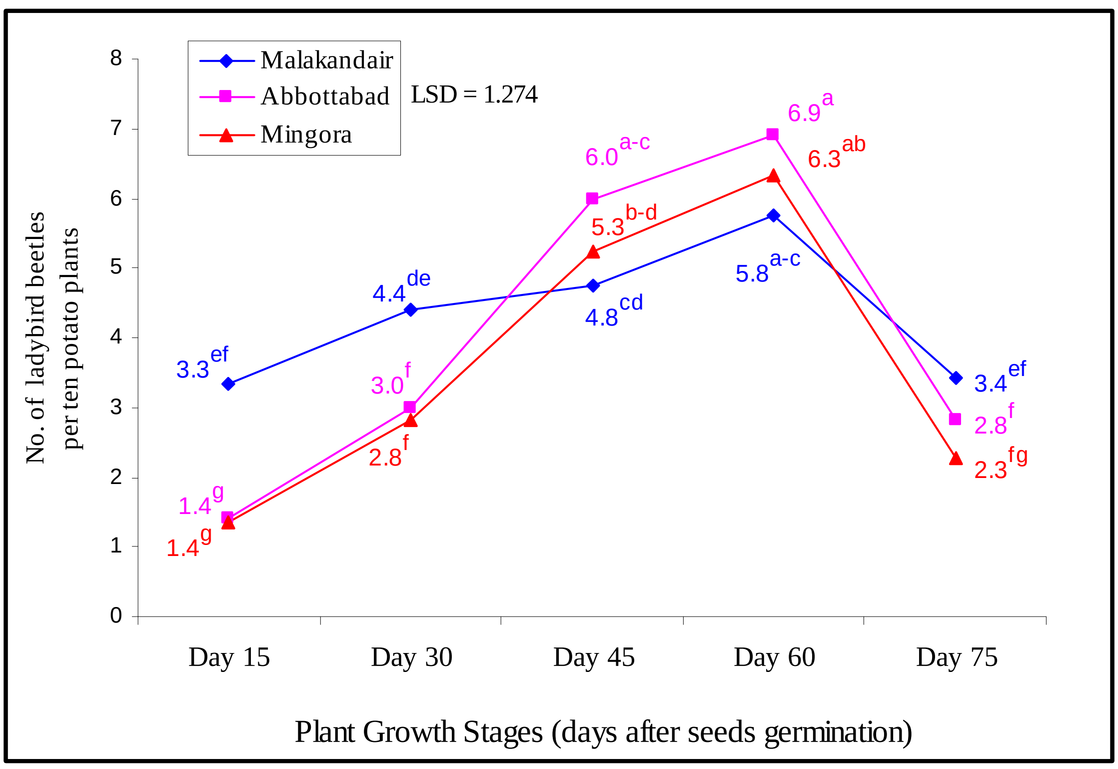


Fig 4.11 Interaction effect of plant growth stages x locations (Pgs x L) on the population means of coccinellids "ladybird beetles" in potato crop

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

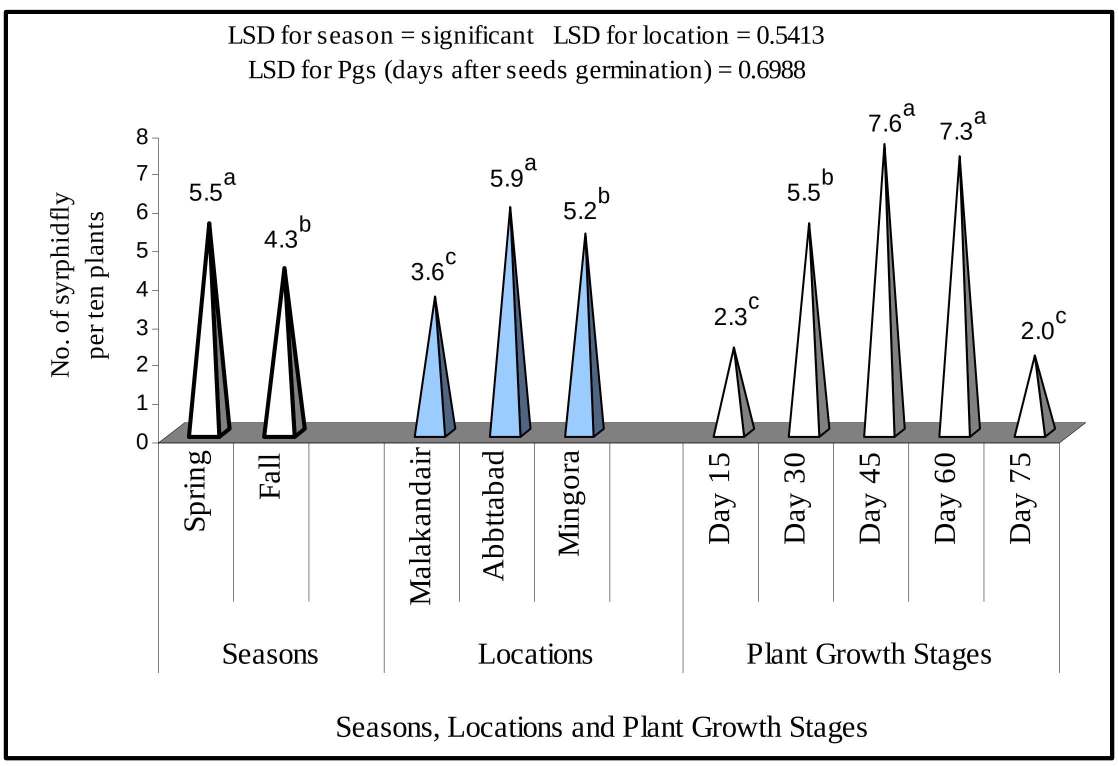
4.3.4 Impact of seasons, locations and Pgs on syrphidfly population

The analysis of variance for population of syrphidfly per ten potato plants showed highly significant effect (P<0.05) due to seasons, locations and plant growth stages (Appendix-A Table-A3). All interaction effects were also significant except for season x location (S x L) and replication x season x location (R x S x L). The results of main factors are shown in Fig 4.12. The mean values for locations showed significant variation with respect to syrphidfly population being significantly highest at Abbottabad and minimum at Malakandair. The number of syrphidfly during spring was significantly higher than fall. Syrphidfly populations on various plant growth stages were also significant being highest on Day 45 and minimum on Day 75 of seeds germination.

Interaction between plant growth stages and seasons (Pgs x S) for syrphidfly populations was significant, Fig 4.13. During spring, the syrphidfly population was at significant increase till Day 60 whereas during fall it was at significant increase till Day 45 day and declined significantly later on. The season effect in respect of syrphidfly populations did not differ on Day 30 and 45. On Day 15 the population during spring was significantly lower than fall while on Day 60 and 75 it was opposite.

Interaction between plants growth stages and locations (Pgs x L) for syrphidfly population was significant, Fig 4.14. The syrphidfly population at Mingora was at increase till Day 60 whereas at Abbottabad and Malakandair it was at increase till Day 45 and thereafter it declined. Abbottabad and Mingora did not differ in respect of syrphidfly population except Day 15 on which Abbottabad had significantly higher population. Malakandair had significantly lowest population of syrphidfly than both the locations except Day 15 and 75 on which it had statistically equal population to that of Mingora.

Interaction effect of seasons x locations x plant growth stages (S x L x Pgs) on syrphidfly population per ten plants was significant, Fig 4.15. The syrphidfly population in each location during spring was at increase till Day 60 whereas during fall it was at increase till Day 45 and thereafter it started decreasing. The syrphidfly populations during both the seasons at Abbottabad on Day 15 were statistically equal and significantly higher than the other two locations (that were statistically equal). On Day 30 during spring and fall, the syrphidfly populations at Abbottabad and Mingora did not differ statistically and were significantly higher than Malakandair. Similarly, on Day 45 during spring and fall, the syrphidfly populations at Abbottabad and Mingora did not differ statistically and were significantly higher than Malakandair; except that during fall the population at Mingora was statistically equal to that of Malakandair during both seasons. The populations during spring at Mingora and Abbottabad on Day 60 did not differ statistically and were significantly highest. The population during spring at Malakandair and fall at Mingora followed it with significant difference. The lowest populations on Day 60 were recorded during fall at Malakandair and Abbottabad, both of which did not differ statistically from each other. The population of syrphidfly during spring at Abbottabad on Day 75 was significantly highest whereas the syrphidfly population during fall at Abbottabad and during both seasons in the other two locations was statistically equal. Overall, significantly highest population was recorded during spring at Mingora and Abbottabad on Day 60 as compared to lowest during both seasons at Malakandair and Mingora, and fall at Abbottabad on Day 15 and 75.



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Fig 4.12 Impact of seasons, locations and plant growth stages (days after seeds germination) on the population means of syrphidae ‘syrphidfly’ in potato crop

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

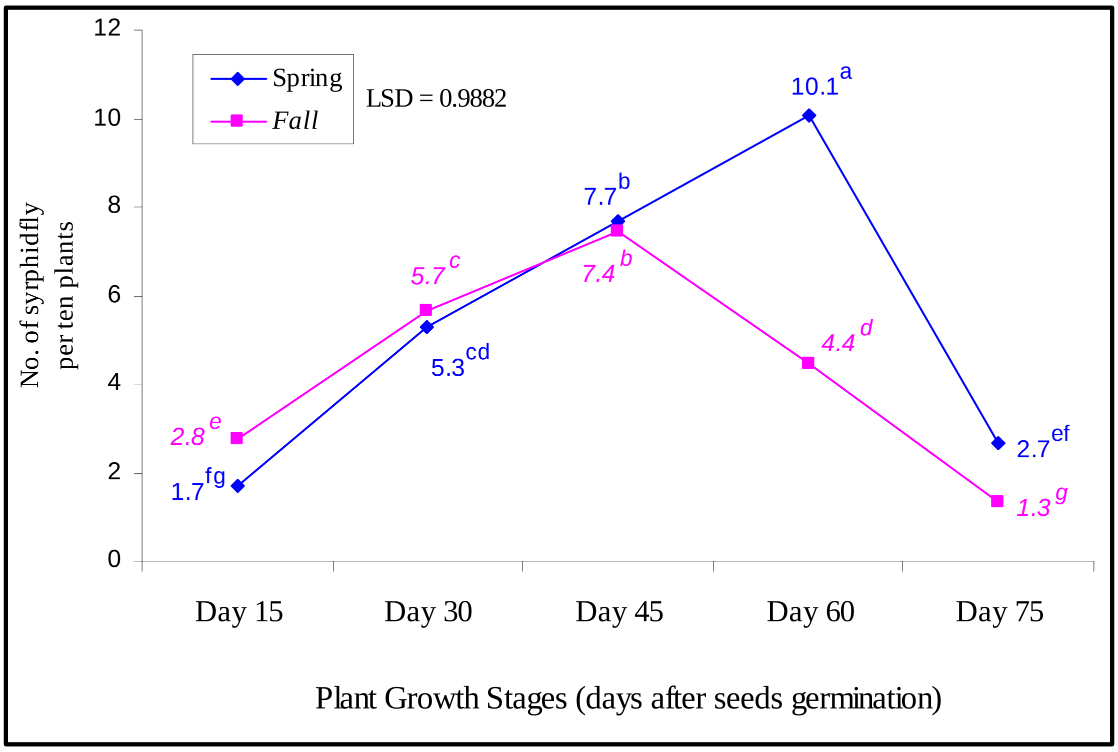


Fig 4.13 Interaction effect of plant growth stages x seasons (Pgs x S) on the population means of syrphidae 'syrphidfly' in potato crop

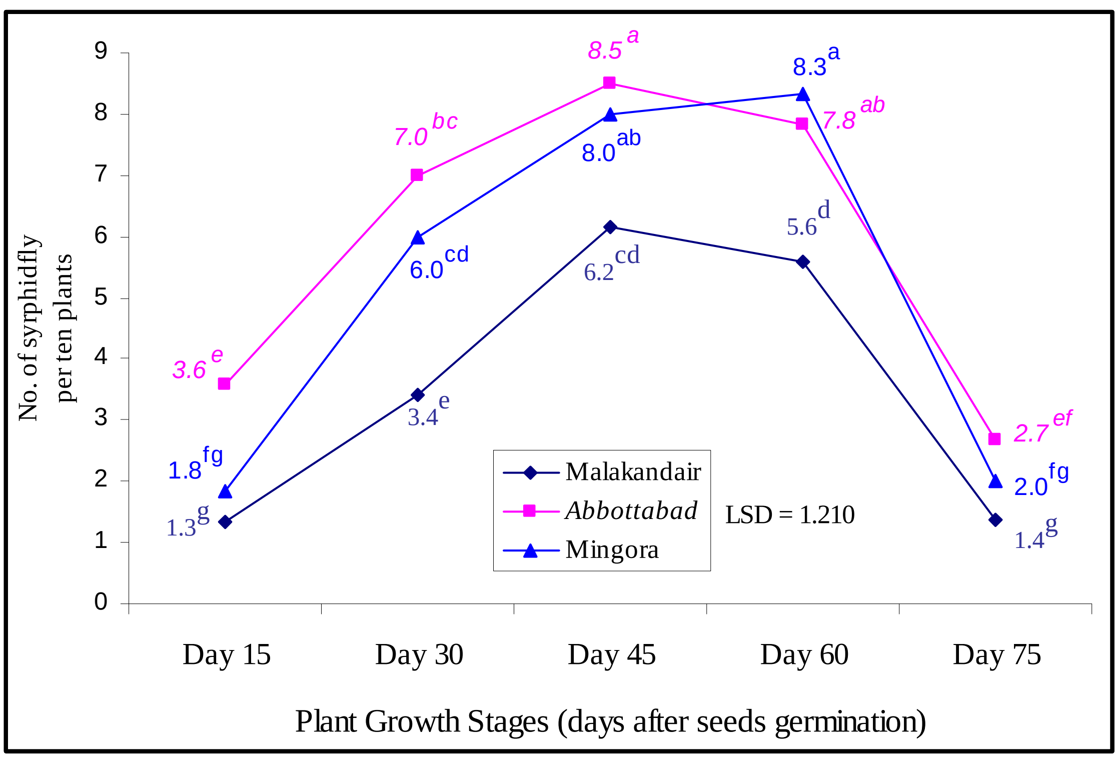
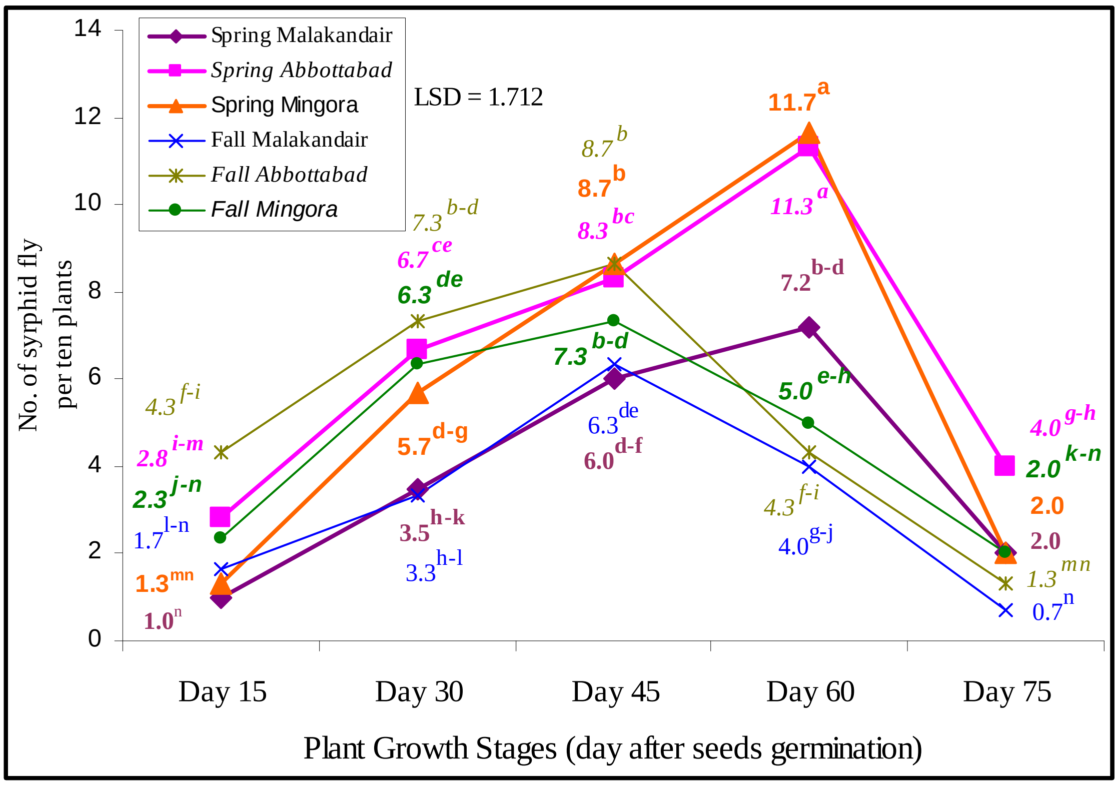


Fig 4.14 Interaction effect of plant growth stages x locations (Pgs x L) on the population means of syrphidae 'syrphidfly' in potato crop



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

Fig 4.15 Interaction effect of plant growth stages x seasons x locations (Pgs x S x L) on the population means of syrphidae 'syrphidfly' in potato crop

4.3.4 Impact of seasons, locations and Pgs on green lacewing population

The analysis of variance for population of green lacewing per ten potato plants showed highly significant effects (P<0.05) due to seasons, locations and plant growth stages (Appendix-A Table-A4). All interactions were non-significant except plant growth stages x seasons (S x Pgs). The results of main factors are shown in Fig 4.16. The mean values for locations showed significant variation with respect to green lacewing population being significantly highest at Abbottabad and minimum at Malakandair; however, the Mingora did not differ statistically from both locations. Population during spring was significantly higher than fall. Green lacewing populations on various plant growth stages were also significant being highest on Day 60 and minimum on Day 15 of the seeds germination.

Interaction between plant growth stages and seasons (Pgs x S) for green lacewing population was significant, Fig 4.17. The green lacewing population was at increase during both seasons till Day 60 before it crashed on Day 75 i.e. crop maturity. The population of green lacewing during spring was consistently higher than fall on each plant growth stage; however, season effect was statistically different only on Day 45 and 60.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

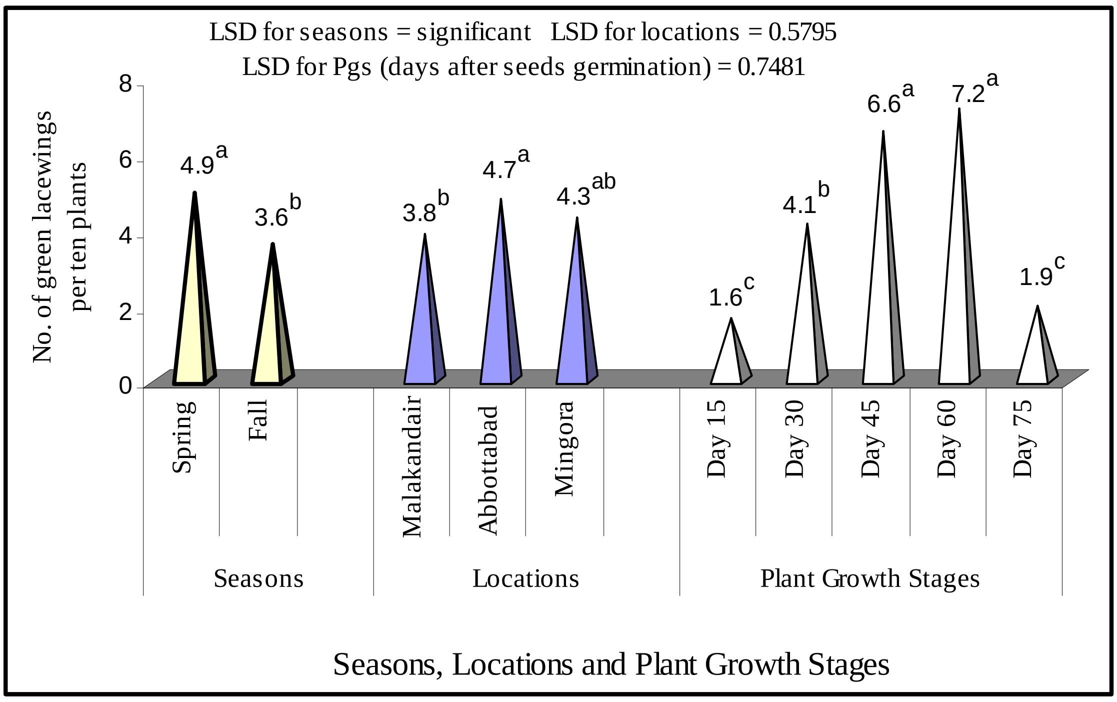


Fig 4.16 Impact of seasons, locations and plant growth stages (days after seeds germination) on the population means of *Chrysoperla spp* “green lacewing” in potato crop

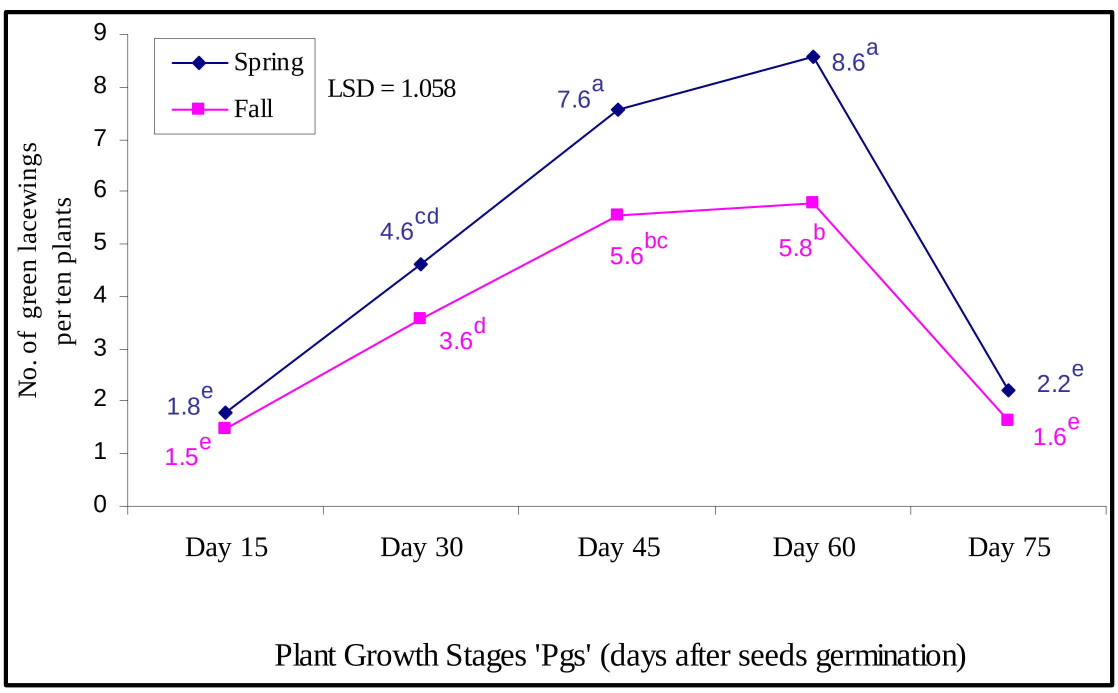


Fig 4.17 Interaction effect of plant growth stages x seasons (Pgs x S) on the population means of *Chrysoperla spp* “green lacewing” in potato crop

4.3.6 Impact of seasons, locations and plant growth stages (Pgs) on population of parasitized *M. persicae* mummies

The analysis of variance for parasitized *M. persicae* mummies population per ten potato plants showed significant effect ($P<0.05$) due to seasons, locations and plant growth stages (Appendix-A Table-A5). All interaction effects were also significant except for season x location x plant growth stages (S x L x Pgs). The results of main factors are shown in Fig 4.18. The mean values for locations showed significant variation with respect to population of parasitized *M. persicae* mummies being significantly highest at Abbottabad and minimum at Malakandair. The number of parasitized *M. persicae* mummies recorded during spring was significantly higher than fall. Parasitized *M. persicae* mummies populations on various plant growth stages were also significant being highest on Day 45 and minimum on Day 15 of the seeds germination.

Interaction between location x season (L x S) for parasitized *M. persicae* mummies population was highly significant, Fig 4.19. The populations of parasitized *M. persicae* mummies in each location during spring were significantly higher than fall. The population of parasitized mummies at Malakandair (during each season) was significantly smaller than Abbottabad and Mingora (both of which had statistically equal parasitized mummies).

Interaction between plant growth stages and seasons (Pgs x S) for parasitized *M. persicae* mummies population was significant, Fig 4.20. The population of parasitized *M. persicae* mummies during spring was at significant increase till Day 60 while during fall it was at increase till Day 45 and thereafter it decreased gradually with significant difference till Day 75. However, the parasitized *M. persicae* mummies recorded during spring were significantly higher than fall on each plant growth stage, except Day 15.

Interaction between plant growth stages and locations (Pgs x L) for the parasitized *M. persicae* mummies population was significant, Fig 4.21. The population of parasitized *M. persicae* mummies in each location was at increase till Day 60 day and thereafter it crashed on Day 75. However, the population at Malakandair was significantly smaller except Day 15 on which it was statistically equal to both the other locations and on Day 60 it was statistically equal to Mingora. Abbottabad and Mingora did not differ statistically in respect of the populations of parasitized *M. persicae* mummies on any plant growth stage.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

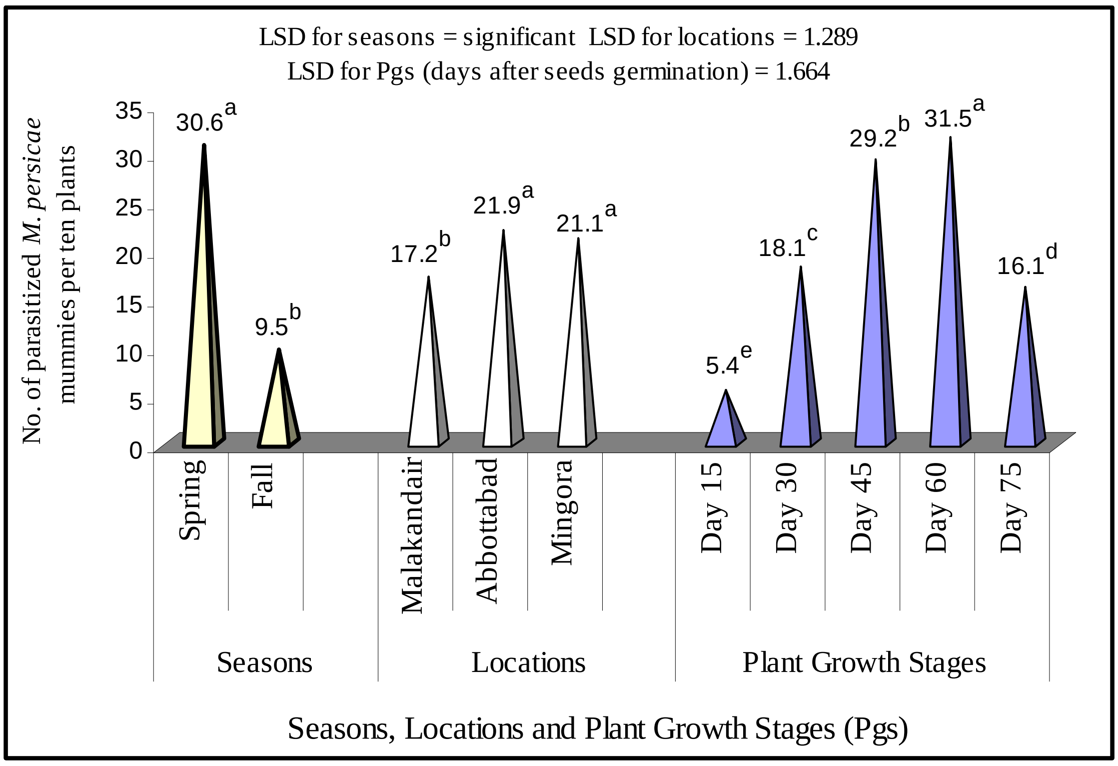


Fig 4.18 Impact of seasons, locations and plant growth stages (days after seeds germination) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop

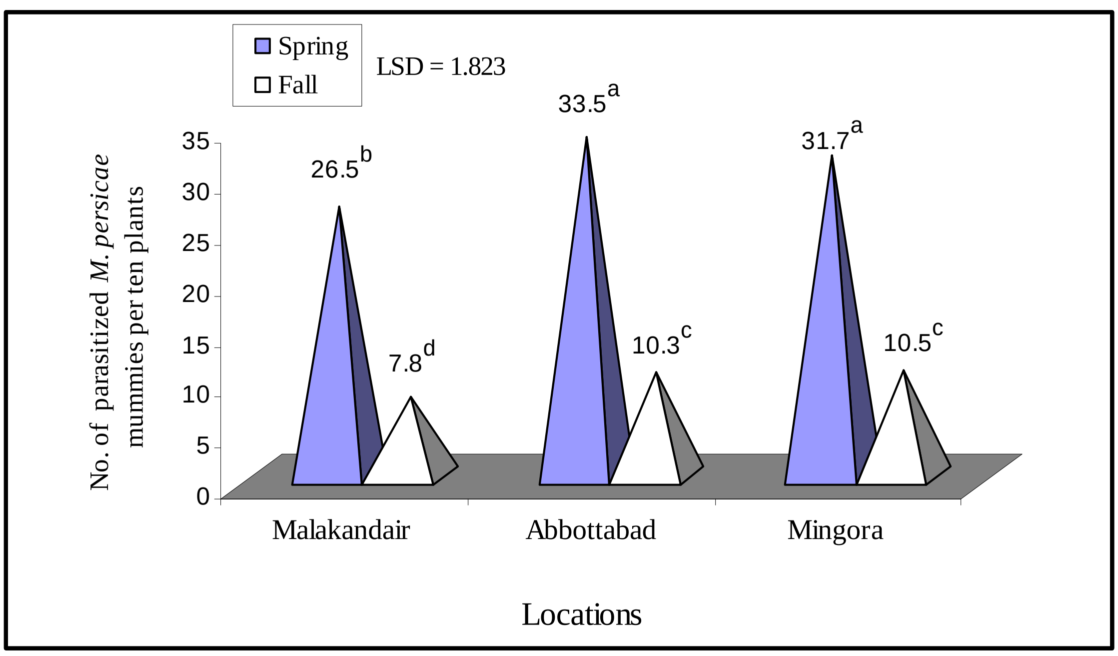


Fig 4.19 Interaction effect of locations x seasons (L x S) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

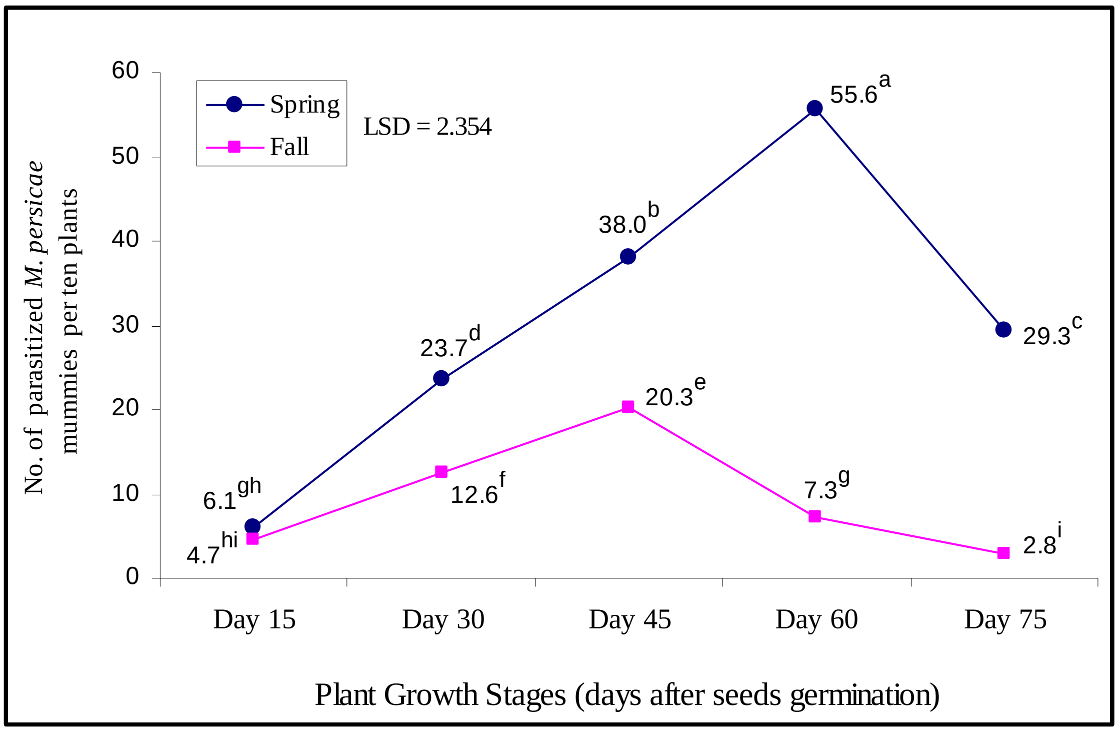


Fig 4.20 Interaction effect of plant growth stages x seasons (Pgs x S) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop

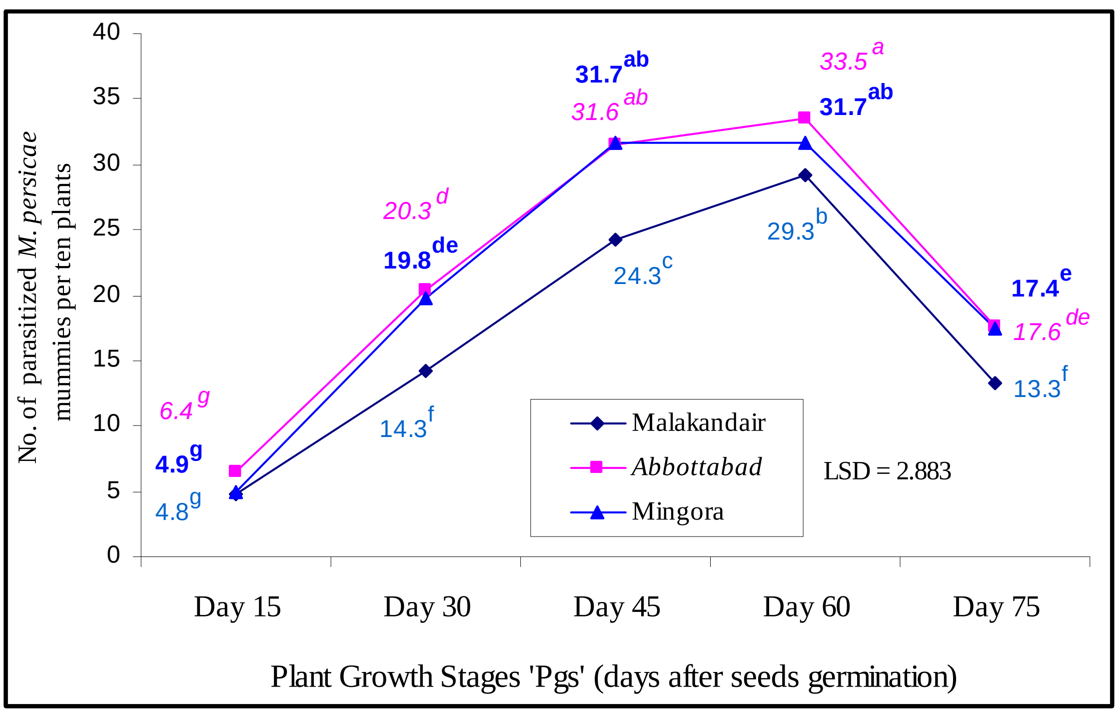


Fig 4.21 Interaction effect of plant growth stages x locations (Pgs x L) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop

4.3.7 Comparison of the population trends of the *M. persicae* and its natural enemies during spring and fall seasons (averaged over locations)

Comparison of the mean populations of *M. persicae* and its natural enemies averaged over locations (Fig 4.22) showed that the impact of all the natural enemies was directly proportional to *M. persicae* populations. Population of *M. persicae* during spring was at its increase till Day 45 of seeds germination and decreased on Day 75. Similar trends were exhibited by the ladybird beetle, syrphidfly, green lacewing and parasitized *M. persicae* mummies. Population of the *M. persicae* during fall was at its increase till Day 45 of seeds germination and then gradually declined till Day 75. The ladybird beetle, syrphidfly, green lacewing and parasitized *M. persicae* mummies showed similarly population trends. However, the population of the *M. persicae* and its all natural enemies was quite appreciably low through out during the fall season as compared to spring.

4.3.8 Comparison of the population trends of the *M. persicae* and its natural enemies during spring and fall at different locations (averaged over Pgs)

Comparison of the mean populations of *M. persicae* s and its natural enemies during spring and fall at various locations, averaged over plant growth stages, is shown in Fig 4.23. Increased natural enemies populations at various locations did not show relevancy with increase in *M. persicae* populations. During spring the ladybird beetle, parasitized *M. persicae* mummies, syrphidfly and green lacewing populations were highest at Abbottabad whereas the *M. persicae* population was highest at Mingora. During fall maximum population of ladybird beetle and *M. persicae* was recorded at Malakandair; parasitized *M. persicae* mummies at Mingora; whereas syrphidfly and green lacewing were found in abundance at Abbottabad.

4.3.9 Comparison of the population trends of the *M. persicae* and its natural enemies during spring and fall at various locations (averaged over seasons)

Mean population comparison of the *M. persicae* and its natural enemies at different locations on various Pgs, averaged over seasons is shown in Fig 4.24. The populations of all the natural enemies increased with increase in the population of *M. persicae* till Day 60 and crashed on Day 75 just like *M. persicae*; except that the peak population of syrphidfly and green lacewing at Malakandair, and the peak population of syrphidfly at Abbottabad were recorded on Day 45.

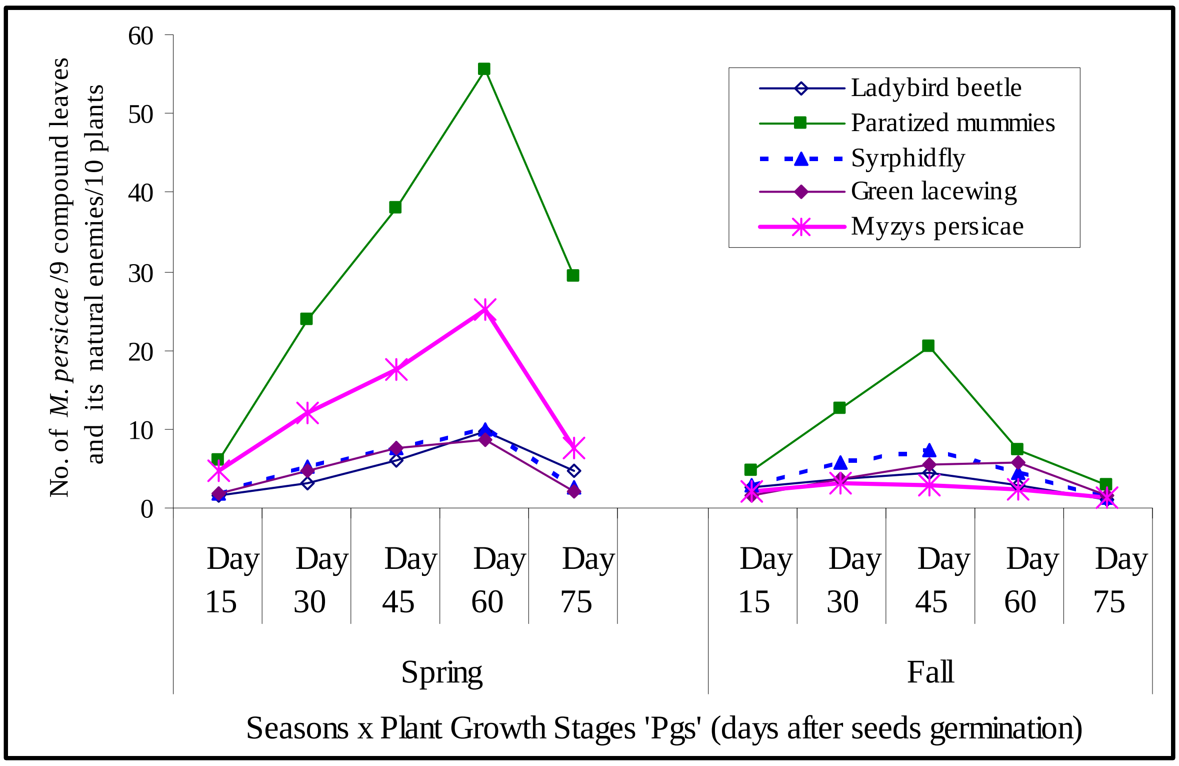


Fig 4.22 Comparison of the population trends of green peach aphid (GPA), *Myzus persicae* (Sulzer), and its natural enemies on various plant growth stages 'Pgs' during spring and fall in potato crop (averaged over locations)

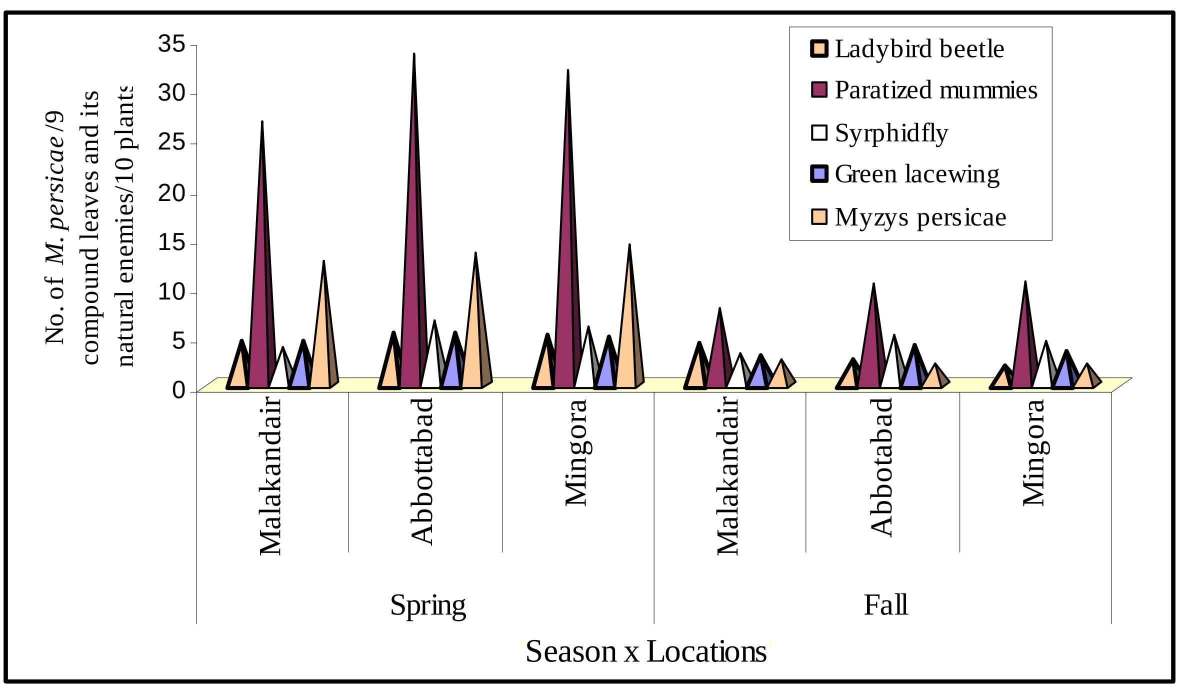


Fig 4.23 Comparison of the population trends of green peach aphid (GPA), *Myzus persicae* (Sulzer), and its natural enemies at different locations during spring and fall in potato crop (averaged over plant growth stages)

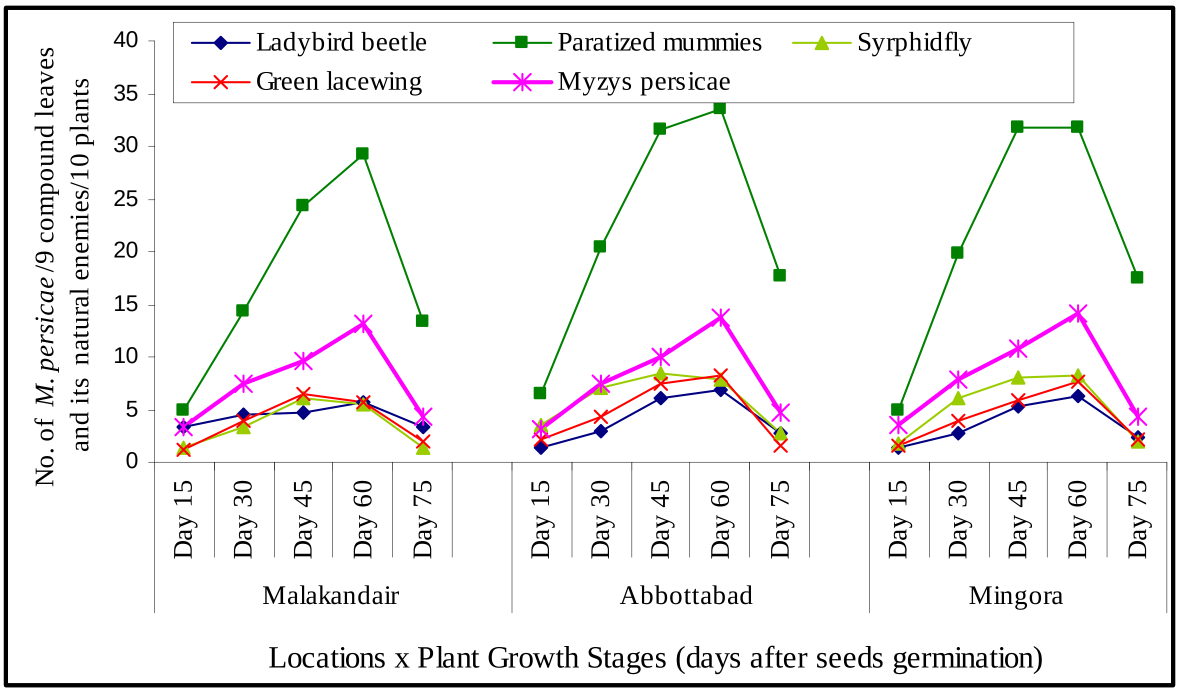


Fig 4.24 Comparison of the population trends of green peach aphid (GPA), *Myzus persicae* (Sulzer), and its natural enemies at different locations on various plant growth stages in potato crop (averaged over seasons).

4.3.10 Comparison of the population trends of the *M. persicae* and its natural enemies on <u>spring season potato crop</u>

Comparison of the mean populations of *M. persicae* and its natural enemies (Fig 4.25) during spring showed that population trends of all the natural enemies in all the three locations were directly proportional to the population trends of *M. persicae*. Population trends of all these biota were at increase till Day 60 of seeds germination before it crashed on Day 75.

4.3.11 Comparison of the population trends of the *M. persicae* and its natural enemies on <u>fall season potato crop</u>

Mean population comparison of *M. persicae* and its natural enemies on various Pgs during fall in potato crop at different locations is shown in Fig 4.26. At Malakandair, population trends of the ladybird beetle and *M. persicae* were at increase till Day 30 of the seeds germination whereas the parasitized *M. persicae* mummies, syrphidfly and green lacewing population trends kept increasing till Day 45 of the seeds germination. At Abbottabad and Mingora the *M. persicae* population trend was at increase till Day 30 whereas population trends of its natural enemies were at increase till Day 45 of seeds germination and thereafter it decreased.

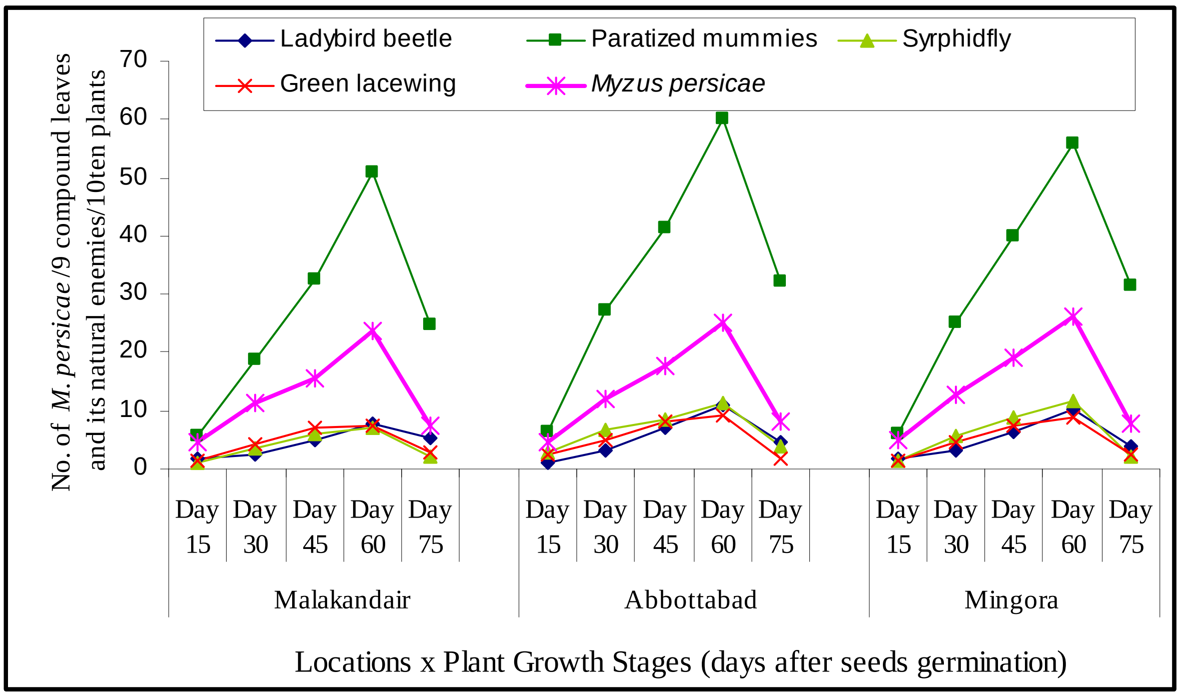


Fig 4.25 Comparison of the population trends of green peach aphid (GPA), *Myzus persicae* (Sulzer), and its natural enemies at different locations on various plant growth stages (Pgs) during **spring-season potato crop**.

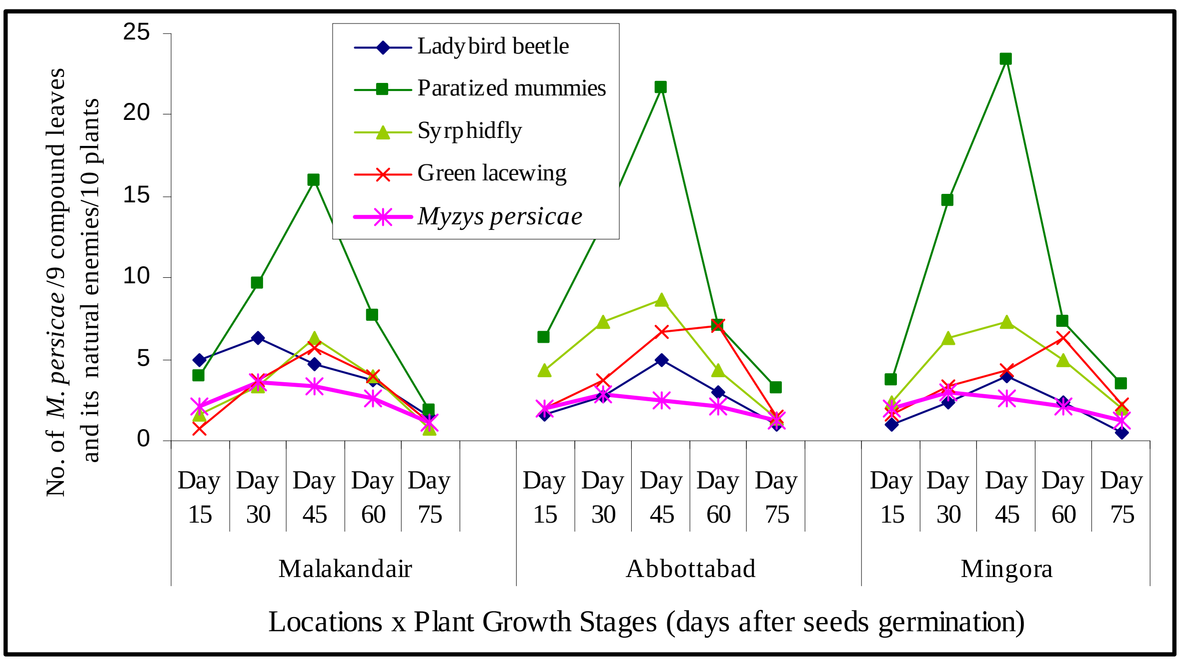


Fig 4.26 Comparison of the population trends of green peach aphid (GPA), *Myzus persicae* (Sulzer), and its natural enemies at different locations on various plant growth stages 'Pgs' during **fall-season potato crop**.

4.4 DISCUSION

Model selection and parameter estimates indicated that the data were consistent with the hypotheses that the *Myzus persicae* infestations and incidence of its natural enemies were associated with the locations, seasons and the potato varieties. During spring, the *M. persicae* was highest at Mingora, lowest at Malakandair and intermediate at Abbottabad. During fall, it was highest at Malakandair and statistically equal at Mingora and Abbottabad. The seasonal response showed that during spring *M. persicae* population was higher than fall by 79.9, 84.2 and 84.5% at Malakandair, Abbottabad and Mingora, respectively. The reversal in populations means at Malakandair as compared to other two locations during the spring and fall was probably due to the difference in temperature, as the temperature effect the range, development, survival and abundance of *M. persicae* (Bale *et al*., 2002; Capinera, 2005; Saljoqi, 2009)..

The temperature in all three locations was at increase from sowing to harvesting during spring while during fall it was at decrease. During spring, the minimum temperature for this period at Malakandair, Abbottabad and Mingora fluctuated between 5.6-20^{o}C, 3-15^{o}C and 4-16^{o}C, respectively, while the maximum temperature fluctuated between 19-35^{o}C, 13-28^{o}C and 14-30^{o}C, respectively. During fall, the minimum temperature fluctuated between 7-25^{o}C, 5-15^{o}C and 6-17^{o}C, respectively, while the maximum temperature fluctuated between 20-33^{o}C, 15-24^{o}C and 17-27^{o}C, respectively, in the corresponding locations (Table 4.I).

These figures clearly indicated that temperature during spring was not favorable for *M. persicae* at Malakandair especially in the later stages of the crop as its fertility drops at temperature above 30°C (Robert, 2003; Saljoqi, 2009). In contrast, at Abbottabad and Mingora the mean monthly minimum-maximum temperature did not cross 30°C at any stage of the crop till harvesting. The higher population of *M. persicae* at Mingora as compared to Abbottabad during spring may be explained by warmer winter (Harrington, 2008), low precipitation (Pinto *et al.*, 2000) and smaller populations of all the four natural enemies studied (Ito *et al.*, 2005). *M. persicae* continues to grow over the winter when it is warm enough. Warm winter make the aphid flight earlier by two weeks for every 1^{o}C rise in combined mean temperature of January and February and thus after a warm winter much larger numbers are detected during earlier spring (Harrington, 2008). The lower population of *M. persicae* during fall at Mingora and Abbottabad vs Malakandair may be explained by the extreme decline in temperature especially in later stages of the crop that suppressed its population, as longevity of various stages of *M. persicae* in its life-cycle increase with decrease in temperature (Godfrey and Haviland, 2003; Robert, 2003; Saljoqi and van Emden, 2003c). Moreover, the declines in temperature signal/stimulate the aphids to migrate to the primary or secondary hosts and thus winged (egg producing) forms are produced (Ramel, 2008). Statistically equal populations of syrphidfly and green lacewing in all locations might be the reason that exerted more pressure on already lower population of *M. persicae* at Abbottabad and Mingora as compared to Malakandair.

The higher population of *Myzus* during spring than fall (averaged over locations) was probably due to the facts that the newly born summer aphid contained within herself not only the developing embryos of her daughters but also those of her grand-daughters developing within her daughters. Parthenogenesis combined with this 'telescoping of generations' gave the aphids an exceedingly rapid turn-over of generations i.e. they built up immense populations very quickly (Ramel, 2008). Moreover, the temperature remained feasible for their development, nearly through out the crop's life. The extremely low population of *M. persicae* during fall indicates that the period from mid April to 1st week of March in Pakistan is regarded as nearly free (Niaz and Muhammad, 2007).

The locations in respect of mean populations of parasitized *M. persicae* mummies, during both the seasons, showed that at Abbottabad and Mingora (being statistically equal) it was significantly higher than Malakandair. While for syrphidfly and green lacewing the difference among locations was not significant. The ladybird beetle responded differently. During spring, its mean population was significantly highest at Abbottabad, lowest at Malakandair and intermediate at Mingora. While during fall, its population at Abbottabad and Mingora (being statistically equal) was significantly lower than Malakandair. The seasonal response of the populations of natural enemies showed that during spring it was higher than fall in all the three locations, similar to *M. persicae*. These results indicated that the abundance of natural enemies may be interlinked with the abundance of prey/food (*M. persicae*), as appropriate foods have favorable effects on reproduction, rate of larval development, larval mortality and adult fresh weight of the predators (Kalushkov and Hodek, 2005). According to Cabral *et al* (2006), *M. persicae* fed ladybird beetle have decreased pre-oviposition period, and increased adult longevity, fecundity and fertility. The lower means of these natural enemies (other than ladybird beetle) at Malakandair during fall may be backed by the intraguild or extraguild predations due to food/ *M. persicae* scarcity (Hindayana *et al.,* 2001; Wiebe and Obrycki, 2002).

On each location *M. persicae* population was at significant increase till Day 60 and 30 of the seeds germination during spring and fall, respectively, thereafter it decreased (at crop maturity during spring). These results indicated that the appearance of *M. persicae* is associated with formation of lateral shoots (Suarez *et al.*, 1991). The difference in population trend between the seasons, as explained earlier, was may be due to the fact that the temperature during spring was at increase from sowing to harvesting while during fall it was opposite; so the rise and fall in *M. persicae* population may be regarded as due to temperature. For example, the developmental time of *M. persicae* from 1st instar to adult stage decrease as the temperature increase under a 16L–8D photoperiod (Ohta and Ohtaishi, 2002). The *M. persicae* appears soon after the emergence of spring planting (alate females and nymphs appears during 2^{nd} and 3^{rd} weeks after planting). Alate adult apterae appear 1-2 weeks later. Alate adults and nymphs increased till 2^{nd} week of March (the reproductive stage of the crop) and thereafter, it declined i.e. during senescence (Narvaez and Notz, 1994; Misra and Agrawal 1998b; Karley *et al.,* 2003). The response of natural enemies in this regard was nearly similar to *M. persicae* for the reasons discussed earlier.

The varieties responded significantly different in resistance to *M. persicae* population buildup (Saljoqi and van Emden, 2003b; Saljoqi *et al*., 2003). However, the sequence of resistance difference among varieties was nearly similar in all locations. During spring at Malakandair, Desiree and Kuroda were the most susceptible and resistant varieties, respectively, with 48.5% difference in *M. persicae* populations. Cardinal was the 2^{nd} highest in resistance with *M. persicae* population fewer by 38.8% than Desiree. The other seven varieties were higher in resistance than Desiree by 27.1 to 30.5%. Nearly similar sequence of resistance difference among these potato varieties was recorded during spring at Abbottabad and Mingora. The difference in resistance to *M. persicae* among potato varieties/lines with up to 51% has been reported (Min *et al.*, 1997; Alvarez *et al.,* 2006; Tobias and Olson, 2006). During fall, at Mingora and Abbottabad, Desiree and Kuroda did not prove (statistically) as the most susceptible and resistant varieties, respectively, as such all the cultivars respondent differently in resistance to *M. persicae*. The reason might be very low incidence of *M. persicae*. However, at Malakandair the Desiree and Kuroda were the most susceptible and resistant varieties, respectively, with 8.9% difference in *M. persicae* populations. These results clearly demonstrated that the susceptible variety in one location was consistently susceptible in other locations and similarly was the resistant variety; although, the locations had significantly different populations densities *M. persicae*.

The difference in resistance between varieties/cultivars has been reported, as due to; trichomes (Lapointe and Tingey, 1986); olfactory and visual cues, and factors residing at cuticular and subcuticular levels (Vargas *et al.*, 2005); the cues located on the plant surface or in subcutaneous tissues being perceived by winged colonizers of several aphid species prior to initiate feeding (Margaritopoulos *et al.*, 2005); the adverse effects on development, longevity and reproduction of *M. persicae* (Saljoqi *et al.*, 2003); harder for the aphids to reach the phloem, initiate sap uptake or sustain food ingestion (Sauge and Monet, 1998); the defensive chemicals i.e. glycoalkaloids (Fragoyiannis *et al.*, 2000); genetic variations (Alla *et al.*, 2003), plants physiology e.g. leaf surface/plant tissues like epidermis, mesophyll, and phloem (Alvarez *et al.*, 2006), and so on. Since the objective of these experiments was field evaluation of potato varieties for resistance to *M. persicae* on the basis of population density/incidence level, hence, the other factors responsible for resistance were beyond the scope of this study and were thus not explored.

4.5 CONCLUSIONS

Kuroda proved as the most resistant and Desiree as the most susceptible to *M. persicae* among the nine tested potato varieties. During spring the *M. persicae* infestation was higher than the fall crop in all the three locations. *M. persicae* infestation during spring was maximum at Mingora and minimum at Malakandair. During fall the maximum population was recorded at Malakandair whereas Mingora and Abbottabad did not differ for *M. persicae* population. In all locations, during spring the population of *M. persicae* was at increase till Day 60 whereas during fall the population was at increase till Day 30 of seeds germination and thereafter it started decreasing.

The populations of all the natural enemies were directly proportional to the *M. persicae* populations in all the locations. Maximum populations of the natural enemies were recorded in Abbottabad and minimum in Malakandair. Season effect on ladybird beetle population was significant at Abbottabad and Mingora being maximum population during spring than fall. Season effect on ladybird beetle population at Malakandair didn’t differ significantly. Population of parasitized *M. persicae* mummies during spring was significantly higher than fall whereas syrphidfly and green lacewing populations during spring did not differ from fall, in all the locations.

4.6 RECOMMENDATIONS

The conclusions above lead the following recommendations:

1) Kuroda is comparatively resistant and Desiree is a susceptible potato variety to *M. persicae*. However, antibiosis test on varieties may further strengthen the hypothesis.

2) *M. persicae* infestation on spring potato crop is more severe compared to fall season crop and thus needs more attention.

3) *M. persicae* infestation at Mingora is severe and followed by Abbottabad and Malakandair. However, the *M. persicae* populations in each location require additional tools of IPM, as even the resistant variety did not keep the infestation below thresh hold level.

4) The populations of ladybird beetle, syrphidfly, green lacewing and parasitized *M. persicae* mummies are encouraging in all the three locations and IPM components may require including techniques with least adverse effect on these natural enemies.

Chapter 5

ANTIBIOTIC RESISTANCE OF POTATO VARIETIES AGAINST GREEN PEACH APHID, *M. PERSICAE* (SULZER)

5.1 INTRODUCTION

Antibiosis, antixenosis and tolerance are the three categories of host plant resistance. Generally host plant resistance is the ability of a variety to yield good quality crop compared to ordinary varieties at equal level of insect infestation. Antibiosis enhances the adverse effects of host/potato plant on life history/biology of the pest due its chemical composition. Some varieties develop larger number of *M. persicae* as compared to others and the resistance again in mature plant varies among the leaves of different ages; young being resistant than older. The variant response of genotypes to *M. persicae* is found at the leaf surface and other plant tissues levels including epidermis, mesophyll and phloem (Alvarez *et al.,* 2006). Such adverse effects of potato plants may depress survival rate, development rate, fecundity and may slow down the intrinsic rate of population increase of the *M. persicae* (van Emden 1987; Saljoqi *et al.*, 2003). Host plants may be assessed for antibiotic properties like development time, adult weight, embryo development and the production of nymphs. And intrinsic rate of population increase (r_m) may be correlated with these parameters of aphid growth and reproduction (Saljoqi *et al.*, 2003).

In light of the above information, the objective of this research experiment was to carry out antibiosis test along with the previous experiment ‘Chapter-4’ on all the nine potato varieties raised at Malakandair.

5.2 MATERIALS AND METHODS

5.2.1 Rearing *M. persicae*

The *M. persicae* was cultured on plants of potato variety Desiree in glass house. The Desiree seeds (Section 3.1) were sown in properly cleaned earthen pots measuring 20cm in diameter and 61cm height. John Innes No.2 compost was applied as planting medium.

The earthen pots were placed in rectangular muslin cages of size 70 x 60 x 60 cm. Frames of the cages and floor were made from wood where as Perspex was used in the top. Cages were closed from all sides with muslin gauze and had sleeved front for access to plants and data collection. In each cage two pots were placed. The *M. persicae* collected from potato crop were cultured on these plants in photoperiods of 14:10 hours (light: dark). The minimum temperature in glass house along the plant growth stages fluctuated between 15 and 22 ^{0}C and maximum between 23 and 46 ^{0}C.

To avoid overcrowding, the older plants in each cage were substituted weekly by new plants. *M. persicae* were then shifted to new plant using fine brush slightly wetted in distilled water. Before shifting aphids to new plants it was ensured that stylets were retracted and would not get damaged. As such, the *M. persicae* colony was first slightly disturbed through the same damped brush. Aphids were sometimes shifted by cutting leaves from older plants and placing them on new plants. Dried leaves were removed later. *M. persicae* culture was kept free of other aphid species and natural enemies.

5.2.2 Performing antibiosis test

Three equal sized plants per experimental unit were randomly selected for antibiosis test, six weeks after seed germination. Single apterous adult on middle leaf of each plant was released and clip caged (transparent clip cages of 20mm diameter and 10mm height). Wooden sticks were used that kept clip cages intact with leaves. The apterous adults were removed from all cages after 24 hours and single first instar nymph was retained per cage. These nymphs were allowed to feed and reproduce for data collection. Three first instar nymphs on middle leaves of same plant were also caged independently to replace nymph that died before reproduction.

5.2.3 Data Collection

Nymph survival; percent nymph survival rate till reproduction was measured as per equation (5.1). ***Development Time;*** it was regarded as development time of aphid from birth to reproduction and measured in days. ***Fecundity;*** the number of nymphs reproduced by aphid were counted each day for up to 10 days. Each day the new born nymphs were removed after counting and the position of gravid female along with clip cage was changed to minimize the risk of leaf damage. The total number of nymphs reproduced in 10 days was analyzed (Dewar 1977; Oakes 1981; Saljoqi *et al.*, 2003). ***The Intrinsic rate of multiplication 'population increase' (r_m);*** the r_m as insect population growth parameter (Birch, 1948; (Saljoqi *et al.*, 2003) was measured by equation (5.2).

$$\text{Percent survival rate} = \frac{\text{Number of aphids survived till reproduction}}{\text{Number of nymphs introduced}} \times 100 \text{------} \quad (5.1)$$

$$r_m = 0.74 (\log_e MD)/d \quad \text{---} \quad (5.2)$$

Where:

MD = The numbers of progeny produced by mature aphid surviving to reproduction.

d = The time from birth to reproduction

5.2.4 DATA ANALYSIS

The data was analyzed using MSTATC package by analysis of variance of ‘one factor randomized complete block design’. Means were compared using LSD Test at 5 % level of significance ($P < 0.05$).

5.3 RESULTS

5.3.1 *M. persicae* survival rate

The analysis of variance for mean survival rate of *M. persicae* on potato varieties showed significant effect ($P<0.05$), Appendix-B Table-B1. The results are presented in Fig 5.1. Lowest survival rate (61.6 %) was recorded on Kuroda as compared to highest (99.0 %) on Desiree. Diamant followed Desiree where as Cardinal and Ajax followed Kuroda significantly. All other varieties showed non-significant difference for percent survival rate of *M. persicae.*

5.3.2 *M. persicae* development time

The analysis of variance for mean development time of *M. persicae* on potato varieties showed significant effect ($P<0.05$), Appendix-B Table-B2. The results are presented in Fig 5.2. The lowest mean development time of 5.1 days was recorded for *M. persicae* fed on Desiree compared to highest (10.4 days) on Kuroda. Cardinal and Ajax did not differ statistically and followed Kuroda.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

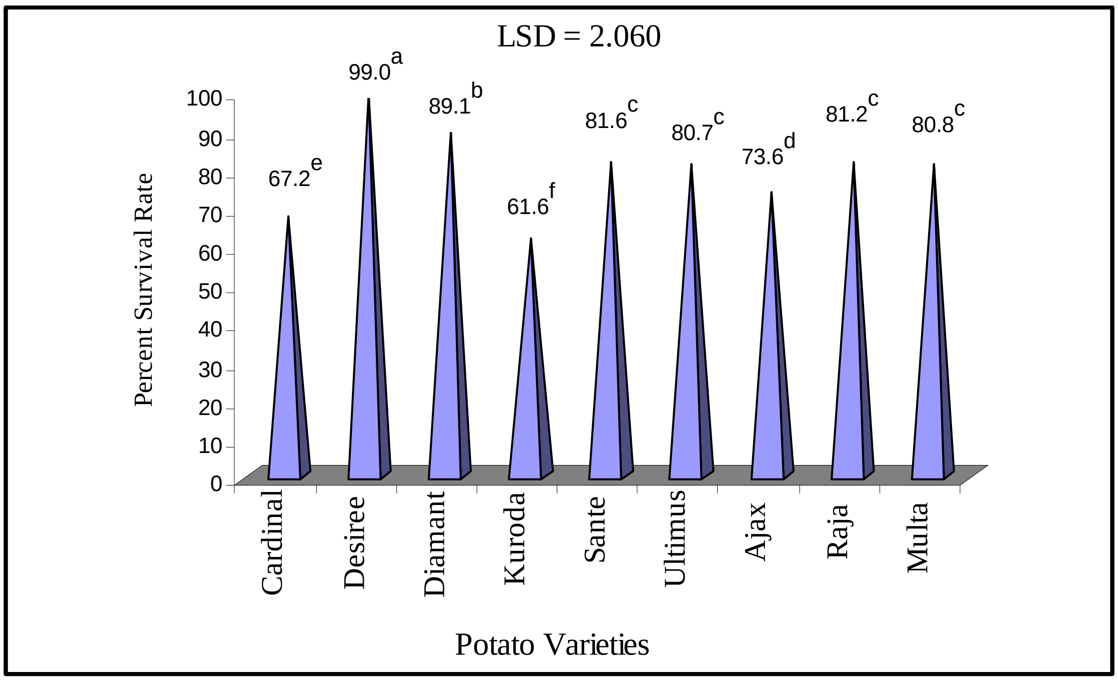


Fig 5.1 Percent survival rate of green peach aphid (GPA), *Myzus persicae* (Sulzer), on potato varieties

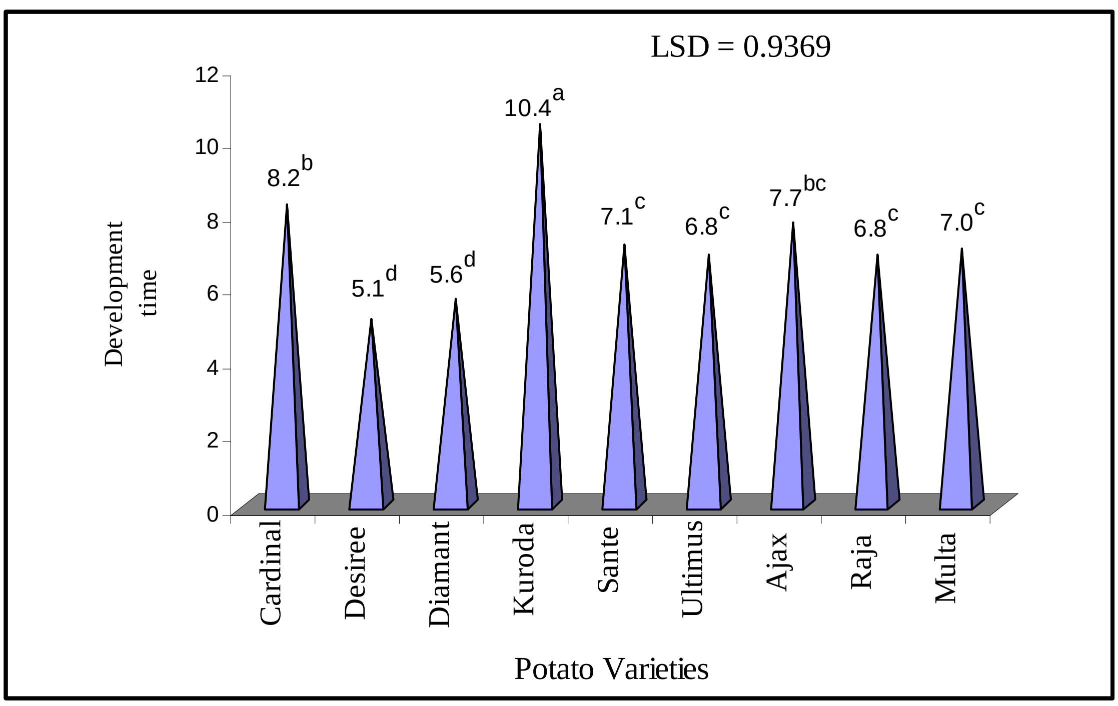


Fig 5.2 Development time (in days) of green peach aphid (GPA), *Myzus persicae* (Sulzer), on potato varieties

5.3.3 *M. persicae* fecundity rate

The analysis of variance for mean fecundity rate of *M. persicae* fed on various potato varieties showed significant effect (P<0.05), Appendix-B Table-B3. The results are shown in Fig 5.3. Highest fecundity of *M. persicae* (44.3%) during ten days was recorded on Desiree as compared to lowest (27.3) on Kuroda. Cardinal and Ajax followed Kuroda.

5.3.4 *M. persicae* intrinsic rate of multiplication (r_m)

The analysis of variance for intrinsic rate of multiplication 'population increase' (r_m) of *M. persicae* for different potato varieties was significant (P<0.05), Appendix-B Table-B4. The results are shown in Fig 5.4. The r_m was significantly highest (0.55) for Desiree as compared to lowest (0.24) for Kuroda. Diamant followed Desiree where as Cardinal and Ajax followed Kuroda. All other varieties did not differ statistically.

5.3.5 Varieties ranking based on treatments (antibiosis test parameters) grades

Potato varieties were ranked in ascending order from most resistant (1^{st}) to susceptible (8^{th}), Table 5.I. LSD lettering at 5% levels of significance were considered as grades achieved by varieties on various parameters of antibiosis test (treatments). However, LSD lettering (grades) sequence for percent survival rates, fecundity and r_m values were reshuffled and arranged in ascending order as best to worst i.e. small to large values instead of larger to small values. Grade points allotted to A, B, C, D, E, F and G were 4.00, 3.67, 3.33, 3.00, 2.67, 2.33 and 2.00, respectively. In cases of two grades for single value like BC or DC; grade points were averaged. The results showed that Kuroda achieved highest grade points and stood as the most resistant variety followed by Cardinal. Desiree was the most susceptible variety followed by Diamant.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

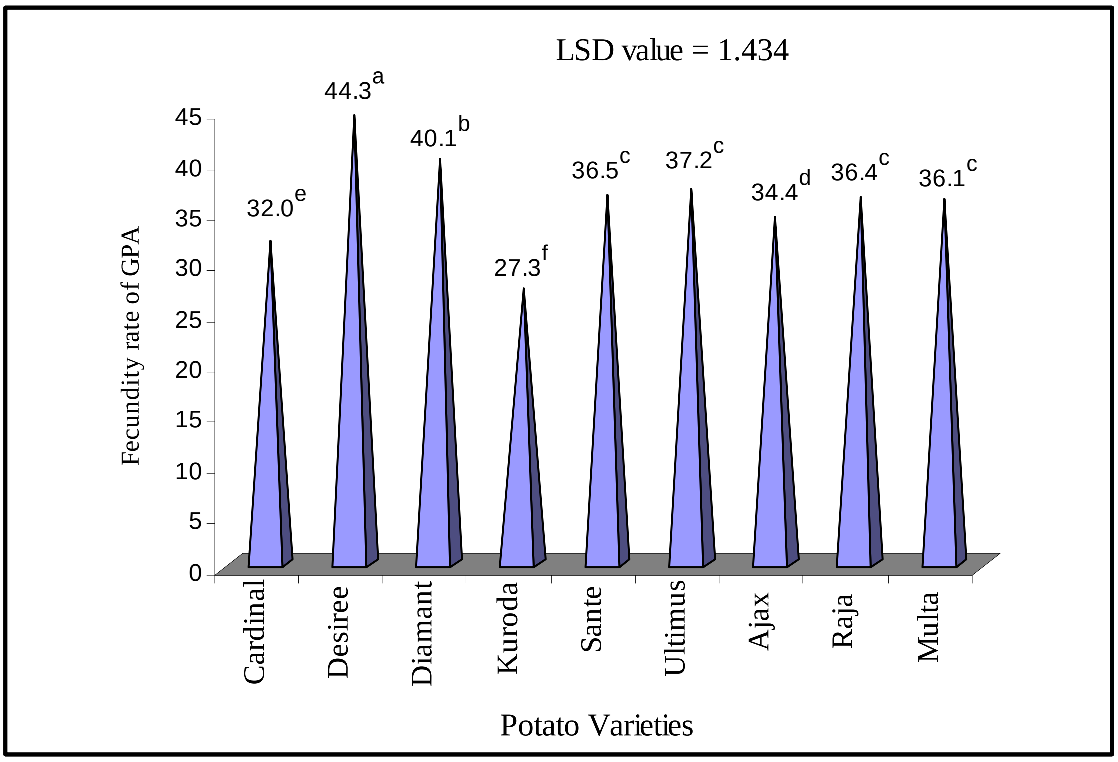


Fig 5.3 Fecundity rate of green peach aphid (GPA), *Myzus persicae* (Sulzer), over ten days on potato varieties

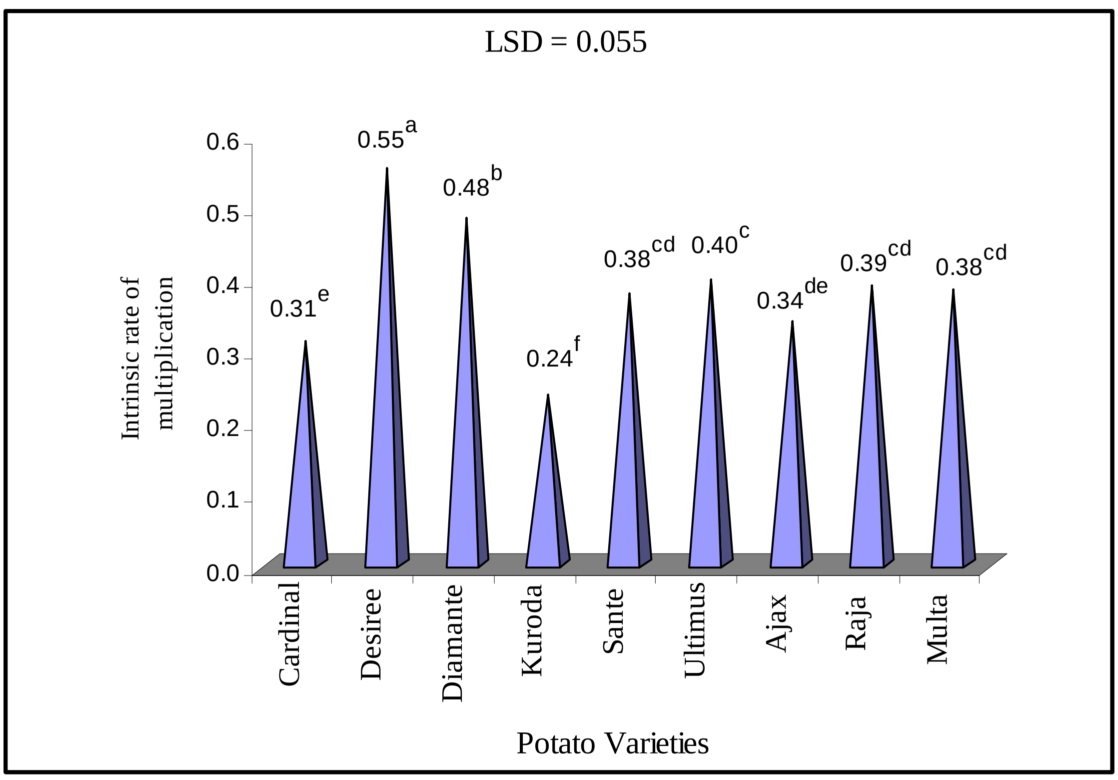


Fig 5.4 Intrinsic rate of multiplication ‘population increase’ (r_m) of green peach aphid (GPA), *Myzus persicae* (Sulzer), over ten days on potato varieties

Table 5.I Ranking of potato varieties for their resistance to green peach aphid, *Myzus persicae* (Sulzer), based on grading points of various antibiosis test parameters

Varieties	Grade/ G. point	Percent Survival	Development Time	Fecundity	r_m	Gross Points	Ranks
Cardinal	Grade	B	B	B	B		2nd
	Grade point	3.67	3.67	3.67	3.67	3.67	
Desiree	Grade	F	D	F	F		8th
	Grade point	2.33	3	2.33	2.33	2.50	
Diamant	Grade	E	D	E	E		7th
	Grade point	2.67	3	2.67	2.67	2.75	
Kuroda	Grade	A	A	A	A		1st
	Grade point	4	4	4	4	4.00	
Sante	Grade	D	C	D	CD		6h
	Grade point	3	3.33	3	3.17	3.13	
Ultimus	Grade	D	C	D	C		5th
	Grade point	3	3.33	3	3.33	3.17	
Ajax	Grade	C	BC	C	BC		3rd
	Grade point	3.33	3.5	3.33	3.50	3.42	
Raja	Grade	D	C	D	C		4th
	Grade point	3	3.33	3	3.33	3.25	
Multa	Grade	D	C	D	CD		6th
	Grade point	3	3.33	3	3.17	3.13	

5.4 DISCUSSION

The model selection and parameter estimates indicated that the data were supportive of the hypotheses that the percent survival rate, development time, fecundity rate and r_m values for *M. persicae* were associated with the resistance/susceptibility of potato varieties. Among the nine tested varieties, Kuroda and Desiree were the most resistant and susceptible, respectively, to *M. persicae* development, based on various parameters for antibiosis test. The lowest survival, fecundity and r_m values and highest development time taken by the juveniles to maturity of the *M. persicae* on Kuroda and vice versa on Desiree were the basic factors for resistance and susceptibility, respectively (Narvaez and Notz, 1993). Similar results were achieved by Cooper and Goggin (2005) whereby they induced systemic defenses/resistance in tomato using foliar application of synthetic Jasmonic acid (JA). According to Sauge and Monent (1998) and *Le et al.* (2004) aphids feeding on susceptible varieties had significantly more embryos in their gonads and laid more nymphs. The intrinsic rate of natural increase (r_m), a synthetic index of biotic potential of aphid population, was also the highest on susceptible varieties. Goundoudaki *et al.* (2003) determined Virginia (tobacco varieties) as more resistant than Oriental varieties to aphid on the basis of longer developmental time, a lower intrinsic rate of increase and higher nymphal mortality.

5.5 CONCLUSIONS

Based on lowest survival rate to reproduction, lowest fecundity rate, lowest r_m value and highest development time by the *M. persicae* juveniles to maturity on Kuroda, via antibiosis test, proved it as the most resistant while Desiree was proved as the most susceptible variety.

5.6 RECOMMENDATIONS

1) Kuroda is comparatively resistant and Desiree more susceptible potato variety.
2) Both the varieties may be included while scrutinizing IPM packages against *M. persicae* with least adverse impact on natural enemies so as to get clear picture of the benefit thus achieved.

Chapter 6

FIELD EVALUATION OF FOLIAR INSECTICIDES AGAINST GREEN PEACH APHID, *M. PERSICAE* (SULZER), ON POTATO VARIETIES AND THEIR IMPACT ON NATURAL ENEMIES

6.1 INTRODUCTION

The low tolerance in the marketplace for net necrosis and the high vectoring capacity of the *M. persicae* shows that there is a very low treatment threshold for this pest in most potato fields (Jensen, 2007). The *M. persicae* populations can often be held below damaging levels by a variety of predators, parasites, diseases, and applied cultural practices. Predators and parasites are killed by broad spectrum insecticides. Frequent applications of fungicides kill the natural beneficial fungi that keep the *M. persicae* populations suppressed. In general, these crop protection chemicals used against a variety of pests in potato, reduce the effectiveness of the natural enemies and allow the aphid populations to increase rapidly. Consequently, the aphid management in potatoes is primarily by insecticides **(**Radcliffe, 1998).

6.2 FOLIAR INSECTICIDES

Chemical control can be achieved by systemic and contact insecticides applied either as soil routed or foliar sprays (Saljoqi and van Emden, 2003a; Saljoqi and van Emden, 2003b). Foliar insecticide may be preferred over the seed dresser or soil routed insecticide as it implies whether there is need to fight or not against pests (Felsot, 2001). Foliar sprays should be employed when the aphid populations exceed thresholds. The empirically established threshold on potato is 25 *M. persicae* per three compound leaves per plant (Edward, 2008). However, thresholds (aphids/25 leaves) vary by end use: for example, for fresh market or processing it may be 50 wingless in early season and 100 wingless after bloom infestations. For fresh or processing, in seed production areas, it is 7.5 wingless *M. persicae* and 50 aphids (of all other species). For seed potatoes (to manage PLRV), it is 2.5 and 7.5 *M. persicae* on susceptible and resistant varieties, respectively (Wyman, 2005)

To evaluate the effectiveness of foliar insecticides against *M. persicae*, two insecticides, Provado 1.6F (imidacloprid) and Actara 25WG (thiamethoxam) were tested. The belief was to allow more comprehensive approach without creating a risk of resistance development. Effectiveness was based on reducing *M. persicae* population and minimum adverse/detrimental effects on its natural enemies like ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, percent parasitism of *M. persicae* by *Aphidius* (PPA*A*), percent emergence rates of *Aphidius* from parasitized *M. persicae* mummies (PER*A*) and fecundity rates of female *Aphidius* (FR*A*). The factors that made the grounds for selection of these insecticides are explained below:

6.2.1 Provado 1.6F

Provado 1.6F is foliar applied insecticide having imidacloprid as active ingredient and is manufactured by Bayer Crop Science. Imidacloprid is a chlorinated analog of nicotine; the compound therefore belongs to the class of chloronicotinyl insecticides, which is not related to any of the major insecticide classes, such as the carbamate, organophosphate and pyrethroid. Imidacloprid works by interfering with the transmission of stimuli in the insect nervous system. It causes a blockage in a type of neuronal pathway (nicotinergic) that is more abundant in insects than in warm-blooded animals (making the chemical selectively more toxic to insects than warm-blooded animals). This blockage leads to the accumulation of acetylcholine, an important neurotransmitter, resulting in the insect's paralysis, and eventually death (Kidd and James, 1994; Jenkins, 1994; Felsot, 2001). Imidacloprid is not mutagenic or carcinogenic. Moreover, it is not primarily a reproductive toxicant or an embryo toxicant, nor is it teratogenic. Due to its high insecticidal potency and relatively low mammalian toxicity, imidacloprid has a very high margin of safety (Sheets, 2001).

Imidacloprid is used as a broad spectrum systemic insecticide against a variety of pests of field crops, fruits and vegetables. It is available in various formulations like dustable powder, seed dresser (flowable slurry concentrates), granules, soluble concentrate, suspension concentrate, and wettable powder designed either for soil or foliar application. It is sold under a variety of trade names including Kohinor, Admire, Advantage, Gaucho, Merit, Confidor, Hachikusan, Premise, Prothor, Winner, Connect, Evidence, Leverage, Muralla, Provado and Trimax. (Meister, 1995; Felsot, 2001). It is especially systemic when used as a seed or soil treatment (Kidd and James, 1994; Jenkins, 1994). Imidacloprid have short persistence on tomato leaf surfaces and 50% of residues dissipate within 1.4 days under cloudy conditions; dissipation is even quicker (50% in 0.7 day) under sunny conditions (Scholz and Fritz, 1998).

Provado is effective on contact and via stomach action (Kidd and James, 1994; Jenkins, 1994). This potentially allows lower concentrations (0.05–0.125 lb a.i./acre or 55–140 g/ha) as compard to other other neurotoxins (particularly organophosphates) for insect control. Moreover, these application rates are considerably lower than older, traditionally used insecticides (Pike *et al*, 1993; Jenkins, 1994; Felsot, 2001). Recommendations for Provado 1.6F against *M. persicae* in potato is 0.047 lb a.i./acre or 3.8 fl oz of the product/acre. A total of 16 fl oz (0.2 lb active ingredient)/acre/season may be applied as a foliar spray. However, Jensen (2007) suggested not to apply more than 15 oz of the product per acre per year. Plant-back restriction is 12 months for all crops not registered. Post harvest interval recommended is 7 days (Wyman, 2005).

6.2.2 ACTARA 25WG

Actara 25WG is a foliar applied product that contains thiamethoxam as active ingredient and formulated as a water dispersible granules. It has contact, stomach and systemic properties (Syngenta, 2008a). It is second-generation neonicotinoid insecticide that belongs to thianicotinyl subclass and gives an excellent control of many sucking and chewing pests. Thiamethoxam interferes with a unique receptor site in the insect's nervous system, the nicotinic acetylcholine receptor, and is not known to be cross-resistant to any other insecticide classes. Actara has an excellent mammalian and environmental safety profile, and is well suited for use in IPM programs (Syngenta, 2008b). It can be used from the humid tropics to the continental climates, against 160 pest species in 110 crops (Radcliffe, 1998). Actara is rapidly taken up by the plants and is thus faster in action than other new insecticides such as flonicamid. The rapid uptake gives rain fastness in wet conditions. Once in the plant, Actara quickly moves through leaves and stems to target the aphid colonies in the crop canopy that might escape contact or trans-laminar insecticide applications. Its long persistency provides high levels of control for more than three weeks, when the aphids treated with other products start to recover **(**Syngenta, 2008c**;** Wyman, 2005). It controls a range of the aphids commonly attacking potatoes including *M. persicae* strains resistant to organophosphate, carbamate and pyrethroid (Syngenta, 2008a).

Due to rapid action, fast knockdown just like pyrethroids, and feasibility for early season application due to long persistency; Actara reduce transmission of the non-persistent viruses that are rapidly transmitted by feeding the aphids (Wyman, 2005). Actara is especially effective in reducing spread of persistent viruses, including Potato Leaf Roll Virus 'PLRV' (McKenzie, 2007).

Actara 25WG is used at very low rates and exhibits excellent trans-laminar movement into plant tissue (Syngenta, 2008b). Actara has the lowest dosage rate of 80g/ha (1.5 ounces of the product per acre or 0.0235 lb a.i./acre). For Seed Potato are two applications each @ 80 g/ha. This low dose rate is entirely concurrent with objectives throughout the potato industry (Wyman, 2005; Syngenta 2008a; Syngenta, 2008c). However, after confirmation, the Special Local Needs Registration (SLN) endorsed application of single 3 oz/acre dose as the most effective one (Johnson, 2001). Jensen (2007) suggested not to apply more than 0.078 lb a.i./acre/year of thiamethoxam. Ware crop growers are permitted only one Actara application per season, which is most likely to be used during rapid canopy development when the aphid numbers can build rapidly in hot weather (Wyman, 2005). Potatoes are not to be harvested for at least 7 days after its application (Syngenta, 2008a).

The research study envisaged the following **objectives**:

1. To evaluate the efficacy of foliar insecticide.
2. To determine the effective dose of each insecticide.
3. To differentiate the efficacy of foliar insecticides on resistant Kuroda and susceptible Desiree potato varieties in reducing the *M. persicae* population and their impact on the natural enemies including: (i) ladybird beetle, (ii) syrphidfly, (iii) green lacewing (iv) parasitized *M. persicae* mummies (v) percent parasitism of *M. persicae* by the *Aphidius* (PPA*A*), (vi) percent emergence rate of the *Aphidius* from *M. persicae* mummies (PER*A*), (vii) fecundity rate of the *Aphidius* (FR*A*).
4. To find the difference in yield between Kuroda and Desiree due to various treatments.

6.3 MATERIALS AND METHODS

Two potato varieties Kuroda and Desiree found as partially resistant and susceptible, respectively, in previous experiments were raised in 'Factorial Randomized Complete Block Design' at Malakandair Research Farm of Khyber Pakhtunkhwa Agricultural University Peshawar during spring 2008. Provado and Actara, each at two dosage rates, were applied as foliar spray seven weeks after sowing when *M. persicae* populations reached 10 to 12 aphids per 9 compound leaves on Kuroda variety (Wyman, 2005; Edward, 2008). Knapsack sprayer was used for insecticides application. As such, there were 36 sub-plots/experimental units representing two varieties, two insecticides, three dosage rates (including zero doses as control) and three replications. Dosage rates of insecticides are given in Table 6.I. Size of experimental units and other agronomic practices were applied as mentioned in Section 3.3.

Table 6.1 Foliar insecticides and dosage rates applied

Foliar (Fr) Insecticide	Treatments	
	Dose	Amount/rate of Dose
Provado 1.6F	Zero dose (Control 'Ct')	No insecticide (Control)
	Provado 1.6F Labeled dose	277.98 ml of the product/hectare
	Provado 1.6F reduced dose (Labeled dose reduced by 20%)	222.39 ml of the product/hectare
Actara 25WG	Zero dose (Control)	No insecticide (Control)
	Actara 25WG Labeled dose	131.70 gm of the product per hectare
	Actara 25WG reduced dose (Labeled dose reduced by 20%)	105.26 gm of the product per hectare

6.3.1 Data Collection /Population Estimates

The *M. persicae* (winged and wingless), ladybird beetle, syrphidfly, green lacewing and parasitized *Myzus* mummies were counted 1, 2, 3, 10 and 18 days of the post spray. The PPA*A*, PER*A* and FR*A* were recorded on Day 3 of the pesticides application. The methods for data collection on all of these parameters are described in Section 3.4.1 to 3.4.5. After harvesting, the yield for each treatment was determined in tons per hectare and analyzed.

6.4 DATA ANALYSIS

The data related to the *M. persicae* population was analyzed using MSTATC package by analysis of variance of 'four factors randomized complete block design' where as data related to other parameters were analyzed using MSTATC package by analysis of variance of 'three factors randomized complete block design'. Means were compared using LSD test at 5 % level of significance ($P < 0.05$).

6.5 RESULTS

6.5.1 Effect of foliar insecticides on *M. persicae* population/9 compound leaves

The analysis of variance for population of *M. persicae* per nine compound leaves showed significant effect (P<0.05) due to foliar insecticides, their doses and post treatments day intervals on potato varieties (Appendix-C Table-C1). All interactions were also significant except insecticides x post treatment day intervals (I x T), varieties x doses x insecticides (V x D x I), doses x insecticides x post treatment day intervals (D x I x T) and varieties x doses x insecticides x post treatment day intervals (V x D x I x T). The results of main factors are shown in Fig 6.1. The mean values for varieties showed significant effect being Kuroda resistant to the *M. persicae* population buildup than Desiree. Similarly Provado proved as significantly more effective than Actara in controlling *M. persicae*. Insecticides dosage rates also showed significant effect with respect to *M. persicae* population being significantly maximum on Control and minimum on plants treated with insecticides labeled doses. The *M. persicae* populations on post treatments day intervals also showed significant variations being maximum on Day 1 and minimum on Day 3.

Interaction effect of varieties x insecticides (V x I) on the means for *M. persicae* population, averaged over doses, was significant (Fig 6.2). The potato varieties responded significantly different to insecticides. Maximum number of *M. persicae* (14.8) was recorded on Desiree plants treated with Actara and minimum (7.3) on Kuroda treated with Provado.

Interaction effect of varieties x insecticides doses (V x D), averaged over insecticides, was significant (Fig 6.3). Maximum number of the *M. persicae* was recorded on Desiree control plants followed by Kuroda control plants. Minimum numbers of *M. persicae* were recorded on Kuroda plants treated with labeled doses of insecticides followed by Kuroda plants treated with reduced doses of insecticides.

Averaged over varieties, both the insecticides interacted significantly different at various insecticide doses (Fig 6.4). The *M. persicae* populations recorded on control plants were significantly maximum than insecticides treated plants. Among treated plots, minimum number of the *M. persicae* was recorded on plants treated labeled doses of Provado followed by Provado reduced doses where as maximum number of the *M. persicae* was recorded on plants treated with Actara labeled doses.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

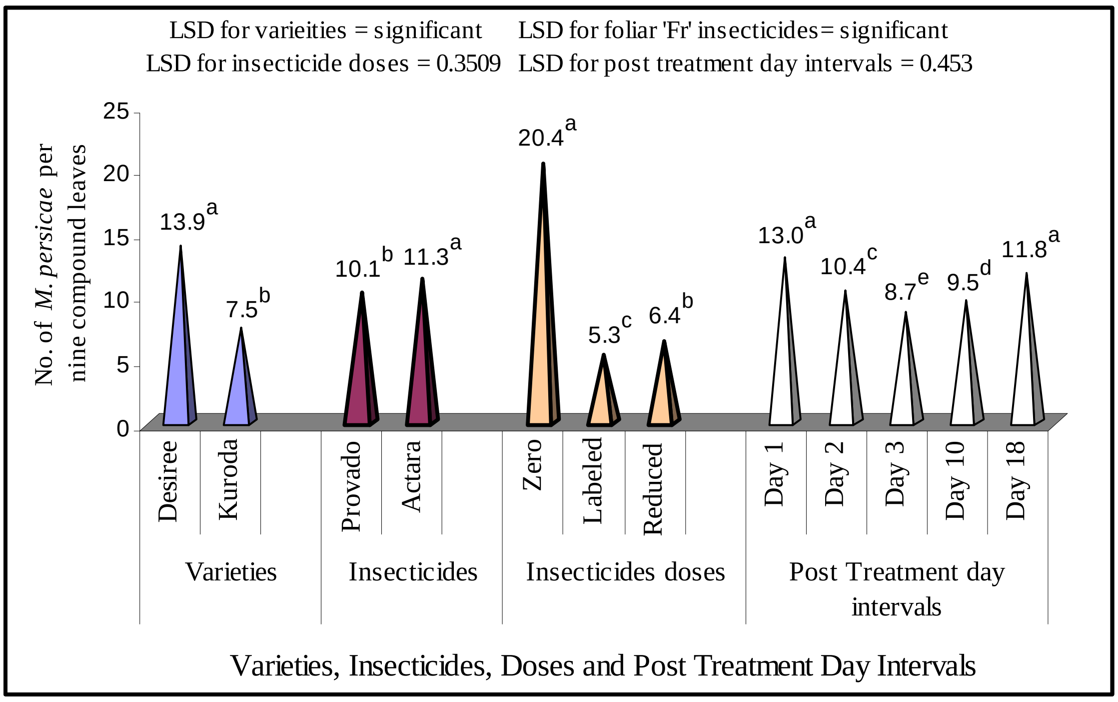


Fig 6.1 Effect of potato varieties, foliar insecticides, doses and post treatment day intervals on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop

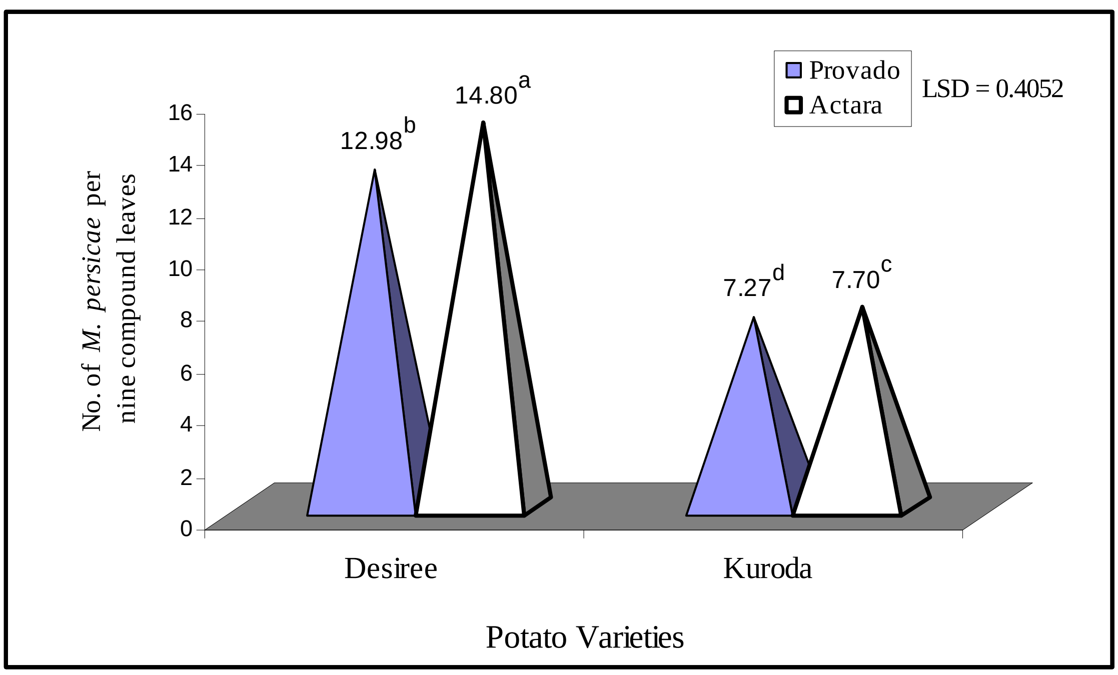


Fig 6.2 Interaction effect of potato varieties x foliar insecticides (V x I) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over doses)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

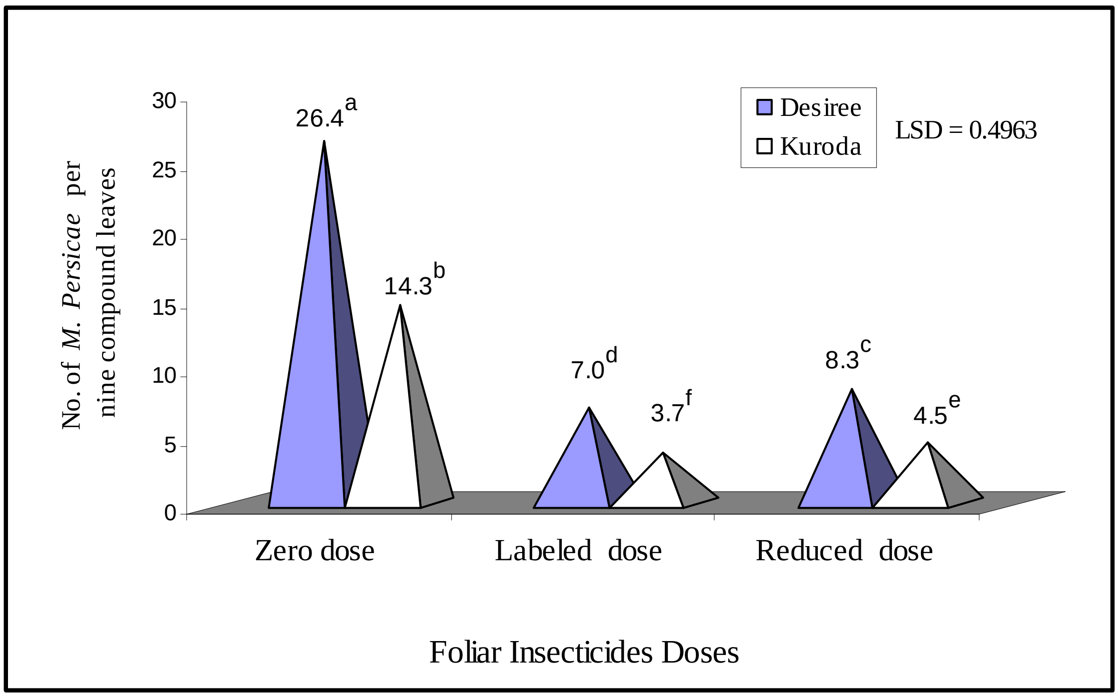


Fig 6.3 Interaction effect of potato varieties x foliar insecticides doses (V x D) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over insecticides)

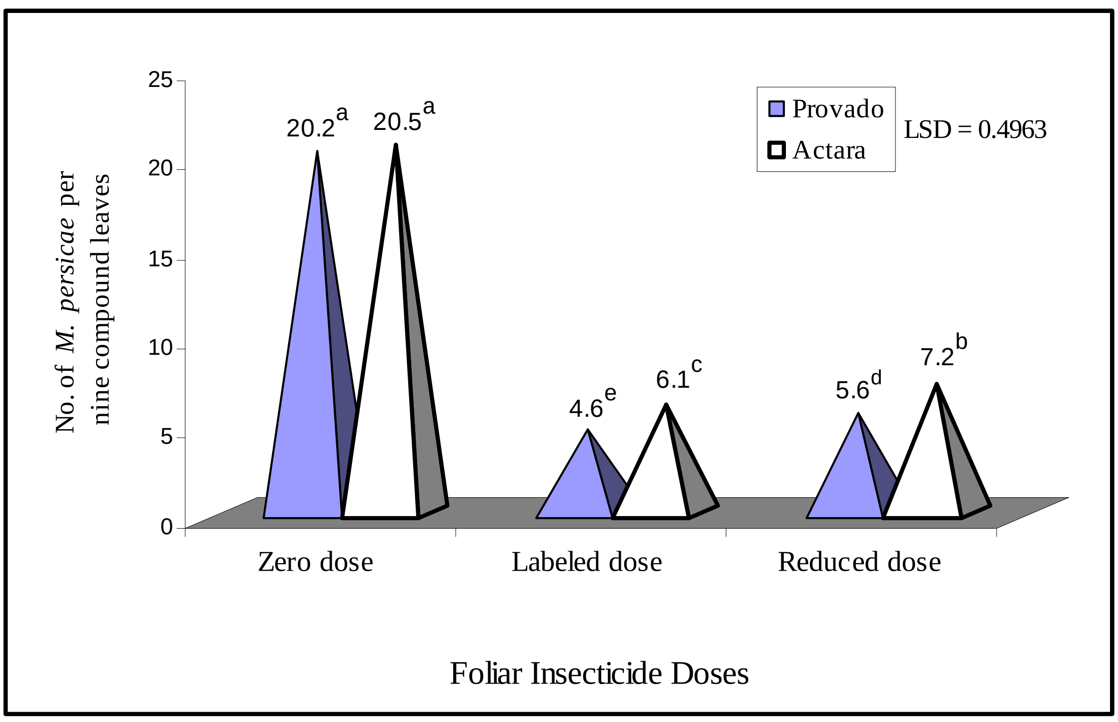


Fig 6.4 Interaction effect of foliar insecticides x insecticides doses (I x D) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over potato varieties)

Interaction of varieties and post treatment day intervals (V x T), averaged over insecticides and doses, showed that both varieties responded significantly different (Fig 6.5). On all the post treatment day intervals, the *M. persicae* populations were smaller on Kuroda as compared to Desiree. Minimum number of *M. persicae* was recorded on Kuroda plants Day 3 as compared to maximum on Desiree plants Day 1 of the post treatments.

Interaction effect of insecticides x post treatments day intervals (D x T), averaged over insecticides and varieties, was significant (Fig 6.6). Both doses of insecticides (labeled and reduced) significantly suppressed the *M. persicae* populations as compared to control plants. Labeled doses proved significantly better than the reduced doses on all post treatment day intervals. Minimum number of *M. persicae* was recorded on Day 10 of the post treatment in plots treated with labeled dose of insecticides as compared to maximum on Day 18 in control plots.

Averaged over doses, the interaction effect of the varieties x insecticides x post treatments day intervals (V x I x T) was significant (Fig 6.7). Kuroda consistently proved resistant than Desiree hosting lesser *M. persicae* populations on each insecticide treatment. On Desiree, Provado significantly reduced the populations of *M. persicae* as compared to Actara on all post treatments day intervals. On Kuroda, the insecticides did not differ significantly except on Day 18. Minimum number of the *M. persicae* was recorded on Day 3 in Kuroda plots treated with Provado as compared to maximum on Day 1 in Desiree plot treated with Actara.

Interaction effect of varieties x doses x post treatment day intervals (V x D x T), averaged over insecticides, was significant (Fig 6.8). The *M. persicae* population during each post treatment day interval, on both varieties, was significantly highest on control plants as compared to plants treated with labeled and reduced doses. On Desiree, the labeled doses significantly reduced the *M. persicae* numbers as compared to reduced doses on Day 1, 2 and 18 of the post treatments. On Kuroda, the doses effect did not differ significantly except on Day 3. Minimum population of the *M. persicae* was recorded on Kuroda Day 3 treated with labeled doses as compared to maximum on Day 18 of the post treatments on Desiree control plants.

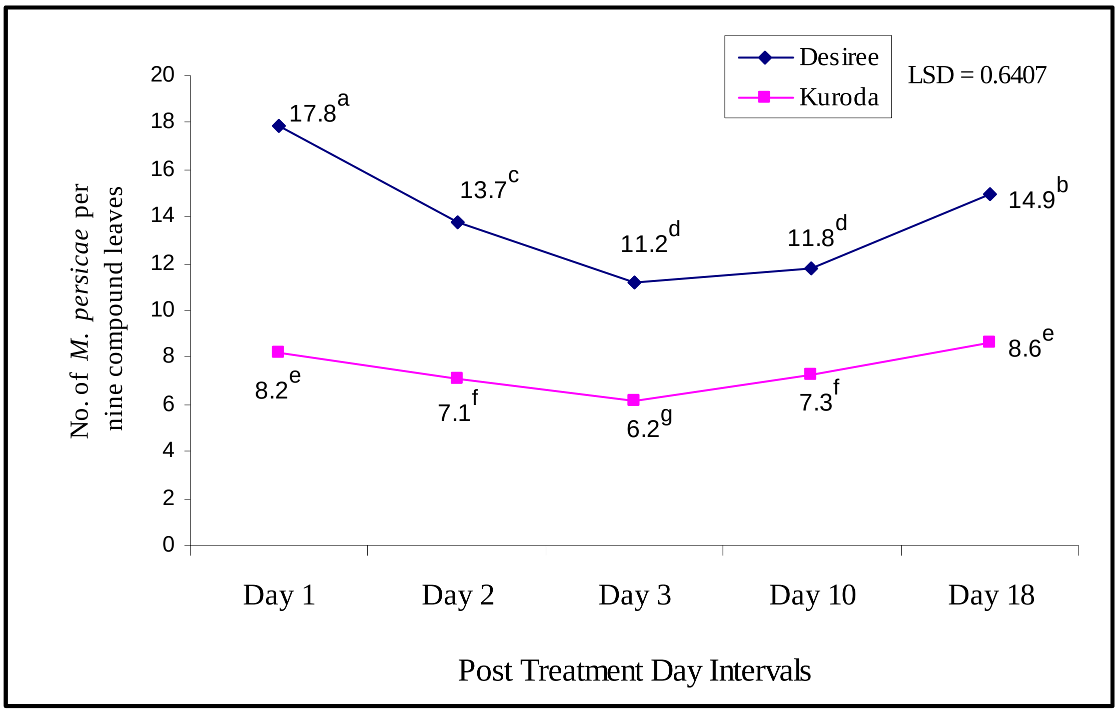


Fig 6.5 Interaction effect of potato varieties x post treatment day intervals (V x T) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over foliar insecticides and doses)

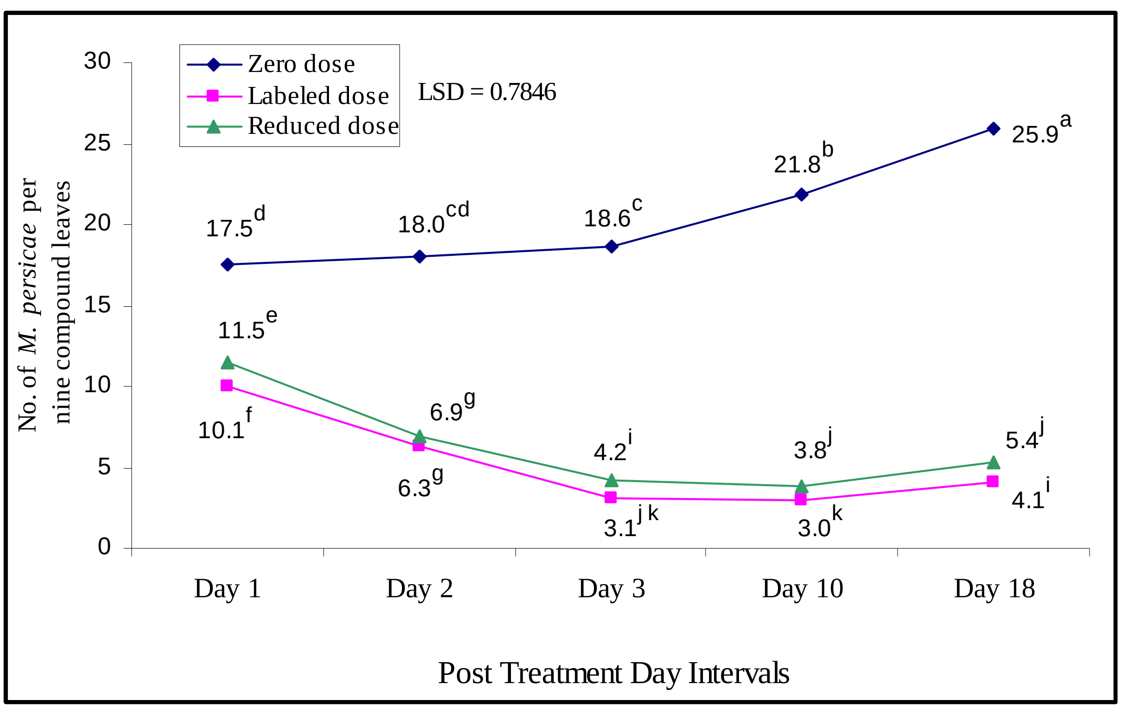


Fig 6.6 Interaction effect of foliar insecticides doses x post treatment day intervals (D x T) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over potato varieties and foliar insecticides)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

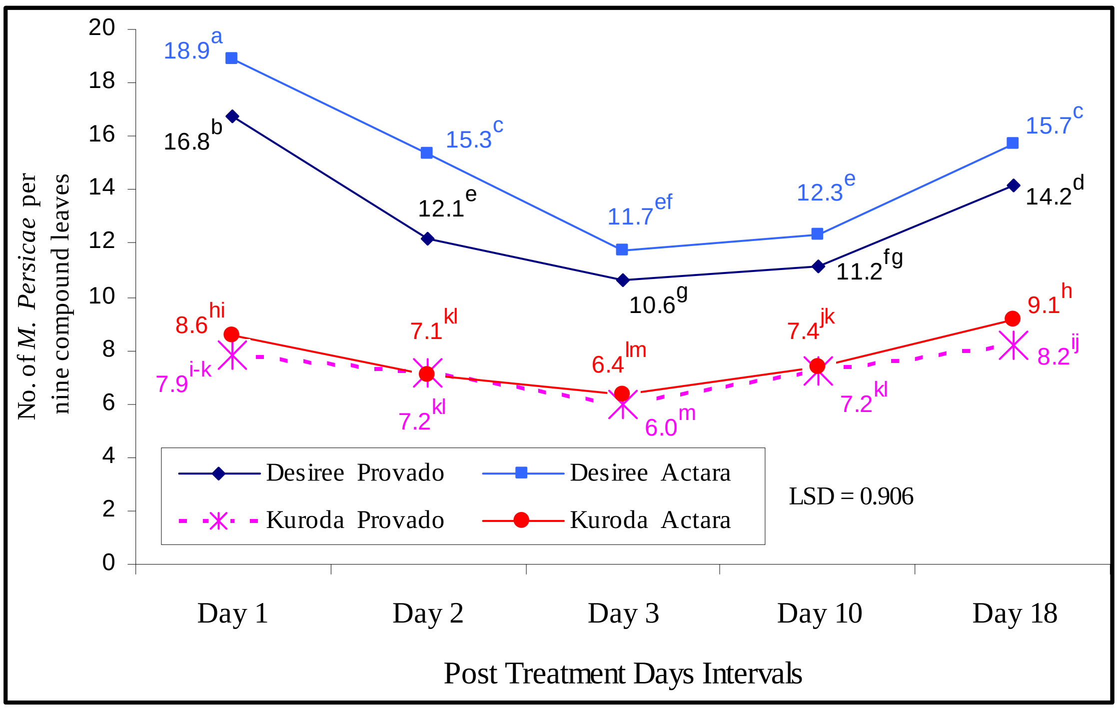


Fig 6.7 Interaction effect of potato varieties x foliar insecticides x post treatment day intervals (V x I x T) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over foliar insecticides doses)

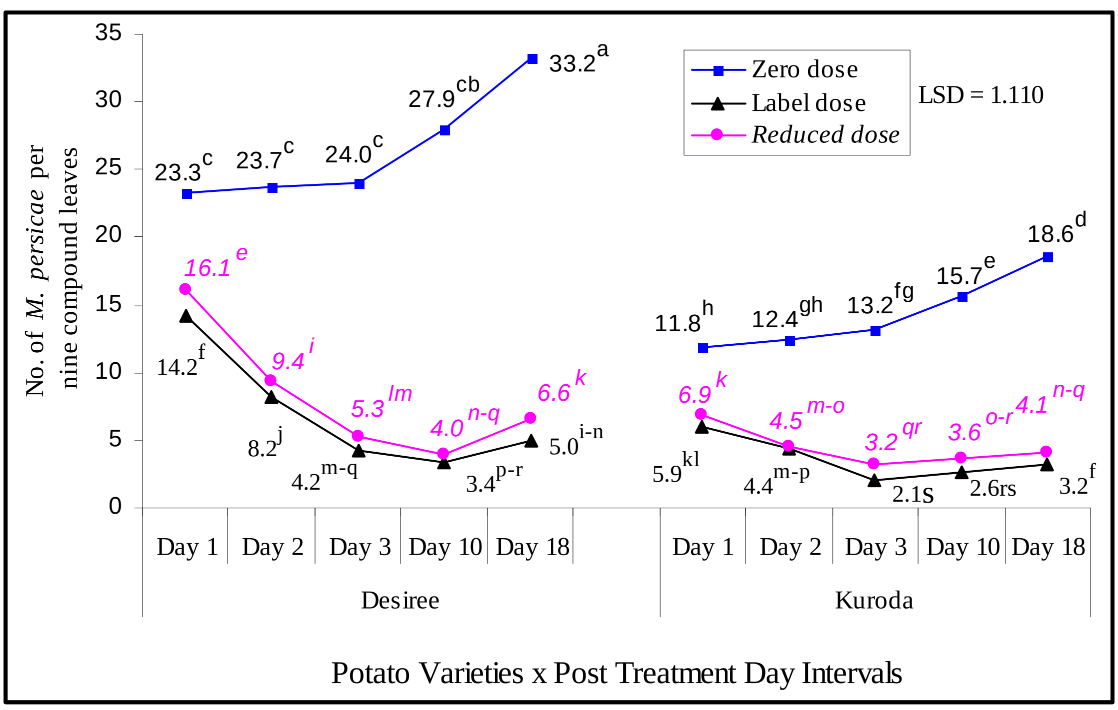


Fig 6.8 Interaction effect of potato varieties x post treatment day intervals x foliar insecticides doses (V x T x D) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over plant growth stages 'Pgs')

6.5.2 Effect of the foliar insecticides on ladybird beetle population per ten potato plants

The analysis of variance for ladybird beetle populations showed significant effect ($P<0.05$) due to foliar insecticides, dosage rates and potato varieties (Appendix-C Table-C2). Only one interaction i.e. foliar insecticide x insecticide doses (I x D) was significant. The results of main factors are shown in Fig 6.9. The mean values for varieties showed significant effect ($P<0.05$) being ladybird beetle population higher on Kuroda as compared to Desiree. Similarly, population on Provado treated plants was significantly ($P<0.05$) higher than Actara. Insecticides dosage rates also showed significant effect ($P<0.05$) with respect to ladybird beetle population being significantly maximum on control plants and minimum on plant treated with labeled doses of insecticides.

Both insecticides interacted significantly different at various doses, Fig 6.10. The ladybird beetle populations on control plants were significantly higher than the insecticides treated plants. Among treated plants, maximum population was recorded on plants treated with reduced doses of Provado and minimum on labeled doses of Actara.

6.5.3 Effect of foliar insecticides on syrphidfly population per ten potato plants

The analysis of variance for syrphidfly population showed significant effect ($P<0.05$) due to foliar insecticides, dosage rates and two potato varieties (Appendix-C Table-C3). Interactions effect for varieties x insecticide doses (V x D) and insecticides x insecticide doses (I x D) were also significant. The results of main factors are shown in Fig 6.11. The mean values for varieties showed significant effect being syrphidfly population higher on Kuroda as compared to Desiree. Similarly, population on Provado treated plants was significantly higher than Actara. Insecticides dosage rates also showed significant effect with respect to syrphidfly population being significantly maximum on control plants and minimum on plants treated with labeled doses of insecticides.

Interaction between varieties and insecticides doses on syrphidfly population, averaged over varieties, was significant (Fig 6.12). The maximum population was recorded on Kuroda control plants followed by Desiree control. Among treated plants, the maximum number of syrphidfly was recorded on Kuroda plants treated with reduced doses as compared to minimum on Desiree plants treated with labeled doses.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

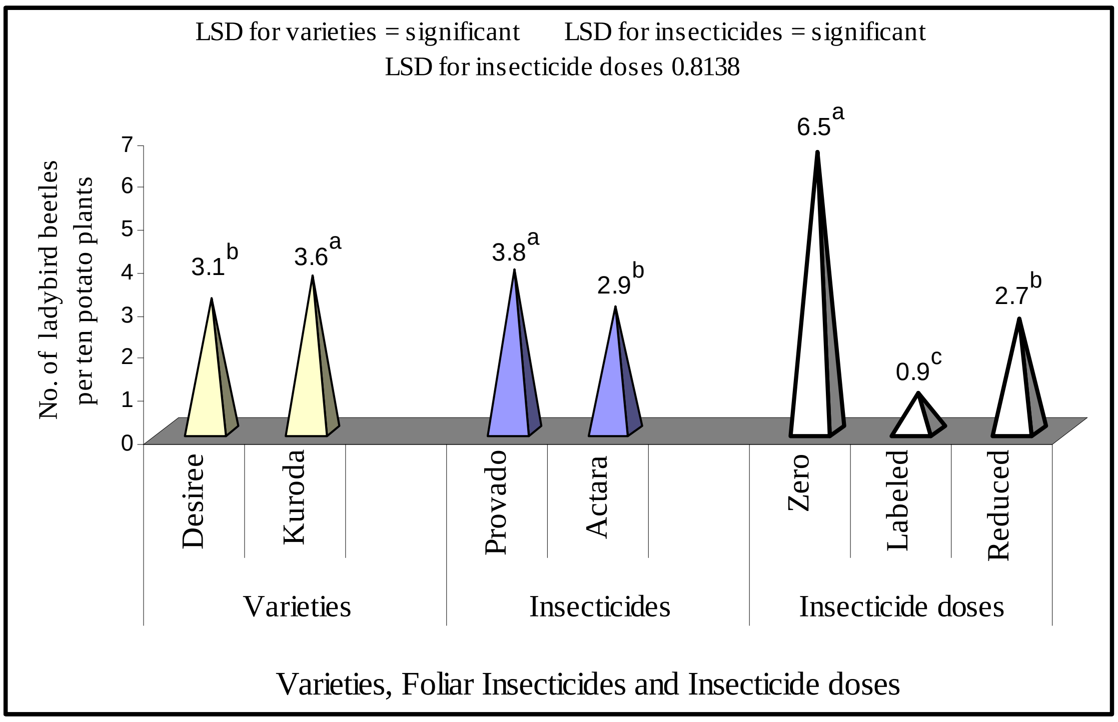


Fig 6.9 Effect of potato varieties, foliar insecticides and foliar insecticides doses on the population means of coccinellids "ladybird beetles" in potato crop

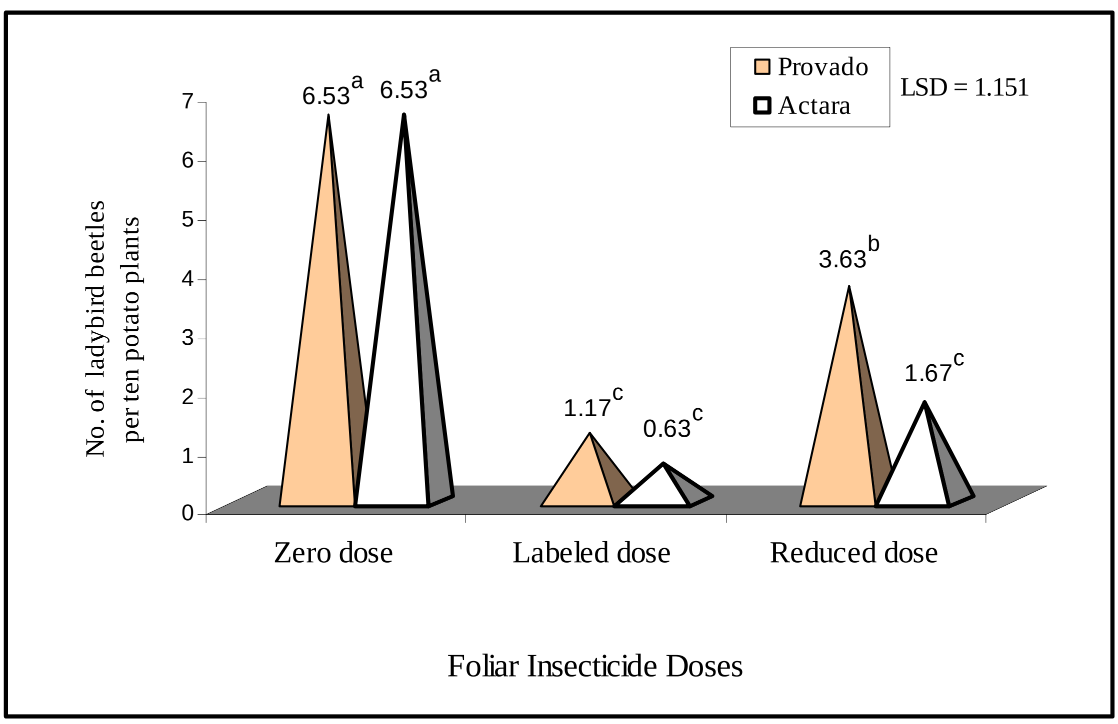


Fig 6.10 Interaction effect of foliar insecticides x doses (I x D) on the population means of coccinellids "ladybird beetles" in potato crop (averaged over varieties)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

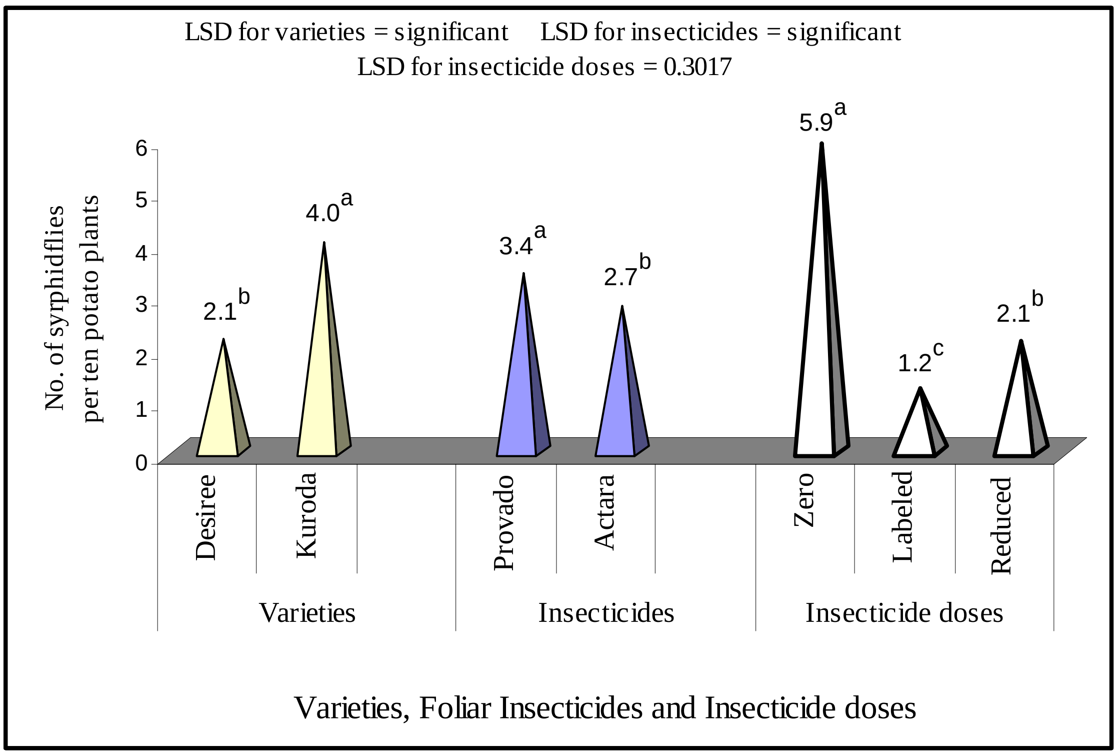


Fig 6.11 Effect of potato varieties, foliar insecticides and insecticide doses on the population means of syrphidfly in potato crop

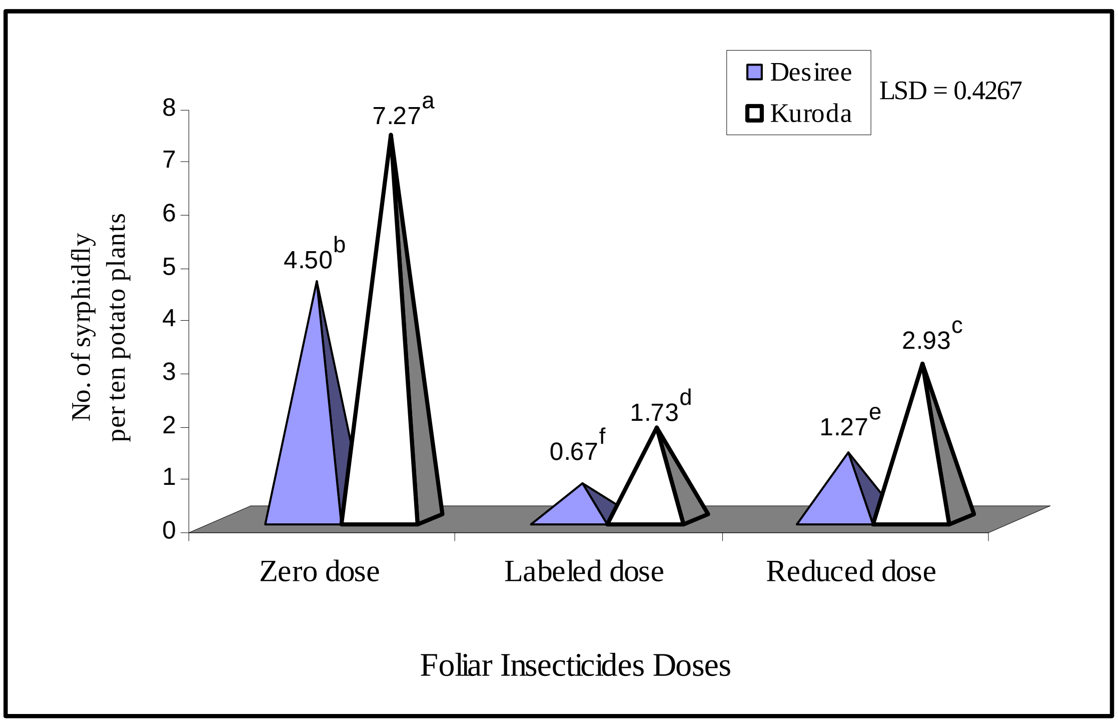


Fig 6.12 Interaction effect of potato varieties x foliar insecticides doses (V x D) on the population means of syrphidae 'syrphidfly' in potato crop (averaged over foliar insecticides)

Both insecticides interacted significantly different at various doses, Fig 6.13. The syrphidfly populations on control plants were significantly higher than insecticides treated plants. Among treated plants, maximum populations were recorded on plants treated with reduced doses of Provado and minimum on plants treated with labeled doses of Actara.

6.5.4 Effect of the foliar insecticides on green lacewing population per ten potato plants

The analysis of variance for green lacewing population showed significant effect ($P<0.05$) due to foliar insecticides, dosage rates and potato varieties (Appendix-C Table-C4). Only one interactions i.e. insecticides x insecticide doses (I x D) was significant. The results of main factors are shown in Fig 6.14. The mean values for varieties showed significant effect being green lacewing population higher on Kuroda as compared to Desiree. Similarly population on Provado treated plants was significantly higher than Actara. Insecticides dosage rates also showed significant effect with respect to green lacewing population being significantly maximum on control plants and minimum on plants treated with labeled doses of insecticides.

Both insecticides interacted significantly different at various doses (Fig 6.15). Populations of green lacewing on control plants were significantly higher than insecticides treated plants. Among treated plants, maximum populations were recorded on plants treated with reduced doses of Provado and minimum on labeled doses of Actara.

6.5.5 Effect of the foliar insecticides on the population of parasitized *M. persicae* mummies per ten plants

The analysis of variance for the populations parasitized *M. persicae* mummies showed significant effect ($P<0.05$) due to foliar insecticides, dosage rates and the potato varieties (Appendix-C Table-C5). Interactions effect for varieties x insecticide doses (V x D) and insecticides x insecticide doses (I x D) were also significant. The results of main factors are shown in Fig 6.16. The mean values for varieties showed significant effect being the population of parasitized *M. persicae* mummies higher on Kuroda than Desiree. Similarly, population on Provado treated plants was significantly higher than Actara. Insecticides dosage rates also showed significant effect with respect to populations of parasitized *M. persicae* mummies being significantly maximum on control plants and minimum on plants treated with labeled doses of insecticides.

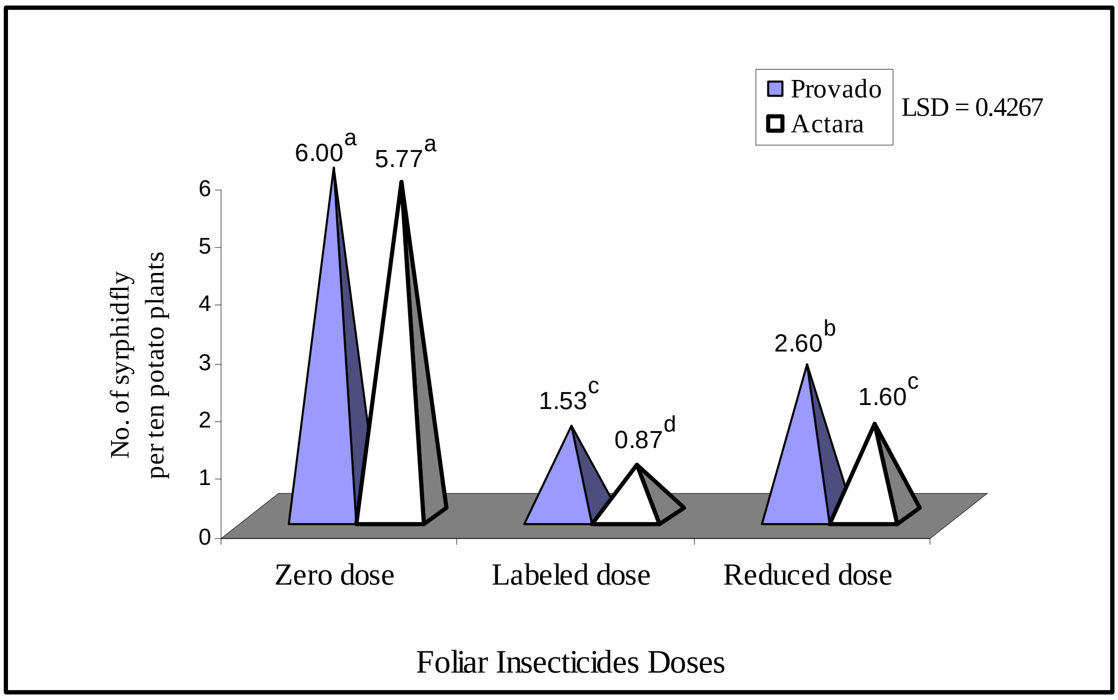


Fig 6.13 Interaction effect of foliar insecticides x insecticides doses (I x D) on the population means of syrphidae ‘syrphidfly’ in potato crop (averaged over potato varieties)

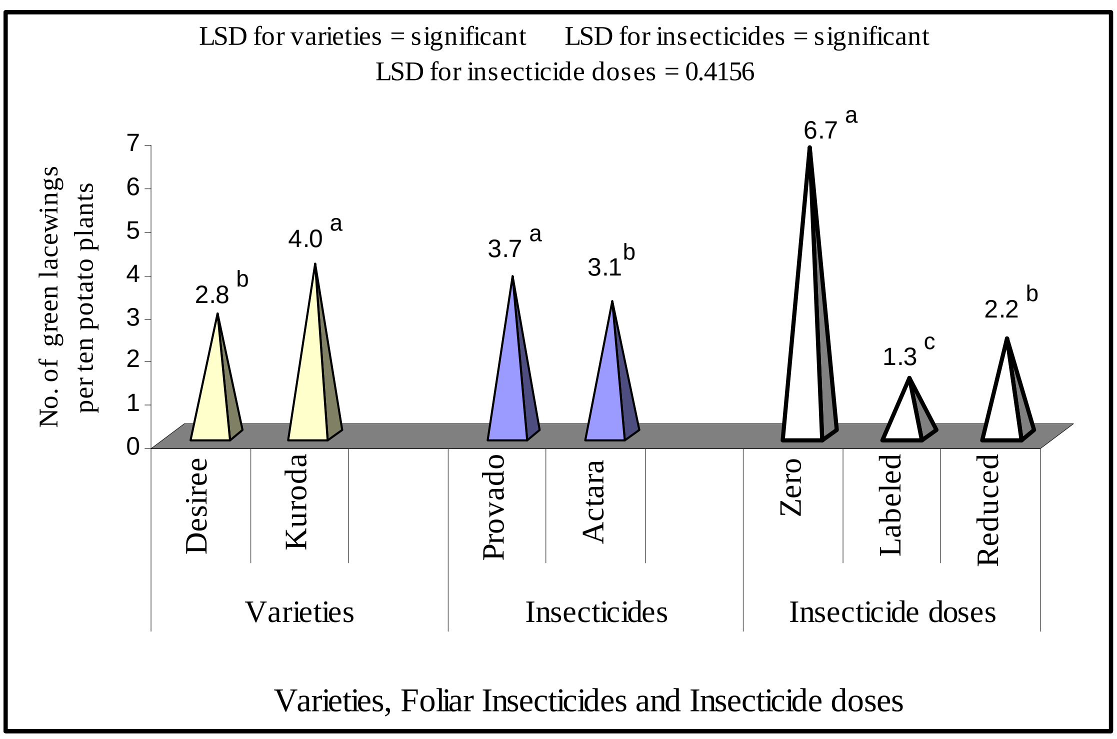


Fig 6.14 Effect of potato varieties, foliar insecticides and insecticide doses on the population means of *Chrysoperla spp* “green lacewing” in potato crop

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

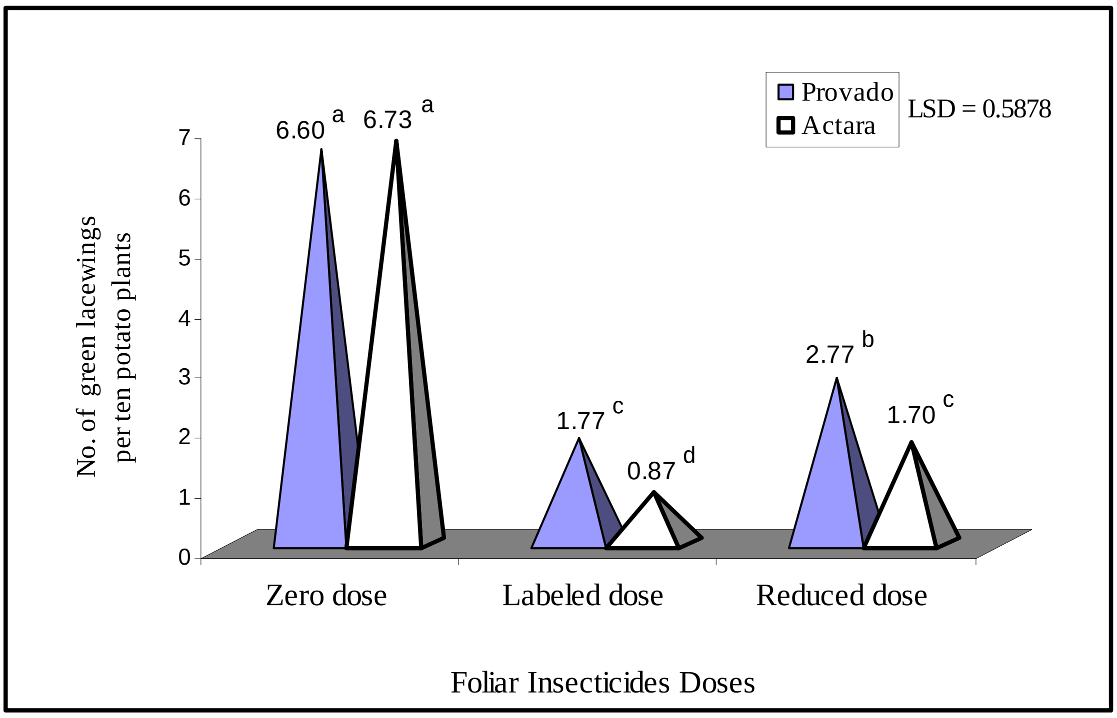


Fig 6.15 Interaction effect of foliar insecticides x insecticides doses (I x D) on the population means of *Chrysoperla spp* "green lacewing" in potato crop (averaged over potato varieties)

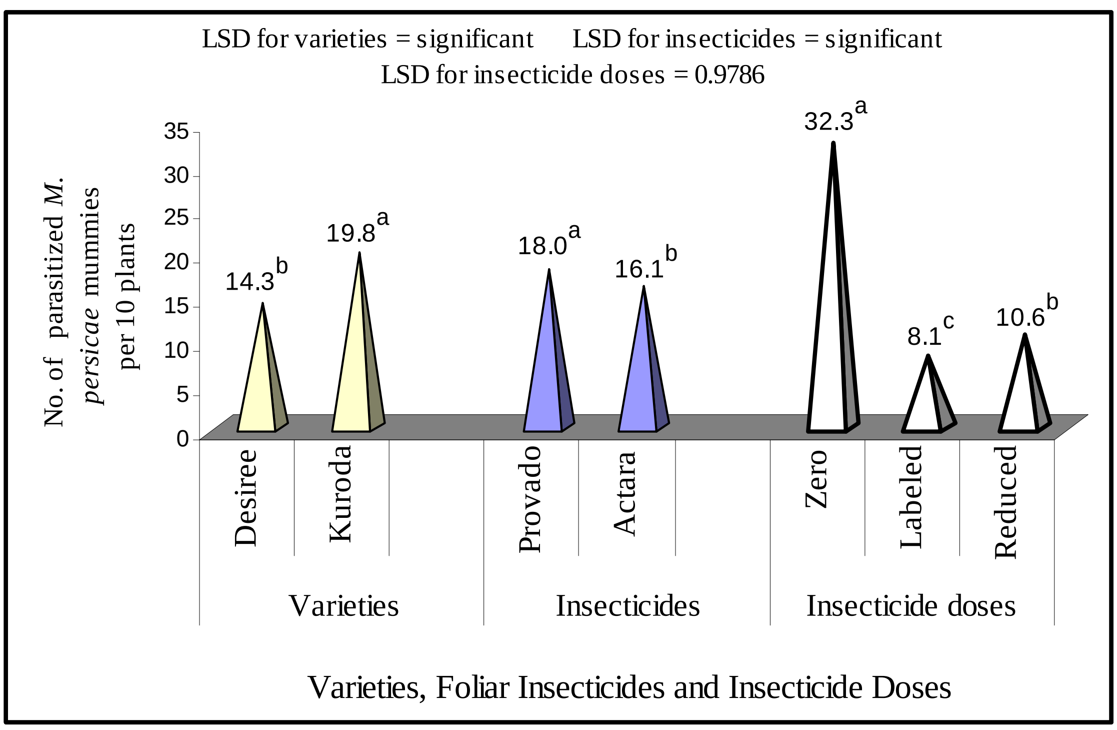


Fig 6.16 Effect of potato varieties, foliar insecticides and doses on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop

Interaction between varieties and insecticides doses (V x D) on population of parasitized *M. persicae* mummies, averaged over insecticides, was significant (Fig 6.17). Maximum population was recorded on Kuroda control followed by Desiree control plants. Among treated plants, maximum parasitized *M. persicae* mummies were recorded on Kuroda plants treated with reduced doses as compared to minimum on Desiree plants treated with labeled doses of insecticides.

Both insecticides interacted significantly different at various doses, Fig 6.18. Populations of the parasitized *M. persicae* mummies on control plants were significantly higher than insecticides treated plants. Among treated plants, maximum number of parasitized *M. persicae* mummies was recorded on plants treated with reduced doses of Provado and minimum on plants treated with labeled doses of Actara.

6.5.6 Effect of the foliar insecticides on the PPA*A*

The analysis of variance for PPA*A* showed significant effect ($P<0.05$) due to foliar insecticides, dosage rates and the potato varieties (Appendix-C Table-C6). All interactions were also significant ($P<0.05$) except varieties x insecticide doses x insecticides (V x D x I). The results of main factors are shown in Fig 6.19. The mean values for varieties showed significant effect, being maximum PPA*A* on Kuroda as compared to Desiree. Similarly, the PPA*A* on Provado treated plants was significantly higher than Actara. Insecticides dosage rates also showed significant effect with respect to the PPA*A* being significantly maximum on control plants and minimum on plants treated with labeled doses of insecticides.

Interaction between varieties and insecticides (V x I) on the PPA*A*, averaged over varieties, was significant (Fig 6.20). The varieties responded significantly different. Maximum PPA*A* (5.20) was recorded on Kuroda plants treated with Provado as compared to minimum (3.21) on Desiree treated with Actara.

Both insecticides interacted significantly different at various doses, Fig 6.21. The PPA*A* recorded on control plants was significantly higher than the treated plants. Among treated plants, the maximum PPA*A* was recorded on plants treated with reduced doses of Provado followed by Actara reduced doses whereas minimum PPA*A* was recorded on plants treated with labeled doses of Actara.

Interaction effect of varieties x insecticides doses (V x D) on the PPA*A*, averaged over insecticides, was significant (Fig 6.22). Maximum PPA*A* was recorded on Kuroda control followed by Desiree control plants. The PPA*A* on plants treated with reduced doses of insecticides was significantly higher than the labeled doses. Among treated plants, the maximum PPA*A* was recorded on Kuroda plants treated with reduced doses and minimum on Desiree plants treated with labeled doses of insecticides.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

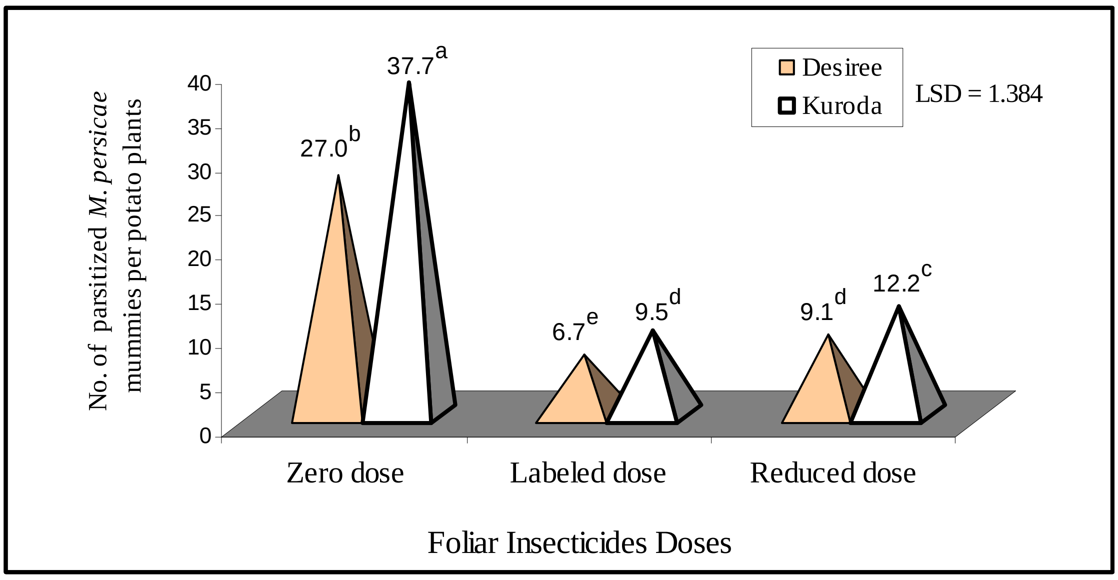


Fig 6.17 Interaction effect of potato varieties x foliar insecticides doses (V x D) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop (averaged over insecticides)

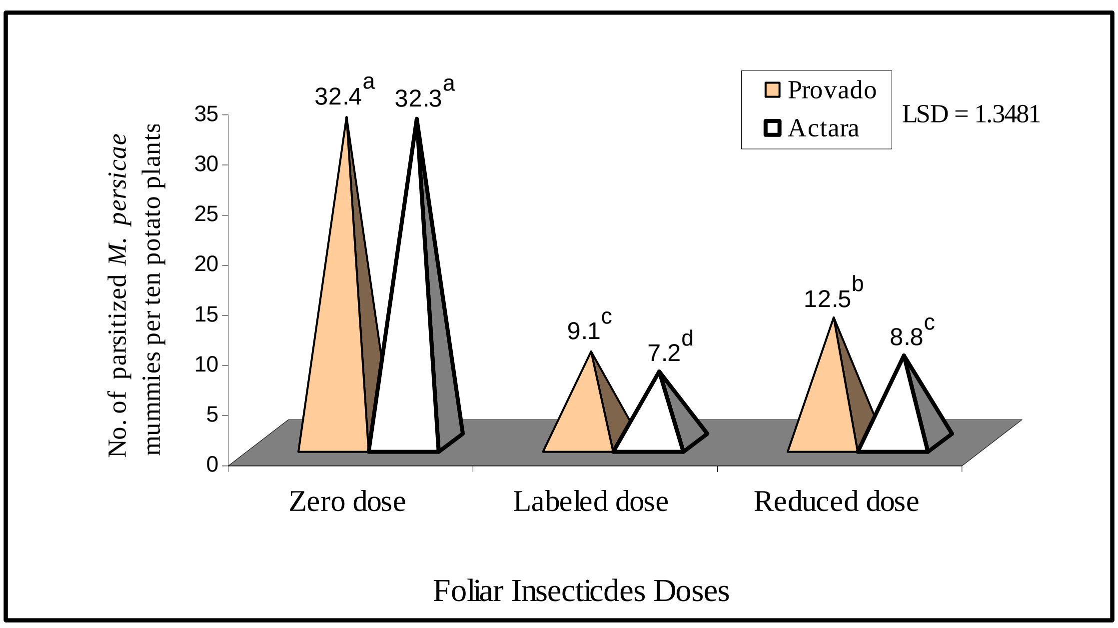


Fig 6.18 Interaction effect of foliar insecticides x insecticides doses (I x D) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop (averaged over potato varieties)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

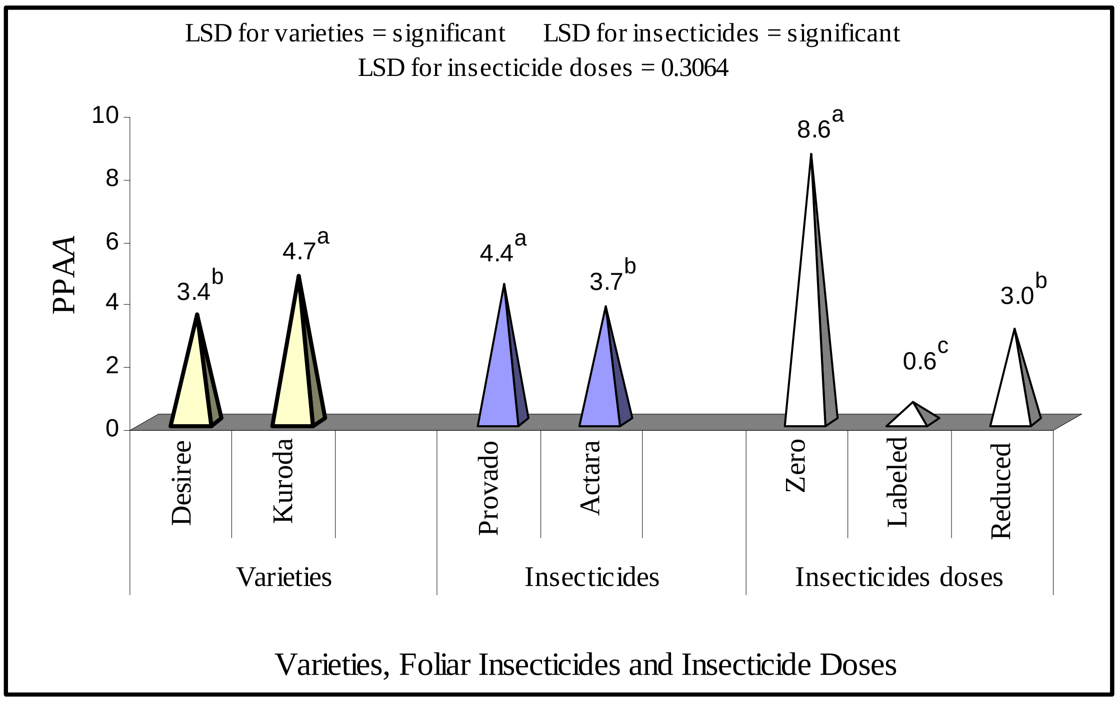


Fig 6.19 Effect of potato varieties, foliar insecticides and doses on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp*' (PPA*A*) in potato crop

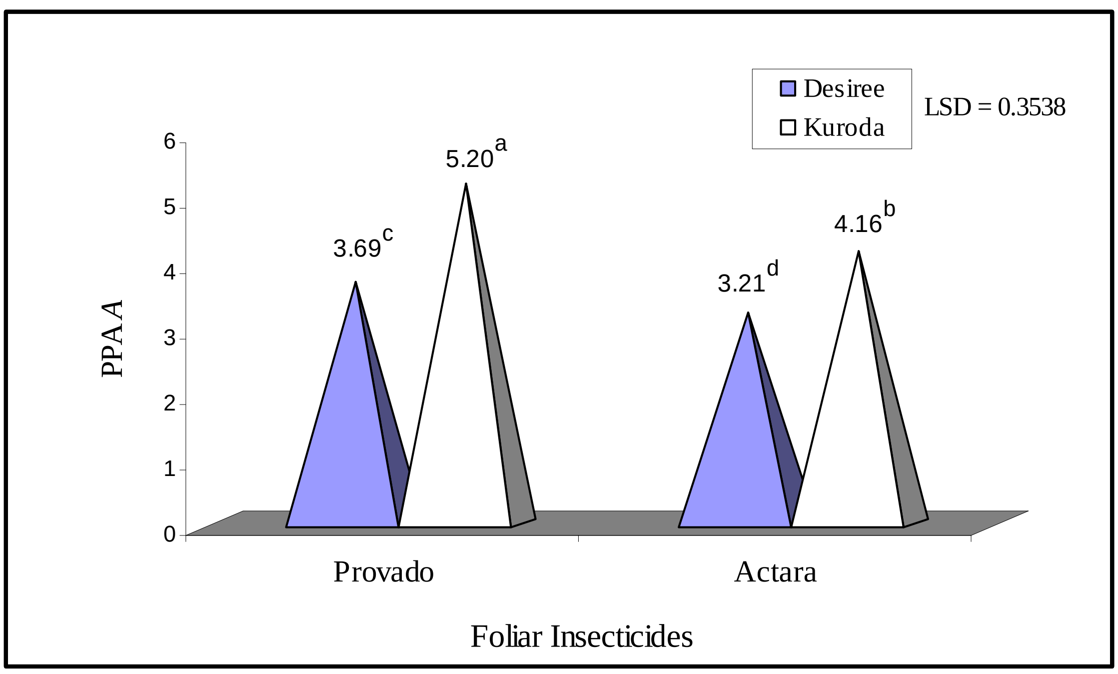


Fig 6.20 Interaction effect of foliar insecticides x potato varieties (I x V) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp*' (PPA*A*) in potato crop (averaged over insecticide doses)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

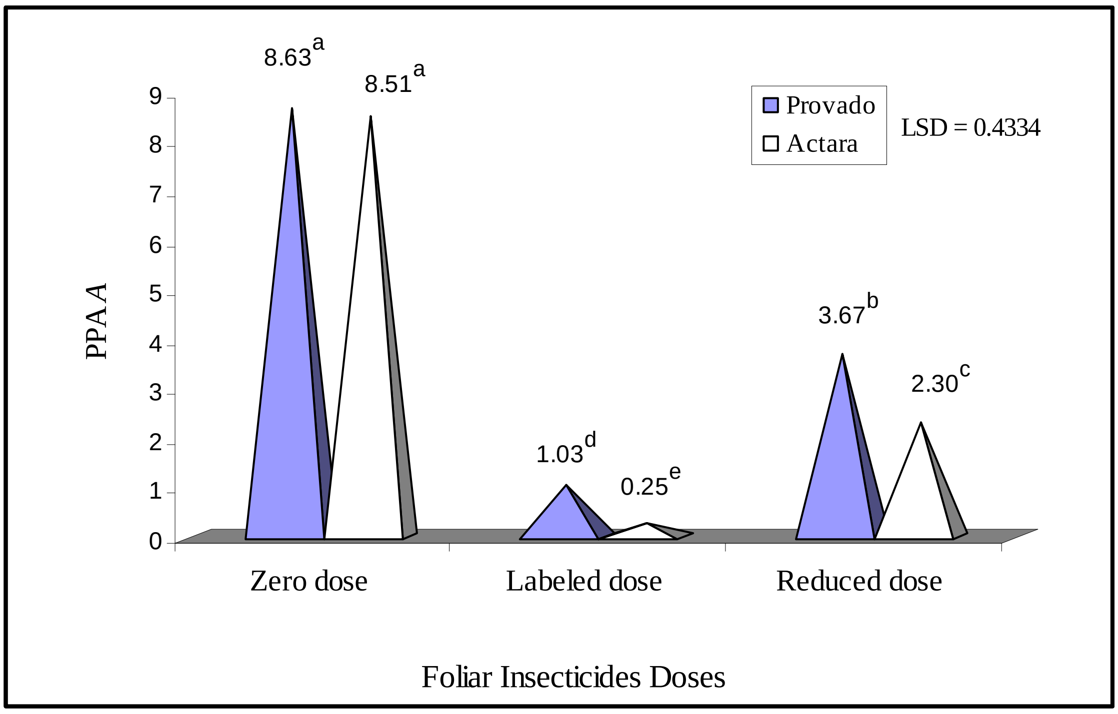


Fig 6.21 Interaction effect of foliar insecticides x insecticide doses (I x D) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp*' (PPA*A*) in potato crop (averaged over potato varieties)

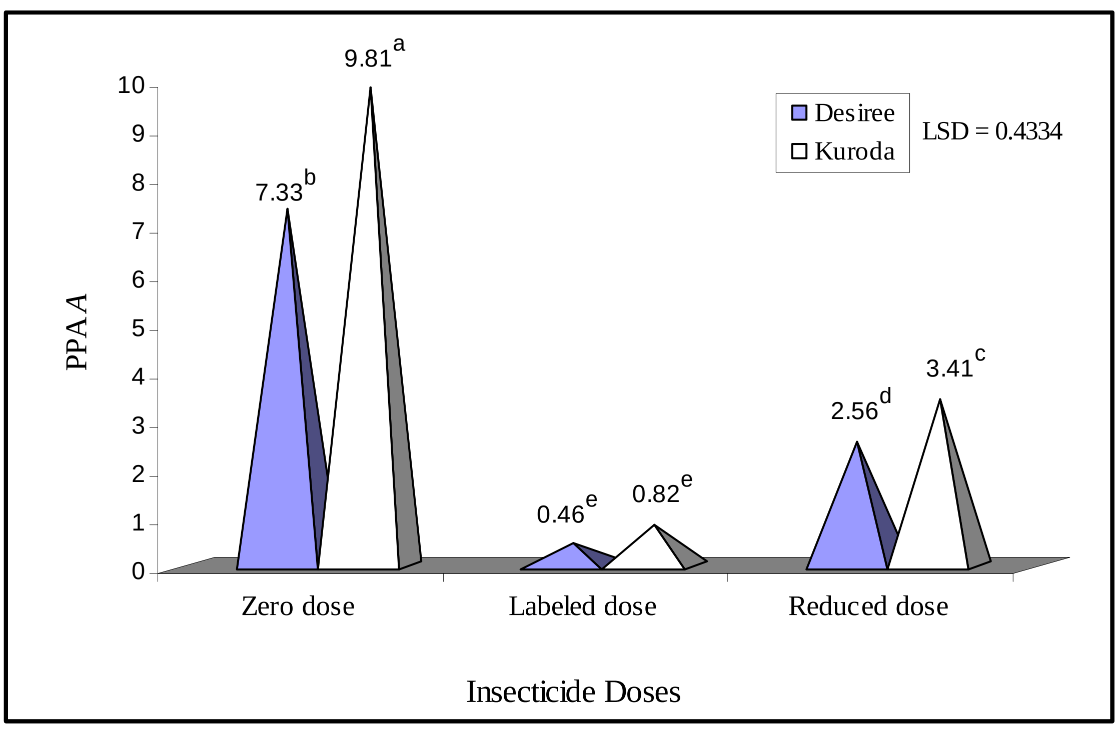


Fig 6.22 Interaction effect of potato varieties x foliar insecticide doses (V x D) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp*' (PPA*A*) in potato crop (averaged over foliar insecticides)

6.5.7 Effect of the foliar insecticides on the PER*A*

The analysis of variance for PER*A* showed significant effect ($P<0.05$) due to foliar insecticides, dosage rates and the potato varieties (Appendix-C Table-C7). All interactions were also significant ($P<0.05$) except varieties x insecticide (V x I). The results of main factors are shown in Fig 6.23. The mean values for varieties showed significant effect being PER*A* higher on Kuroda than Desiree. Similarly, PERA on Provado treated plants was significantly higher than Actara. Insecticides dosage rates also showed significant effect with respect to PER*A* being significantly maximum on control plants and minimum on labeled doses of insecticides.

Both insecticides interacted significantly different at various doses, Fig 6.24. The PER*A* recorded on control plants were significantly higher than insecticides treated plants. Among treated plants, maximum PER*A* was recorded on plants treated with reduced doses of Provado followed by Actara reduced doses. Minimum PER*A* was recorded on plants treated with labeled doses of Actara.

Interaction between varieties and insecticides doses (V x D) on PER*A*, averaged over insecticides, was significant (Fig 6.25). Maximum PER*A* was recorded on Kuroda control followed by Desiree control plants. Among treated plants, PER*A* on plants treated with reduced dose of insecticides was significantly higher as compared to labeled doses. Maximum PER*A* was recorded on Kuroda plants treated with reduced doses as compared to minimum on Desiree treated with labeled doses.

Interaction effect of potato varieties, insecticide doses and foliar insecticides (V x D x I) on the PER*A* was significant, Fig 6.26. The maximum PER*A* was recorded on Kuroda control plants followed by Desiree control. The PER*A* on plants treated with reduced doses was significantly higher than labeled doses. Among treated plants, the maximum PER*A* was recorded on Kuroda plants treated with reduced dose of Provado as compared to minimum on Desiree plants treated with labeled dose of Actara.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

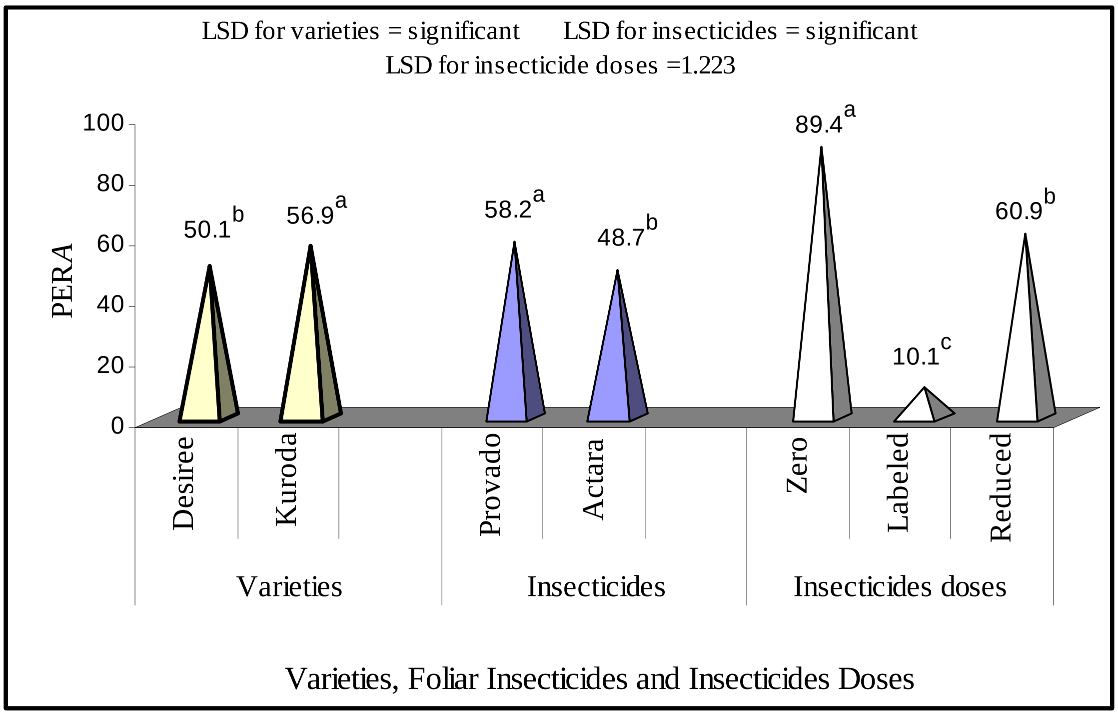


Fig 6.23 Effect of potato varieties, foliar insecticides and doses on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PER*A*) in potato crop

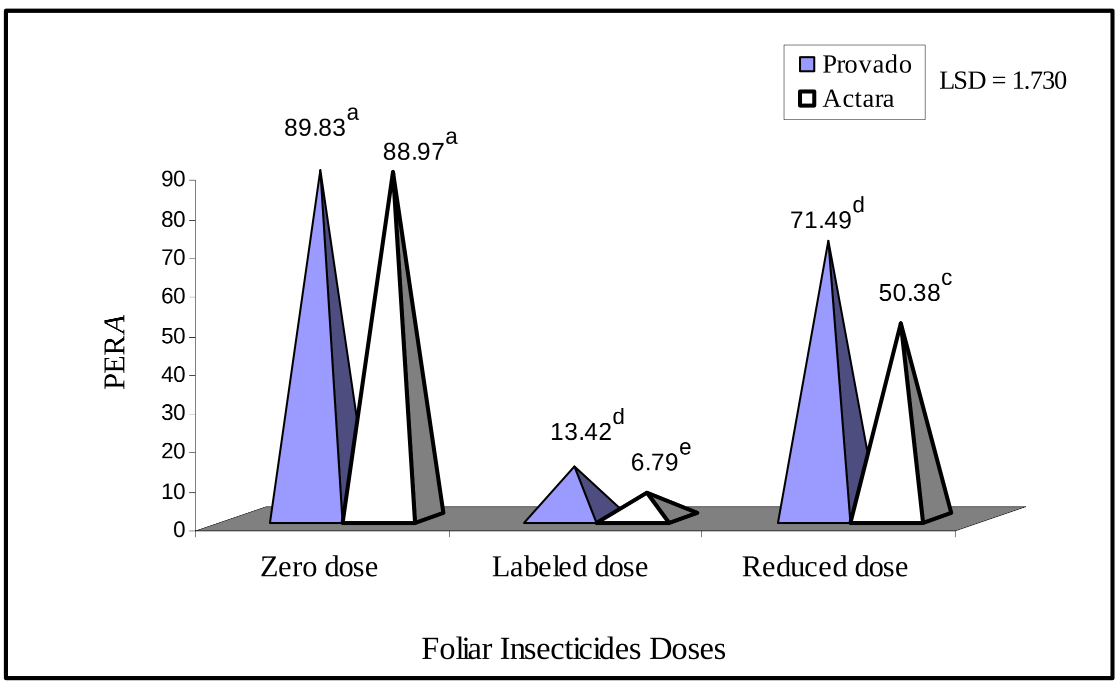


Fig 6.24 Interaction effect of foliar insecticides x insecticide doses (I x D) on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PER*A*) in potato crop (averaged over potato varieties)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

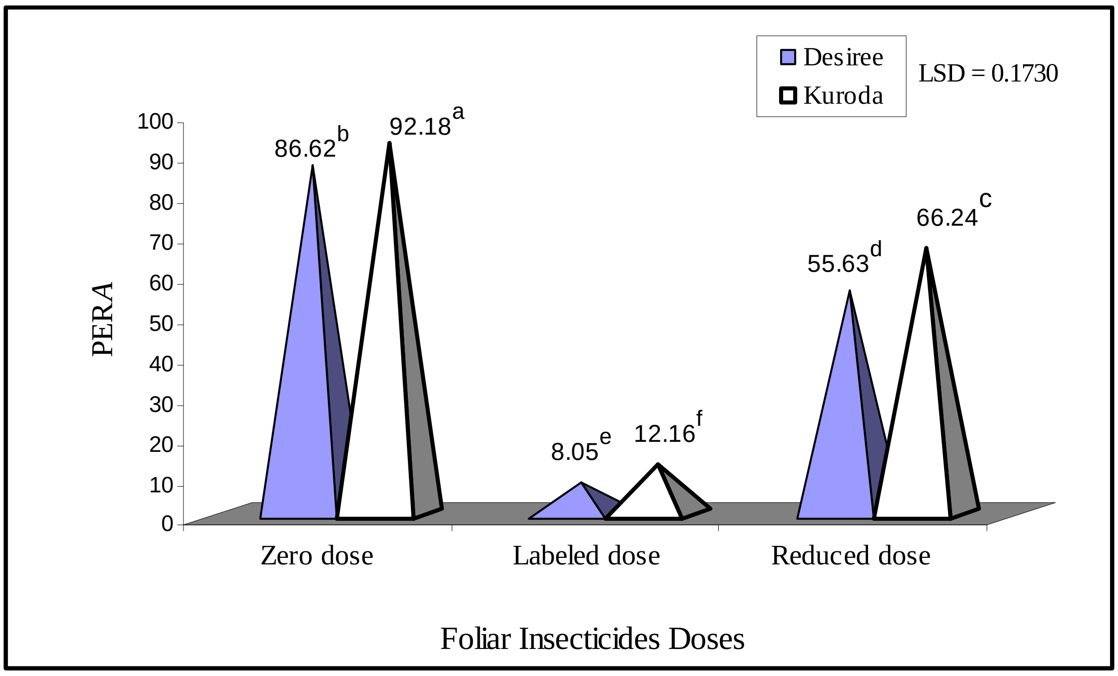


Fig 6.25 Interaction effect of potato varieties x foliar insecticide doses (V x D) on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PER*A*) in potato crop (averaged over foliar insecticides)

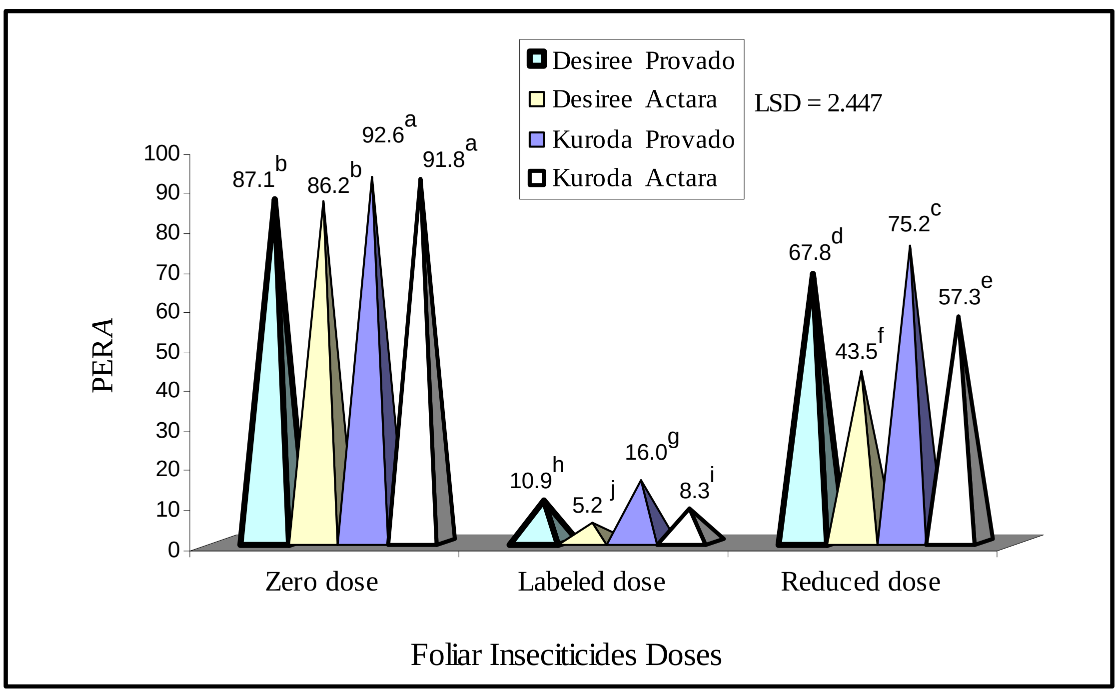


Fig 6.26 Interaction effect of potato varieties x foliar insecticides x insecticide doses (V x I x D) on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PER*A*) in potato crop

6.5.8 Effect of the foliar insecticides on the FR*A*

The analysis of variance for FR*A* showed significant effect ($P<0.05$) due to the foliar insecticides, dosage rates and the potato varieties (Appendix-C Table-C8). All the interactions were also significant ($P<0.05$) except for varieties x insecticides (V x I). The results of main factors are shown in Fig 6.27. The mean values for varieties showed significant effect being FR*A* higher on Kuroda as compared to Desiree. Similarly FR*A* on Provado treated plants was significantly higher than Actara. Insecticides dosage rates also showed significant effect with respect to FR*A* being significantly maximum on control and minimum on plants treated with labeled doses of insecticides.

Insecticides interacted significantly different to FR*A* at various doses, Fig 6.28. FR*A* recorded on control plants was significantly higher than insecticides treated plants. Among treated plants, maximum FR*A* was recorded on plants treated with Provado reduced doses followed by Actara reduced doses whereas minimum was recorded on plants treated with Actara labeled doses.

Interaction between varieties and insecticides doses (V x D) on FR*A*, averaged over insecticides, was significant (Fig 6.29). Maximum FR*A* was recorded on Kuroda control followed by Desiree control. Among treated plants, FR*A* was significantly higher on plants treated with reduced doses of insecticides as compared to labeled doses. Maximum FR*A* was recorded on Kuroda plants treated with reduced doses and minimum on Desiree plants treated with labeled doses.

Interaction effect of potato varieties, insecticide doses and foliar insecticides (V x D x I) on PER*A* was significant, Fig 6.30. Maximum FR*A* was recorded on Kuroda control followed by Desiree control plants. FR*A* on Provado treated plants was higher than Actara. Similarly, FR*A* on plants treated with reduced doses was higher than labeled doses. Among treated plots, the maximum FR*A* was recorded on Kuroda plants treated with reduced dose of Provado followed by Desiree plants treated with reduced dose of Provado. Minimum FR*A* was recorded on Desiree plants treated with Actara labeled dose followed by Kuroda plants treated with Actara labeled dose.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

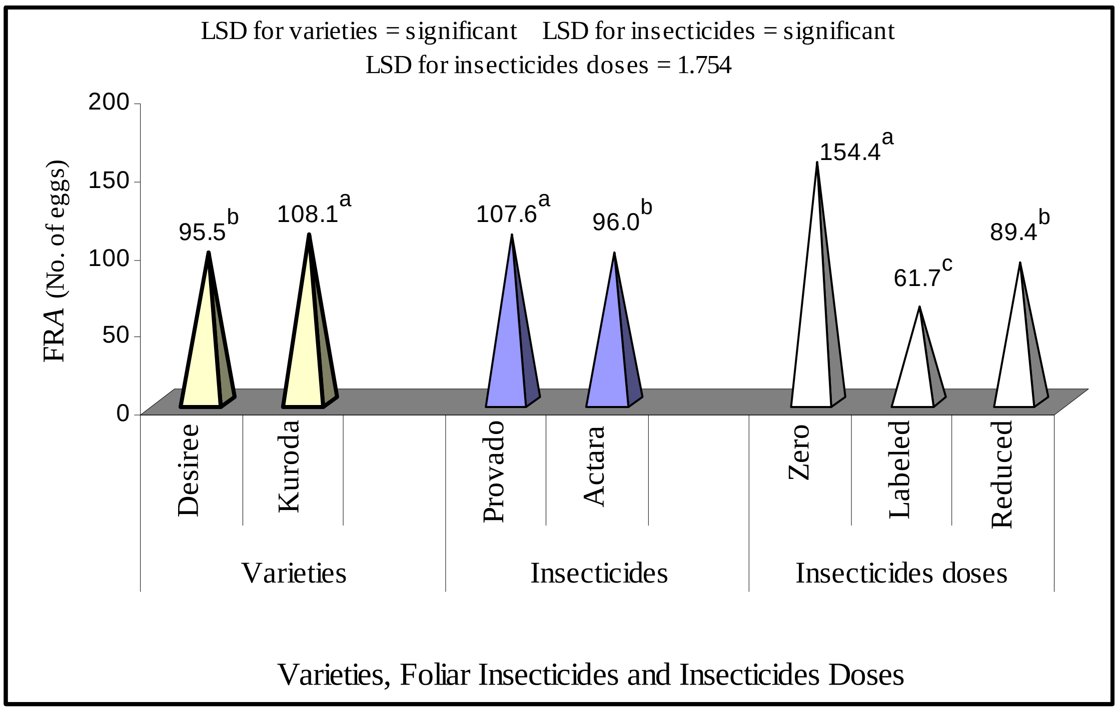


Fig 6.27 Effect of potato varieties, foliar insecticides and insecticide doses on the mean fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop

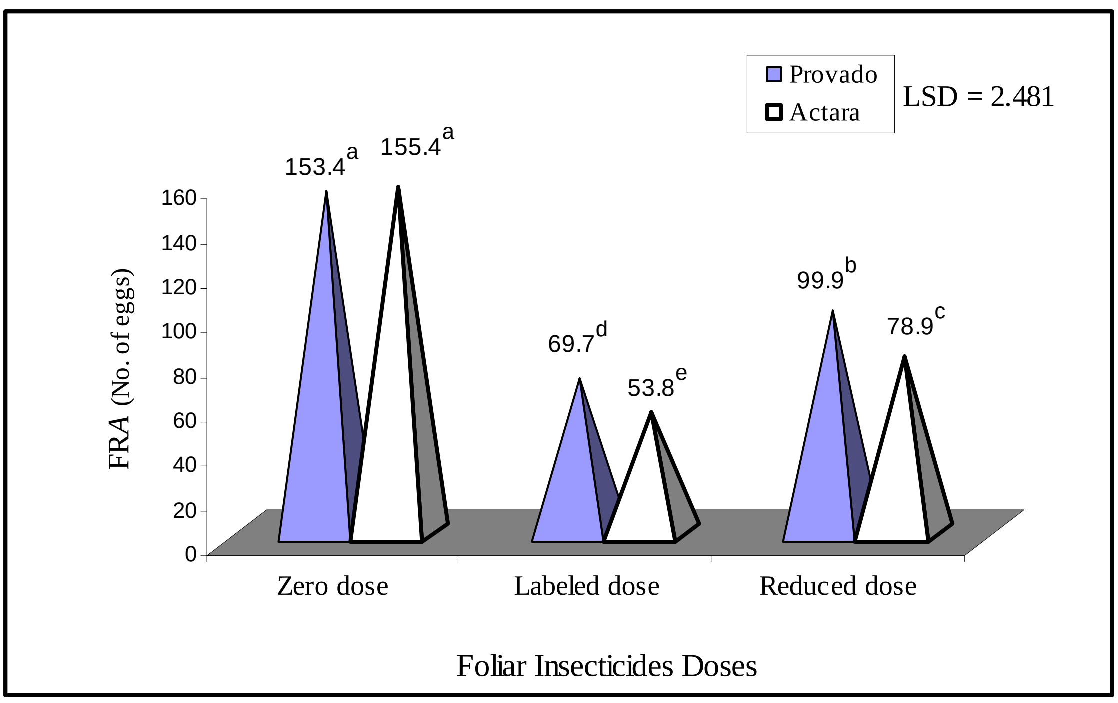


Fig 6.28 Interaction effect of foliar insecticides x doses (I x D) on the mean fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop (averaged over potato varieties)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

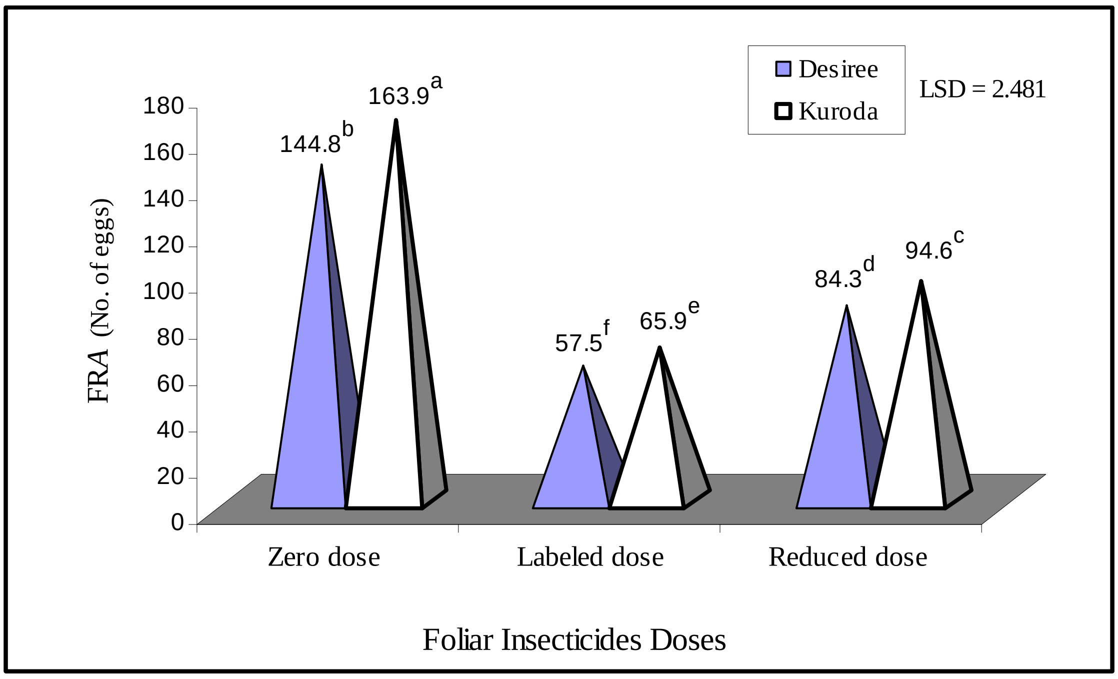


Fig 6.29 Interaction effect of potato varieties x doses (V x D) on the mean fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop (averaged over foliar 'Fr' insecticides)

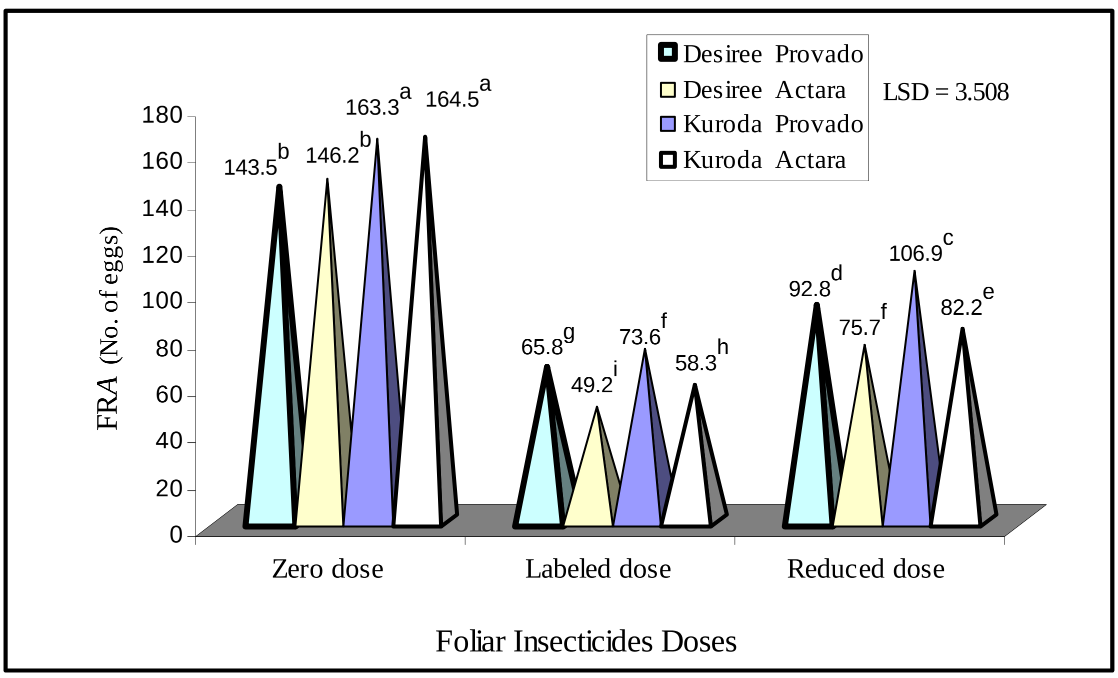


Fig 6.30 Interaction effect of potato varieties x foliar insecticides x insecticide doses (V x I x D) on the mean fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop

6.5.9 Effect of the foliar insecticides on the yield of potato varieties

The analysis of variance for potato yields showed significant effect (P<0.05) due to foliar insecticides, dosage rates and the potato varieties (Appendix-C Table-C9). Only one interaction i.e. insecticides x insecticide doses (I x D) was significant (P<0.05). The results of main factors are shown in Fig 6.31. The mean values for varieties showed significant effect being Kuroda yield higher than Desiree. Similarly yield of plots treated with Provado was significantly higher than Actara. Insecticides dosage rates also showed significant effect with respect to yield being significantly minimum from control plants and maximum from plants treated with reduced doses of insecticides. However, reduced and labeled doses did not differ significantly.

Both insecticides interacted significantly different at various doses to potato yield, averaged over varieties (Fig 6.32). Potato yields obtained from control plants were significantly lower than insecticides treated plants. Among treated plots, significantly higher yield was obtained from plots treated with Provado reduced and labeled doses (both being statistically equal) as compared to plots treated with Actara labeled and reduced doses (both being statistically equal).

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

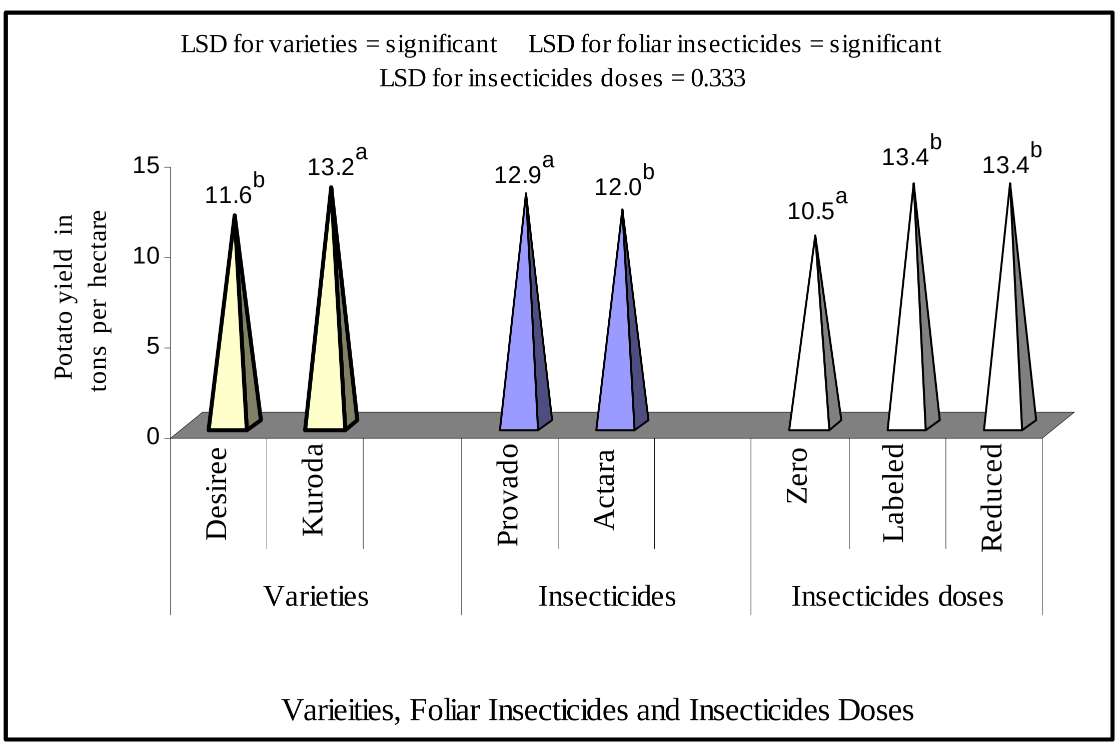


Fig 6.31 Effect of potato varieties, foliar insecticides and insecticide doses on the yield means of potato tubers in tons/hectare

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

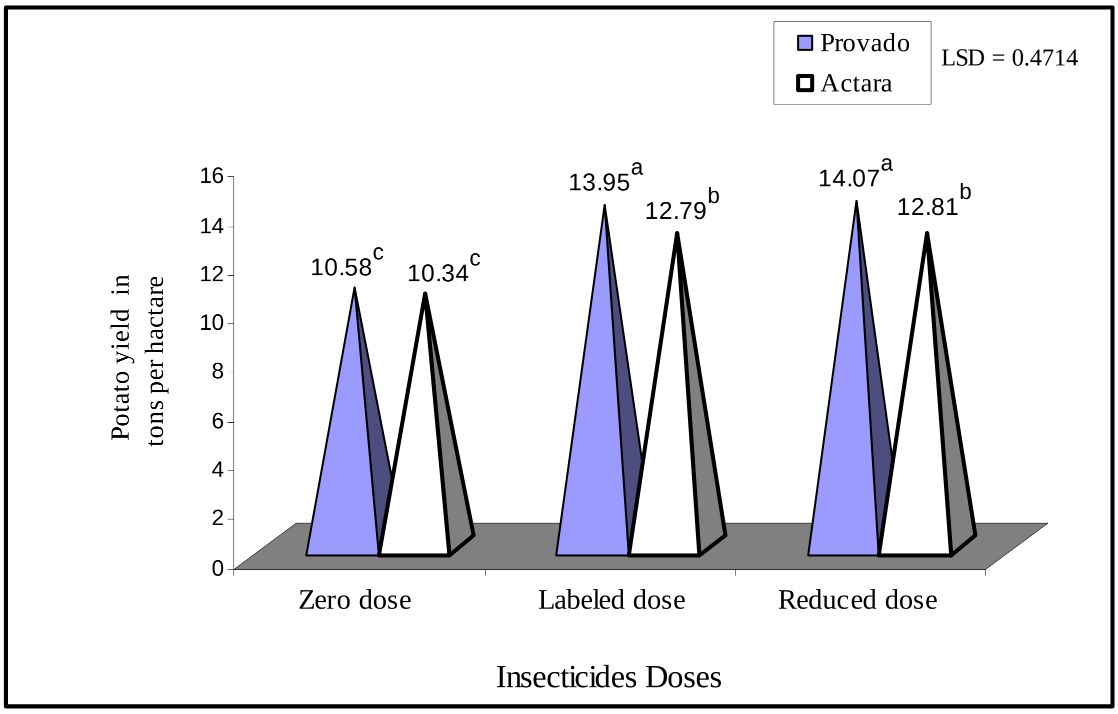


Fig 6.32 Interaction effect of foliar insecticides x insecticide doses (I x D) on the yield means of potato tubers in tons/hectare

6.6 DISCUSSION

The hypothesis that resistant variety responds significantly different to foliar insecticides treatments than susceptible variety in reducing *M. persicae* populations and the lower doses of insecticides have minimum adverse effect on natural enemies were found true. Both the foliar insecticides viz Provado and Actara significantly reduced *M. persicae* population and thus may be applied especially when alarming population explode or reach the threshold level (Wyman, 2005), as both the insecticides significantly reduced all the natural enemies studied. The susceptibility of natural enemies may be due to their slow development (Radcliffe, 1998). Reduced parasitism of *M. persicae* and toxic effect of imidacloprid on *M. tasmaniae* suggests to avoid insecticides or may be applied wisely (Kassem *et al.*, 2005; Walker *et al.*, 2007; Saljoqi *et al.*, 2009) However, imidacloprid is much less toxic to natural enemies than carbamate, organophosphorus, pyrethroid, etofenprox and acetamiprid (James and Coyle, 2001; Youn *et al.*, 2003).

Provado was significantly more effective than Actara by being more toxic to *M. persicae* and less toxic to natural enemies. Provado reduced *M. persicae* population higher by 7.1% than Actara and had higher populations of ladybird beetle, parasitized *M. persicae* mummies, syrphidfly, green lacewing, PPA*A*, PER*A* and FR*A* by 19.1, 8.6, 13.1, 15.3, 12.2, 15.1, 12.6 and 8.6 %, respectively. Saljoqi *et al*. (2009) also recorded lower mortality or lesser toxic effect of imidacloprid to ladybird beetle (*C. septempunctata*), syrphidfly (*E. balteatus*), green lacewing (*C. carnea*) and *M. persicae* mummies being parasitized by *A. matricariae* when applied to manage *M. persicae* in potato crop. The highest efficacy/toxicity of imidacloprid against insects/aphids is due to its blockade in neuronal pathway (nicotinergic) that is more often abundant in insect nervous system (Felsot, 2001). There is no/less resistance to imidacloprid in *M. persicae* and that is why too many official phytosanitary rely on neonicotinoids insecticides (Nauen and Denholm, 2005; Unruh and Willett, 2008). The comparatively less toxicity of insecticides including thiamethoxam may be due to amplification of certain genes/mutation in *M. persicae* (Natwick *et al*., 2002; Linda and Blackman, 2003). Imidacloprid have low/non toxic effect on spiders, ladybird beetle and green lacewing (Elzen, 2001; Gautam and Tesfaye 2002; Varghese and Beevi, 2004; Walker *et al.,* 2007). There are no latent detrimental effects on important biological parameters of adult parasitoids exposed to pesticides in immature/mummy stages within their host (Jones *et al.,* 1998; Moschettie, 2003).

The Labeled dose of each insecticide was more toxic than reduced dose to *M. persicae*. The difference between the labeled and reduced dose in reducing *M. persicae* population for Provado was 4.7 % while for Actara it was 5.5 %. This finding was in conformity with that of Saljoqi and van Emden (2003a) whereby it was reported that increased in *M. persicae* mortality appeared to be dose dependent. Interestingly, even Provado reduced dose was significantly more effective (by 2%) than Actara labeled dose in reducing *M. persicae* population. The difference in reduction of *M. persicae* population at various insecticides concentrations was also reported by Solangi *et al.* (2007b). Imidacloprid at lower dose is highly toxic to insects/aphids than other neurotoxins, particularly organophosphate (Felsot, 2001).

Plants treated with Provado reduced dose had significantly higher population of ladybird beetle than Provado labeled, Actara labeled and Actara reduced doses by 37.7, 45.9 and 30.1%, respectively, that were statistically equal in toxicity. It may be explained as that reduced doses and selective insecticides encourage the activity of ladybird beetle (Moschetti, 2003; Galvan *et al.,* 2005). Plants treated with Provado reduced dose had significantly higher population of the parasitized *M. persicae* mummies than Provado labeled, Actara labeled and Actara reduced doses by 10.5, 11.4 and 16.3%, respectively;

syrphidfly by 17.8, 15.6 and 28.3%, respectively; green lacewing by 15.2, 16.7 and 29.0%, respectively; PPA*A* by 30.6, 39.6 and 15.5%, respectively; PER*A* by 64.6, 72.0 and 23.0%, respectively; and FR*A* by 19.7, 30.5 and 14.3%, respectively. Whereby, Provado labeled and Actara reduced doses did not differ significantly for parasitized *M. persicae* mummies, syrphidfly and green lacewing. These results may be supported by the finding of Walker *et al.* (2007) while reporting that lowest to highest dose rate of imidacloprid is somewhere between 5 and 15 ml/1000 cell transplants for mortality of green lacewing larvae fed on intoxicated aphids; however, the impact on next generation may be investigated. Lower mortality of *M. persicae* parasitoids *D. rapae and A. matricariae* by diluted concentration of some insecticides was also recorded by Shean and Ranshaw (1991), and Saljoqi and van Emden (2003a).

Reference to the persistency of foliar insecticides, *M. persicae* population was reduced till day 10 of the post treatments, thereafter it started increasing; however the population was consistently quite lower than control even on the last day of recording data i.e. Day 18. These results proved that persistent activity of Actara may offer extra protection with up to three week's residual activity and no known resistances (McKenzie, 2007; Wyman, 2005). According to Boiteau and Osborn (1997) and Lauderdale (2005) the flonicamid inhibit *M. persicae* feeding and delayed its mortality up to 40 hours while to attain 50-70% control the *M. persicae* be exposed for at least 5 d to foliar applications of imidacloprid at the rate of 50 g (AI)/ha.

Varieties comparison on control plants showed that *M. persicae* population was lesser by 45.8% on resistant Kuroda than susceptible Desiree variety. Saljoqi and van Emden (2003c) also recorded lesser population of *M. persicae* on resistant potato variety than susceptible one. The various traits as possible reasons for variation in resistance among potato varieties to *M. persicae* are discussed in Section 4.4. The presumption of maximum populations of natural enemies on resistant varieties for suppressed population of *M. persicae* (Section 4.4) got verified in this experiment. Populations of ladybird beetle, parasitized *M. persicae* mummies, syrphidfly, green lacewing, PPA*A*, PER*A* and FR*A* were higher by 9.6, 39.6, 61.6, 19.8, 33.8, 6.4 and 13.2%, respectively, on Kuroda as compared to Desiree. Higher PPA*A*, PER*A* and FR*A* on resistant potato variety were in conformity with the finding of Saljoqi and van Emden (2003a). Several factors influence the abundance of natural enemies, for example; the density of aphids and certain weeds (Cottrell and Yeargan, 1998a), the abundance of pollen (Coderre and Tourneur, 1986; Cottrell and

Yeargan, 1998b), plant density (Smith, 1971), agriculture landscape (Elliott *et al.*, 1998), temperature (Pappas *et al.*, 2008), plant-based cues while searching for food or shelter (Verkerk *et al.*, 1998; Cortesero *et al.*, 2000), scarcity of high quality prey (aphids) and insecticidal toxin in plant-based foods like honeydew, vegetative tissue, seeds, pollen, floral and extra floral nectar (Picard-Nizou *et al.*, 1995; Coll and Guershon, 2002; Wäckers, 2005; Lundgren, 2009; Lundgren *et al*., 2009), capability of the prey (hosts/pests/aphids) to acquire the toxin (Obrist *et al.*, 2006) etc.

Higher population of natural enemies on Kuroda may be linked with their preference for comparatively sluggish or sessile and relatively small aphids with thin cuticles that are easy prey (Balduf, 1939). Moreover, fecundity of natural enemies are not affected when they are fed aphids reared on induced resistance potato plants that may be due to very low levels, or a complete lack, of Cry protein in the phloem consumed by the aphid (Davidson *et al.*, 2006). The availability of key resources that are essential for their compatibility with the biological control agents may also be higher on Kuroda than to Desiree (Lundgren, 2009; Lundgren *et al*., 2009). The ladybird beetle don not respond to headspace chemicals from aphids alone. Aphid-induced plant chemicals could act as an arrestment or possibly an attractant stimulus to *C. septempunctata*. The effectiveness of *C. septempunctata* as natural enemies of *M. persicae* may be strongly affected by cultivar being grown (Girling and Hassal, 2008). Higher percentage of parasitized *M. persicae* mummies on Kuroda may be linked with smaller population of *M. persicae* and abundance of parasitoid. Further, higher population of ladybird beetle might complement *M. persicae* control by the parasitoid *A. asychis*, rather than disrupting control through intraguild predation (Girling and Hassal, 2008). Similarly, cry toxin that contribute to resistance of certain varieties against pests shows no direct toxic effect on the fecundity of parasitoids, as the fecundity of females parasitoids emerged from larval hosts reared on moderately resistant transgenic tubers did not differ from that of control (Davidson *et al.*, 2006).

Excluding the above mentioned population difference of *M. persicae* and natural enemies on Kuroda vs Desiree that was due to resistance, the insecticides (averaged over both insecticides) reduced the *M. persicae* higher by 0.5 % on Kuroda as compared to Desiree. This showed that that the *M. persicae* on Kuroda was more sensitive to insecticides (Mohamed and van Emden, 1989; Saljoqi and van Emden, 2003a). Whereas, at the same time the populations of ladybird beetle, parasitized *M. persicae* mummies, syrphidfly, green lacewing, PPA*A*, PER*A* and FR*A* were reduced lesser by 4.9, -0.4, 10.6, 12.6, 1.0, 5.8 and

0.0, respectively, on Kuroda as compared to Desiree. Non-target effects of pesticides are extremely important in predator/prey systems for IPM (Dent, 2000). Higher sensitivity of *M. persicae* to insecticides on Kuroda might result in lesser intoxication and in return higher populations natural enemies than Desiree. Parasitoid larvae could be exposed to insecticide selection via the hosts, selection with more resistant hosts could accelerate development of resistance in the parasitoid, and resistance genes selected during larval development could be expressed at the adult stage (Liu *et al.*, 2003).

On Kuroda, the difference between labeled and reduced doses of insecticides for reduction in *M. persicae* population was 5.7 % while on Desiree was 4.8 %. Kuroda treated with reduced doses had significantly suppressed the *M. persicae* population as compared to Desiree treated with labeled and reduced doses of insecticides. It may conclude that labeled vs reduced doses of insecticides were more effective against *M. persicae* on Kuroda than Desiree. Synergistic interaction at the lower doses with plant resistance was also reported by Saljoqi and van Emden (2003a) whereby it was mentioned that reduced doses applied to resistant variety Cardinal gave equal level of control as achieved by highest dose of insecticides on susceptible potato variety Desiree.

On Kuroda the difference between reduced and labeled doses of insecticides for populations of ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A* was 27.8, 7.1, 16.5, 14.2, 26.4, 58.7 and 17.5 %, respectively; while on Desiree was 25.7, 8.6, 13.3, 13.2, 28.6, 54.9, and 18.5 %, respectively. These results showed that reduced doses were less toxic than labeled doses to ladybird beetle, syrphidfly, green lacewing and PER*A* on Kuroda than Desiree. However, the effects on parasitized *M. persicae* mummies, PPA*A* and FR*A* were apposite. Overall treatments assessment showed that Kuroda treated with reduced doses had highest populations of all natural enemies. Kuroda treated with labeled and Desiree treated with reduced doses had nearly equal number of natural enemies whereas Desiree treated with labeled doses had lowest populations of the natural enemies. Lower concentration of insecticides, short residual effect of insecticides and traits of Kuroda might maintain higher population of natural enemies. Sutherland and Poppy (2004) explained it as; host-plant volatiles have an important role in attracting predators and parasitoids to their prey and hosts. According to Koss *et al.* (2005), selective soft/diluted insecticides allowed conventional growers to achieve predator densities similar to those seen in organic fields.

Kuroda as compared to Desiree, treated plants (of each variety) as compared control and Provado treated plants as compared to Actara gave significantly higher yields. Provado reduced and labeled doses did not differ for yield. Similarly, Actara labeled and reduced doses did not differ for yield. The reasons for higher yields may be linked with healthy plants and higher population of natural enemies that in return suppressed the *M. persicae* population and injury to plants. Moreover, the viral diseases that were not assessed in this study might not develop. Similar results were achieved by Saljoqi and van Emden (2003a). Further, these results were in conformity with that of Raman and Midmore (1983) where by foliar-applied insecticide reduced *M. persicae* pest damage and increased yields significantly. According to Abdalla *et al.* (1995) chemical control resulted in a significantly higher yield as compared with the untreated plants in both summer seasons.

6.7 CONCLUSIONS

M. persicae population was suppressed and populations of the natural enemies (ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A*) were consistently higher in all the treatments on Kuroda than Desiree. The foliar insecticides significantly reduced *M. persicae* infestation as compared to control plants, however, at the same time it significantly reduced the populations of the natural enemies. As such, minimum yield was obtained from control plants. Provado was more effective than Actara. Provado reduced dose was less effective in reducing *M. persicae* infestation as compared to Provado labeled dose. However, Provado reduced dose was least toxic to the natural enemies as compared to the other insecticides treatments. As such, maximum yield was obtained from Kuroda treated with Provado reduced dose and Provado labeled dose (both of which did not differ statistically).

6.8 RECOMMENDATIONS

The above findings lead to the following recommendations.

1) To study the impact of foliar insecticides on *M. persicae* and its natural enemies, the comparison on partially susceptible Desiree and partially resistant Kuroda potato varieties provides solid and valuable basis.

2) Kuroda is comparatively more resistant to *M. persicae* infestation and encourages the development of natural enemies as compared to Desiree, even after insecticides applications.

3) Among the tested foliar insecticides, Provado is more effective than Actara.

4) Foliar insecticides has negative impact on natural enemies of *M. persicae*, however, natural enemies alone fails to suppress the *M. persicae* population below threshold level, as the yield obtained from control was significantly lower than the insecticide treated plants.

5) Reduced dose of foliar insecticides (Provado 1.6F) delivered potato yield statistically equal to its labeled dose that might be due to lesser toxicity (higher numbers) to natural enemies. As such, it may be recommended that reduced doses are more effective than labeled doses.

6) Since soil applied insecticides are also widely used for the control of *M. persicae* in potato crop so they may need to be evaluated for comparison with foliar insecticides.

Chapter 7

FIELD EVALUATION OF SOIL ROUTED INSECTICIDES ON POTATO VARIETIES AGAINST GREEN PEACH APHID, *M. PERSICAE* (SULZER), AND THEIR IMPACT ON NATURAL ENEMIES

7.1 INTRODUCTION

Chemical control can be achieved by seed dresser or soil routed systemic insecticides with nicotinyls being used frequently as the most effective tool in early and mid season potato crop (Wyman, 2005). An unexpected increase in virus levels is witnessed in potato crop even before aphids, being conventionally associated with virus spread, were caught in monitoring traps. As such, growers especially seed producers of potato need to revise the practice of waiting for aphid warnings, or treating when there are signs of aphid build up in the crop (Wyman, 2005). Application of soil routed insecticides at planting might be better option in such a situation and is also good for the environment because less chemical is sprayed in the air (Felsot, 2001).

This research experiment was replication of the previous experiment (Chapter 6) except that foliar insecticides were substituted by the soil routed insecticides of the same groups i.e. Admire 2F (imidacloprid) and Platinum 2SC (thiamethoxam). Reason for testing the same groups, used earlier in foliar insecticides experiment, was to prioritize the effective formulation. Evaluation was based on the same parameters as described in Section 6.2. Importance of these groups is explained in Sections 6.4.1 and 6.4.2. An addendum to the information described above is given below:

7.1.1 Admire 2F

Admire provides low cost, economic broad spectrum control of many important insects on different crops, most notably potatoes. Being applied at planting, it provides extended control of Colorado potato beetles, aphids, potato leafhoppers, and potato flea beetles (Bayer Crop Science, 2008). While it’s not certain that imidacloprid is compatible with IPM systems, it is obvious that the ability of imidacloprid as a systemic soil or seed treatment have definite benefits in protecting predators and parasitoids. Internal plant residues are not accessible to insects probing along the leaf surface or scraping the epidermis (James and Coyle, 2001).

Admire and Provado have the same active ingredient, as imidacloprid, but differ in the formulations and percent active ingredients. Imidacloprid is taken up by the roots and translocated to new leaf tissue. As such, it may allow a return to a management program based on application of a systemic insecticide at planting supplemented with few foliar sprays, but with much lower acute toxicity. If Admire is used at planting (soil applied) then Provado may not be used later in the season as a foliar applied material. This may accelerate the development of resistance in aphids and Colorado potato beetles (Radcliffe, 1998). Admire has not shown any compatibility issues with fungicides but it does have compatibility when mixed directly into concentrated fertilizer solutions. Micro nutrients should not pose a problem but one may proceed with caution (Bayer Crop Science, 2008).

Admire may be applied as a narrow band. For best results, it may be directly sprayed on seed pieces or seed potatoes. The recommendations for Admire 2F when applied in furrows is 7.5 to 12 ml per 100 meter row or 344 ml to 526 ml per acre (based on 90cm row spacing). For seed piece treatments the recommendations are 26-39 ml/100 kg seed pieces (12-18 ml/cwt). For late maturing varieties/longer control, 39 ml/100 kg (18 ml/cwt) may be used. The higher rate is used for extended control and for resistance management (Bayer Crop Science, 2008). Tests showed that Admire provides season-long aphid control, especially when applied at the maximum labeled rate (13.1 fl oz/1000 row feet or 18.9 oz/acre with 36" row spacing (Radcliffe, 1998).). Admire 2F may be applied at 0.9-1.3 fl oz/1000 ft of row as a narrow band directly below the seed row in a bedding operation 7 or fewer days before planting, or as an in-furrow spray during planting. Best results have been reported when used on irrigated potatoes. Pre-harvest interval required for potato is 7 days (Glogoza, 2005).

7.1.2 Platinum 2SC

Nicotinyl insecticide, Platinum (thiamethoxam), is a flexible systemic insecticide and due to its low mammalian toxicity, low environmental impact, and excellent efficacy against key potato pests (Colorado potato beetle and aphids) it is widely used by the Wisconsin potato industry (Wyman and Chapman, 2003). Platinum 2SC may be applied as in-furrow during planting; impregnated on dry soil applied fertilizer before or during planting; or at plant emergence as a direct spray and incorporated into the soil with overhead irrigation within 24 hours. The recommended rate is 0.078 to 0.125 lb a.i./acre or

5 to 8 fl oz of the product per season. Only one soil application per season is suggested and may not be exceeded (Glogoza, 2005; County, 2007).

The present study envisaged the following **objectives**:

1) To evaluate the efficacy of soil routed insecticide.
2) To determine the effective dose of each insecticide.
3) To differentiate the efficacy of soil routed insecticides on resistant Kuroda and susceptible Desiree potato varieties in reducing the *M. persicae* population and their impact on natural enemies including: (i) ladybird beetle, (ii) syrphidfly, (iii) green lacewing (iv) parasitized *M. persicae* mummies (v) percent parasitism of *M. persicae* by the *Aphidius* (PPA*A*), (vi) percent emergence rate of the *Aphidius* from *M. persicae* mummies (PER*A*), (vii) fecundity rate of the *Aphidius* (FR*A*).
4) To find the difference in yield of Kuroda and Desiree due to various treatments.

7.2 MATERIALS AND METHODS

This experiment was conducted at Malakandair Farm, Khyber Pakhtunkhwa Agricultural University Peshawar during spring 2008. The same two potato varieties Kuroda and Desiree were used in an experimental layout along with other agronomic measures already described in Section 6.3, except that the foliar insecticides were substituted for soil routed insecticides. Admire and Platinum were sprayed along the seed beds directly over the seeds and then covered with soil (Glogoza, 2005; Bayer Crop Science, 2008). Dosage rates of insecticides were as shown in Table 7.I. Knapsack sprayer was used for insecticidal spray applications.

7.2.1 Data Collection /Population Estimates

The *M. persicae* (winged and wingless), ladybird beetle, syrphidfly, green lacewing and parasitized *M. persicae* mummies were counted on 27th, 34th, 41st, 48th and 55th day of insecticides application. The PPA*A*, PER*A* and FR*A* were recorded on the 41st day of pesticide application. The methods for data collection on all of these parameters are described in Section 3.4.1 to 3.4.5. After harvesting, the yield for each treatment was determined in tons per hectare and analyzed.

7.3 DATA ANALYSIS

Since the experimental design, factors and parameters were similar to those mentioned in Section 6.3; therefore the data were analyzed in the same way as described in Section 6.4.

Table 7.I Soil routed insecticides and dosage rates applied

Soil routed insecticides	Treatments	
	Dose	Amount/rate of Dose
Admire 2F	Zero dose (Control 'Ct')	No insecticide (Control)
	Admire 2F Labeled dose	1083.00 ml per hectare
	Admire 2F reduced dose (Labeled dose reduced by 20%)	866.50 ml per hectare
Platinum 2SC	Zero dose (Control 'Ct')	No insecticide (Control)
	Platinum 2SC Labeled dose	585.12 ml per hectare
	Platinum 2SC reduced dose (Labeled doses reduced by 20%)	468.00 ml per hectare

7.4 RESULTS

7.4.1 Effect of the soil routed insecticides on the *M. persicae* population per nine compound leaves

The analysis of variance for population of *M. persicae* per nine compound leaves showed significant effect ($P<0.05$) due to the soil routed insecticides, the insecticide doses and the post treatment day intervals on potato varieties (Appendix-D Table-D1). Few interactions were also significant ($P<0.05$) that included varieties x insecticide doses (V x D), varieties x post treatment day intervals (V x T) and insecticides doses x post treatment day intervals (D x T). The results of main factors are shown in Fig 7.1. The mean values for varieties showed significant effect being Kuroda resistant than Desiree to *M. persicae* population buildup. Similarly Admire was significantly more effective in controlling *M. persicae* than Platinum. Insecticides dosage rates also showed significant effect with respect to *M. persicae* population being significantly maximum on control plants and minimum on plants treated with labeled doses of insecticides. The *M. persicae* populations on post treatments day intervals also showed significant variations being maximum on Day 55 and minimum on Day 27 of insecticides application.

Interaction between varieties and soil routed insecticides doses (V x D), averaged over insecticides, was significant, Fig 7.2. Both doses on each variety significantly reduced the *M. persicae* population as compared to control. Kuroda plants treated with labeled and reduced doses showed smaller populations of *M. persicae* as compared to Desiree plants treated with same doses of insecticides. Maximum number of *M. persicae* was recorded on Desiree control followed by Kuroda control plants. Minimum populations of *M. persicae* were recorded on Kuroda plants treated with labeled doses of insecticides followed by Kuroda treated with reduced doses of insecticides.

Interaction between varieties and post treatment day intervals (V x T), averaged over insecticides and doses, showed that both varieties responded significantly different at various post treatment day intervals (Fig 7.3). Kuroda consistently showed smaller *M. persicae* population as compared to Desiree; however, on both varieties the population was at significant increase on each successive post treatment day interval. Minimum number of *M. persicae* was recorded on Kuroda Day 27 as compared to maximum on Desiree Day 55 of insecticides application.

Averaged over varieties, interaction between insecticides doses and post treatment day intervals (D x T) showed significant effect (Fig 7.4). The population of *M. persicae* was gradually increasing, on control as well as insecticides treated plants, with significant difference from Day 27 to Day 55 of the post treatments. However, both insecticides doses i.e. labeled and reduced doses significantly suppressed *M. persicae* population as compared to control. Among insecticide doses, the difference between labeled and reduced doses was significant only on Day 34 and 55 of the post treatments. Minimum number of *M. persicae* (0.3) was recorded on Day 27 of the post treatments in plots treated with labeled and reduced doses of insecticides as compared to maximum on Day 55 in control plots.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

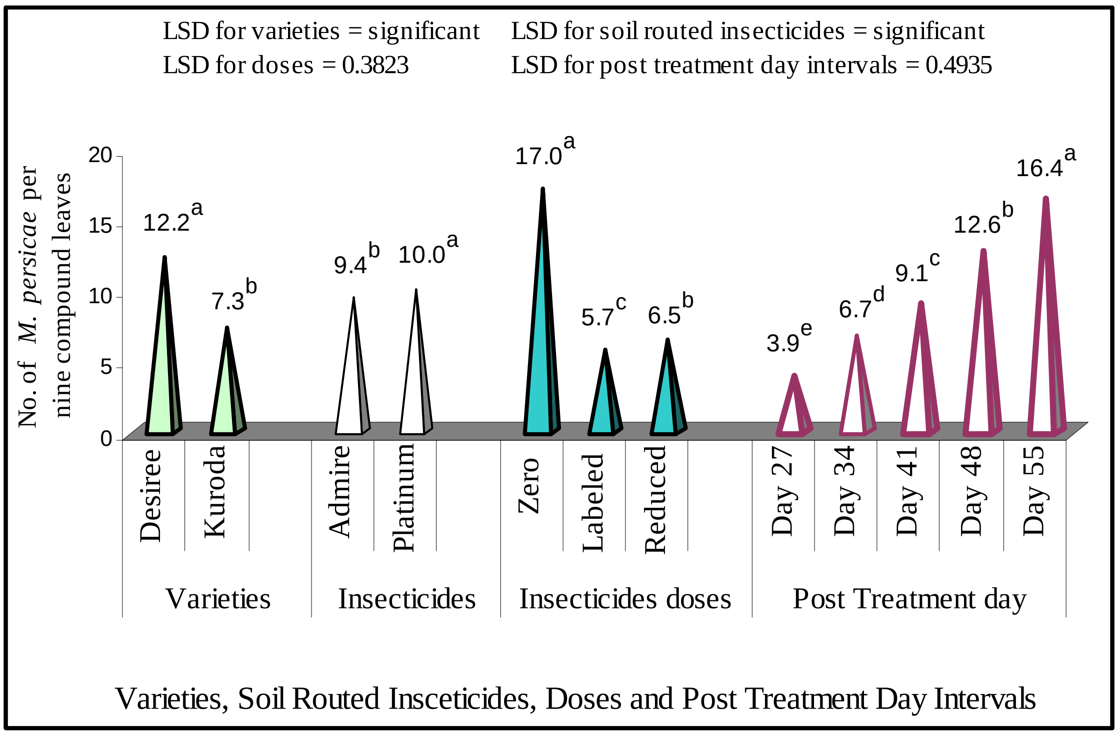


Fig 7.1 Effect of potato varieties, soil routed insecticides, doses and post treatment day intervals on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop

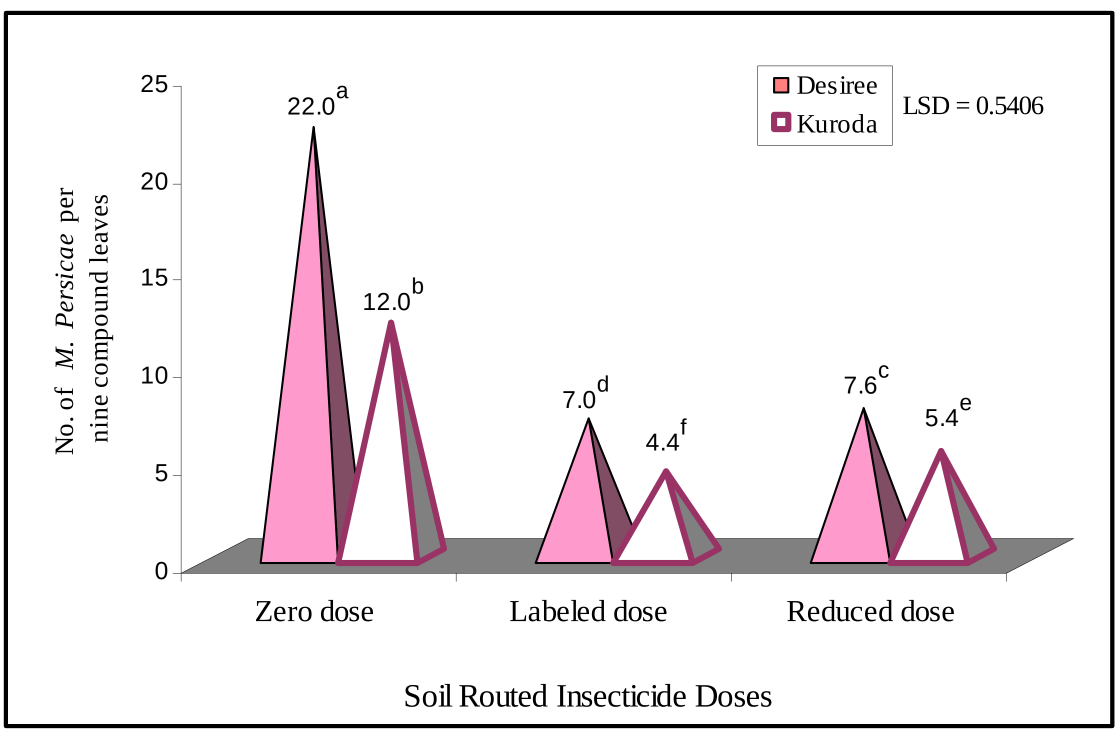


Fig 7.2 Interaction effect of soil routed insecticide doses x potato varieties (D x V) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over insecticides)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

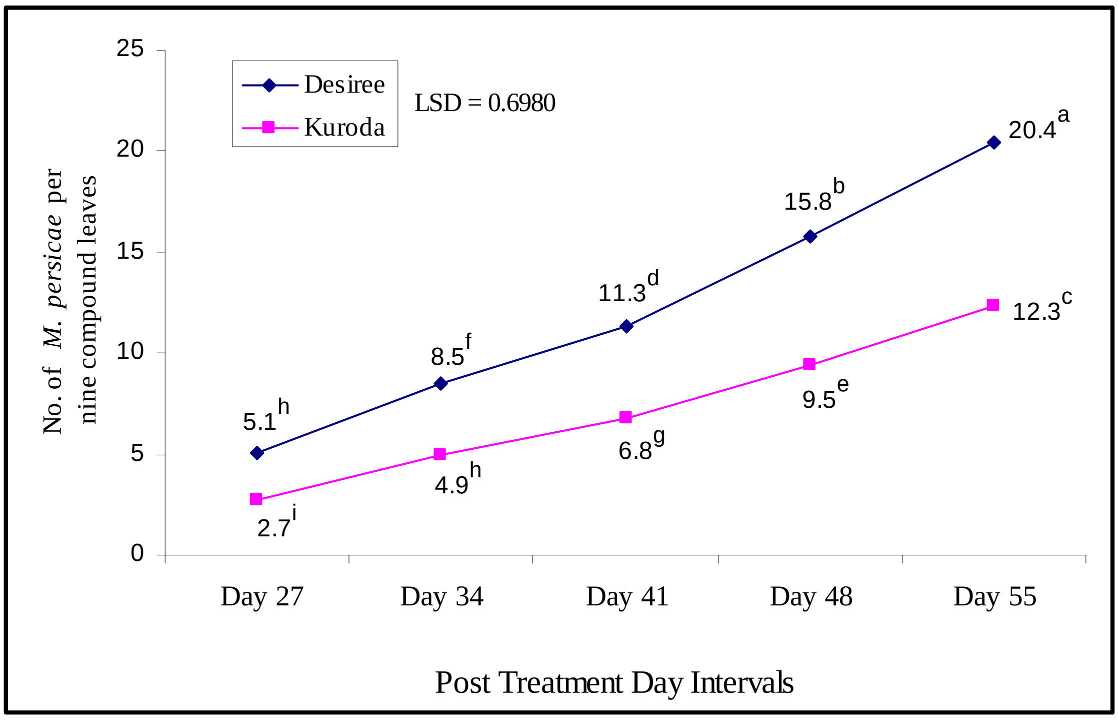


Fig 7.3 Interaction effect of potato varieties x post treatment day intervals (V x T) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over soil routed insecticides and doses)

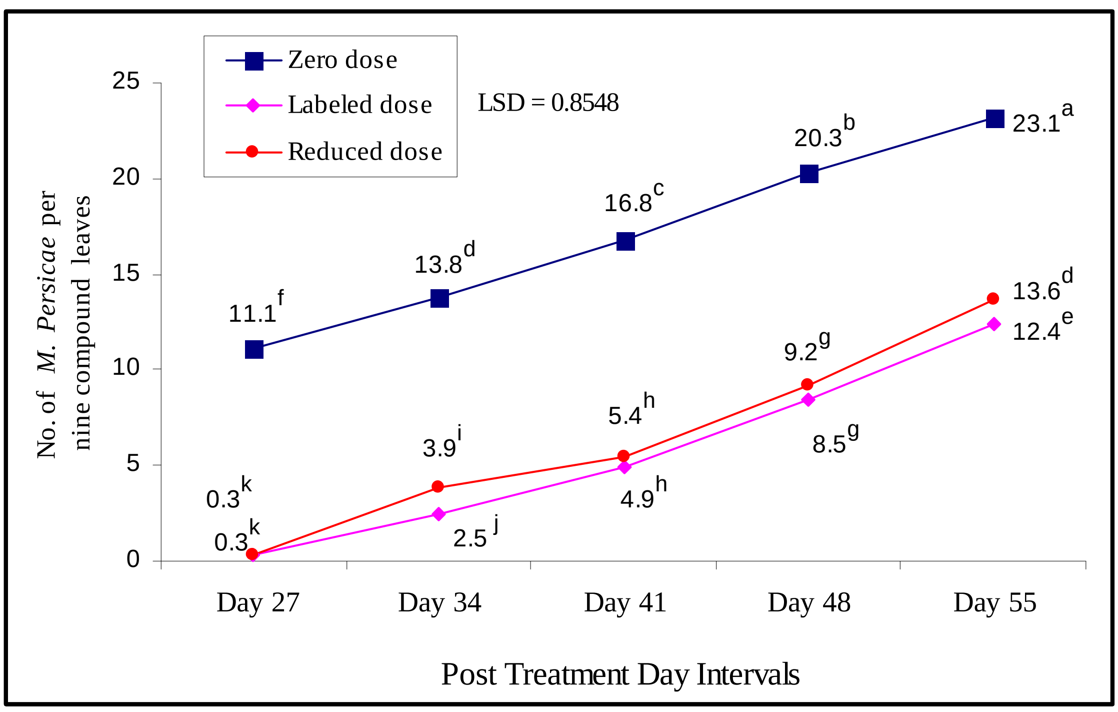


Fig 7.4 Interaction effect of soil routed insecticide doses x post treatment day intervals (D x T) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over potato varieties and insecticides)

7.4.2 Effect of the soil routed insecticides on ladybird beetle population per ten potato plants

The analysis of variance for ladybird beetle population showed significant effect ($P<0.05$) due to soil routed insecticides, dosage rates and the potato varieties (Appendix-D Table-D2). Interaction effects of insecticides doses x insecticides (D x I) and varieties x insecticides x doses (V x I x D) were significant ($P<0.05$). The results of main factors are shown in Fig 7.5. The mean values for varieties showed significant effect being ladybird beetle population higher on Kuroda as compared to Desiree. Similarly population on Admire treated plants was significantly higher than Platinum. Insecticides dosage rates also showed significant effect with respect to ladybird beetle population being significantly maximum on control and minimum on plants treated with labeled doses of Platinum.

Averaged over varieties, both insecticides interacted significantly different at various doses (I x D), Fig 7.6. Ladybird beetle populations on control plants were significantly higher than insecticides treated plants. Among treated plants, maximum population was recorded on plants treated with as compared to minimum on plants treated with Platinum labeled doses. Plants treated with Admire labeled doses and Platinum reduced doses did not differ in respect of ladybird beetle populations.

Interaction effect of potato varieties x soil routed insecticides x insecticide doses (V x I x D) on ladybird beetle populations was significant, Fig 7.7. On both varieties, insecticides as compared to control and labeled doses as compared to reduced doses significantly reduced ladybird beetle populations. Among treated plots, maximum population was recorded on Kuroda plants treated with Admire reduced doses as compared to minimum on Desiree plant treated with Platinum labeled doses.

7.4.3 Effect of the soil routed insecticides on syrphidfly population per ten potato plants

The analysis of variance for syrphidfly population showed significant effect ($P<0.05$) due to soil routed insecticides, dosage rates and potato varieties (Appendix-D Table-D3). All interactions were also significant ($P<0.05$). The results of main factors are shown in Fig 7.8. The mean values for varieties showed significant effect being syrphidfly population higher on Kuroda as compared to Desiree. Similarly population on Admire treated plants was significantly higher than Platinum. Insecticides dosage rates also showed significant effect with respect to syrphidfly population being significantly maximum on control plants and minimum on plants treated with labeled doses of soil routed insecticides.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

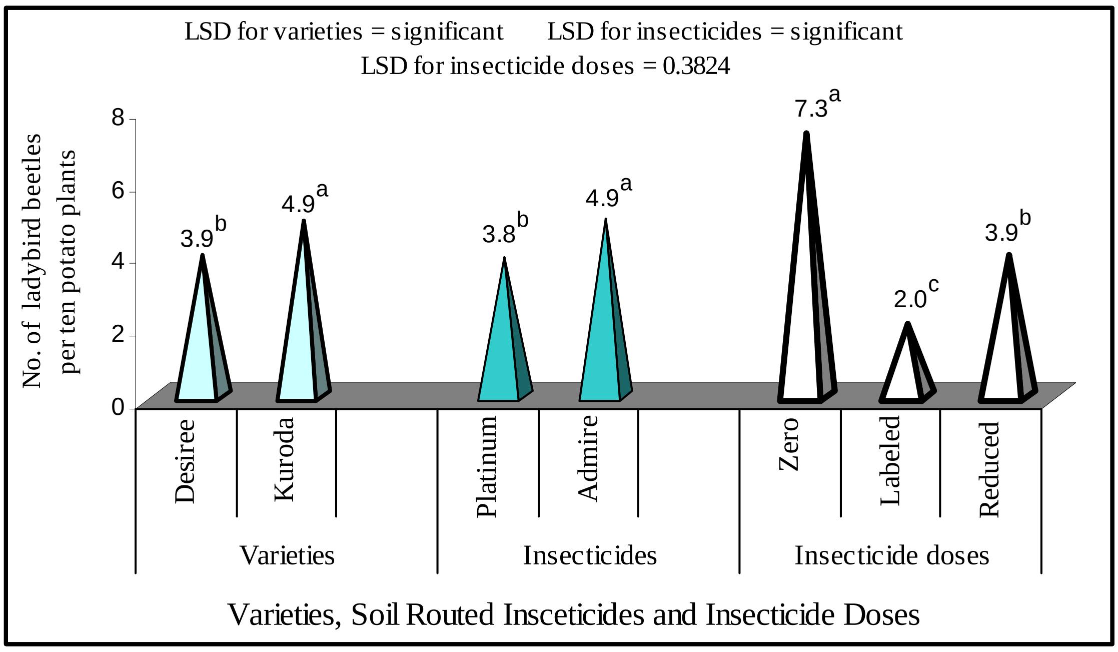


Fig 7.5 Effect of potato varieties, soil routed insecticide and insecticide doses on the population means of coccinellids “ladybird beetles” in potato crop

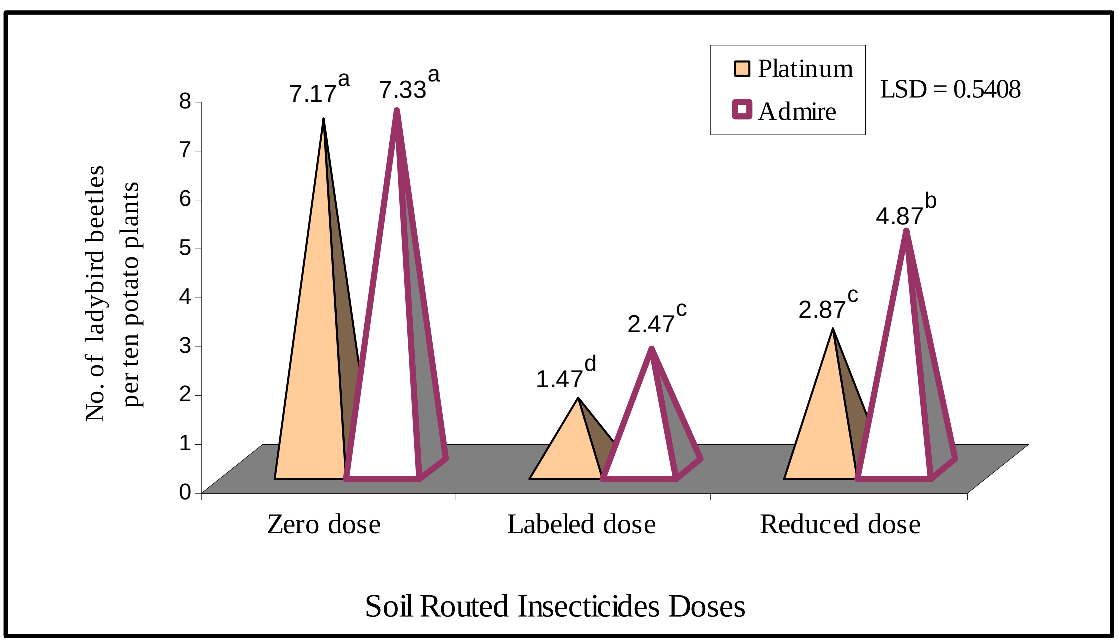


Fig 7.6 Interaction effect of soil routed insecticide and doses (I x D) on the population means of coccinellids “ladybird beetles” in potato crop (averaged over varieties)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

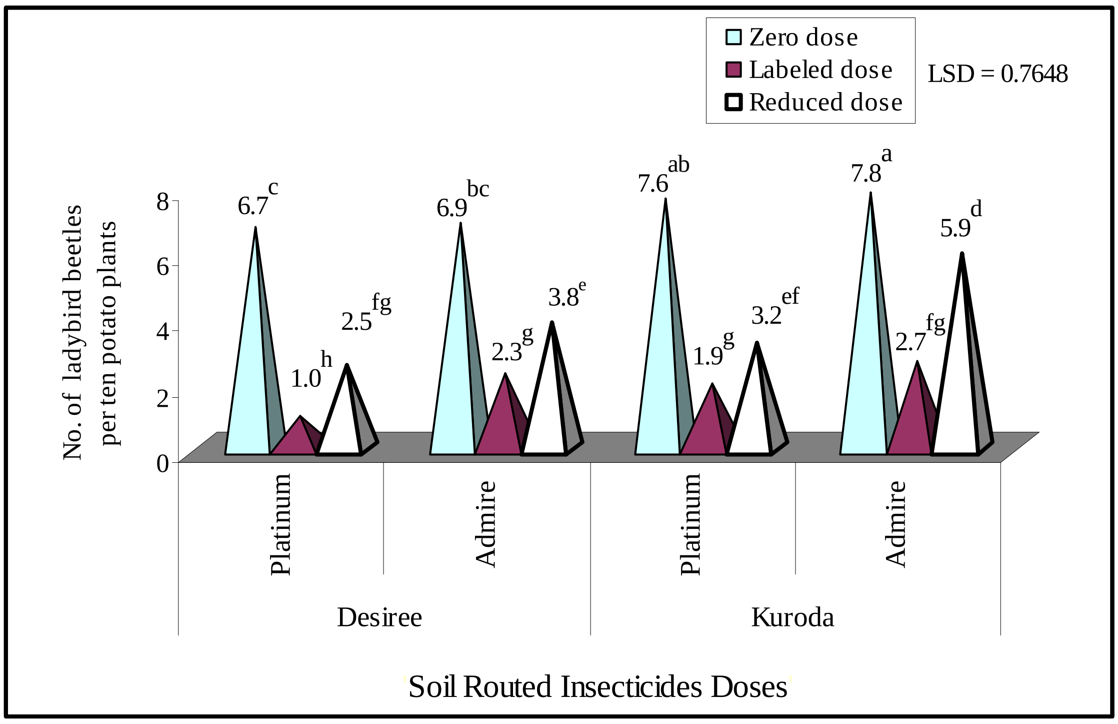


Fig 7.7 Interaction effect of potato varieties x soil routed insecticide and doses (V x I x D) on the population means of coccinellids "ladybird beetles" in potato crop

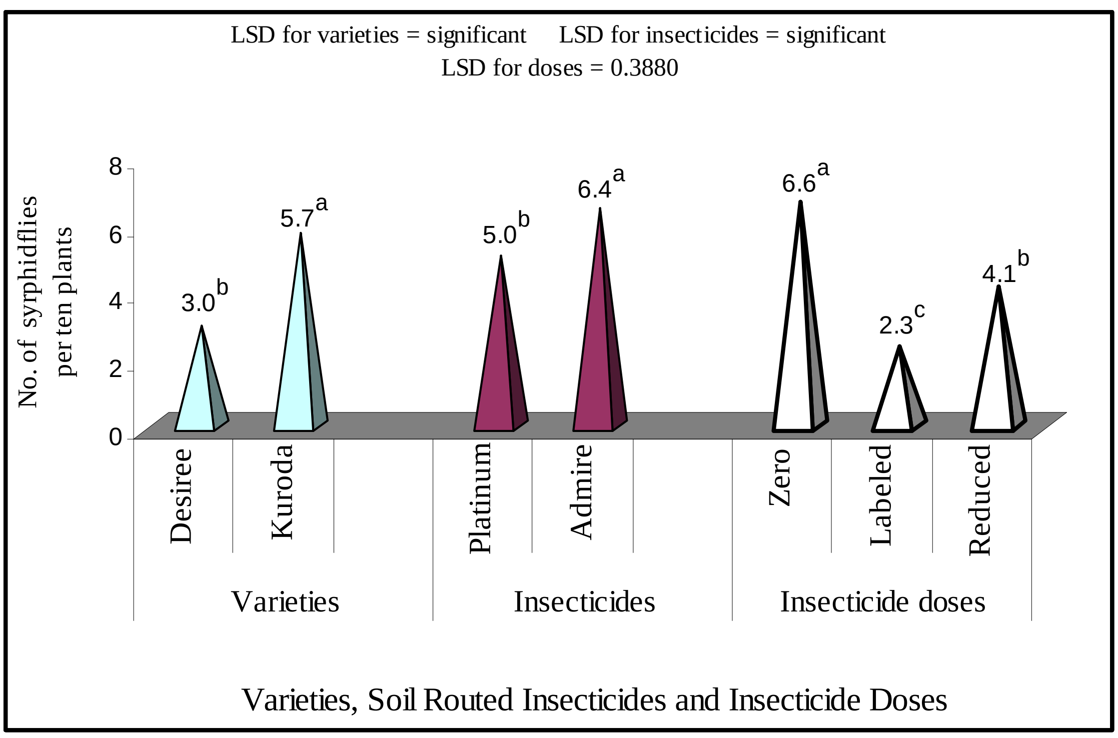


Fig 7.8 Effect of potato varieties, soil routed insecticides and insecticide doses on the population means of syrphidae 'syrphidfly' in potato crop

Averaged over insecticides, interaction between varieties and insecticides doses (V x D) was significant, Fig 7.9. Kuroda plants treated with labeled and reduced doses showed higher populations of syrphidfly as compared to Desiree plants treated with same doses of insecticides. Significantly maximum number of syrphidfly was recorded on Kuroda control plants. It was followed by Kuroda plants treated with reduced doses and Desiree control (both did not differ significantly). Minimum number of syrphidfly was recorded on Desiree plants treated with labeled doses of insecticides.

Averaged over doses, interaction between varieties and soil routed insecticides (V x I) on syrphidfly population was significant, Fig 7.10. Maximum population was recorded on Kuroda plants treated with Admire followed by Kuroda plants treated with Platinum. Minimum population was recorded on Desiree plants treated with Platinum.

Both insecticides interacted significantly different at various doses (Fig 7.11), effect averaged over varieties. Each insecticide at both doses significantly reduced syrphidfly populations as compared to control plants. Labeled doses were significantly more toxic (in terms of reducing syrphidfly population) than reduced doses. Among treated plants, maximum population was recorded on plants treated with Admire reduced doses and minimum on Platinum labeled doses.

Interaction effect of varieties x insecticides x doses (V x I x D) was significant, Fig 7.12. Kuroda plants treated with Admire reduced dose did not differ significantly from Kuroda control that had significantly maximum population of syrphidfly as compared to all other treatments including Desiree control plants. Kuroda plants treated with Admire labeled dose did not differ significantly from Kuroda plants treated with Platinum labeled and reduced doses. However, Kuroda plant treated with Platinum reduced dose had higher population of syrphidfly as compared to Kuroda plants treated with Platinum labeled dose. All insecticides treated Desiree plants had significantly smaller population of syrphidfly as compared to Kuroda treated plants, except that Desiree plants treated with Admire reduced dose did not differ statistically from Kuroda plants treated with Platinum labeled dose. Minimum population of syrphidfly was recorded on Desiree plants treated with Platinum labeled dose.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

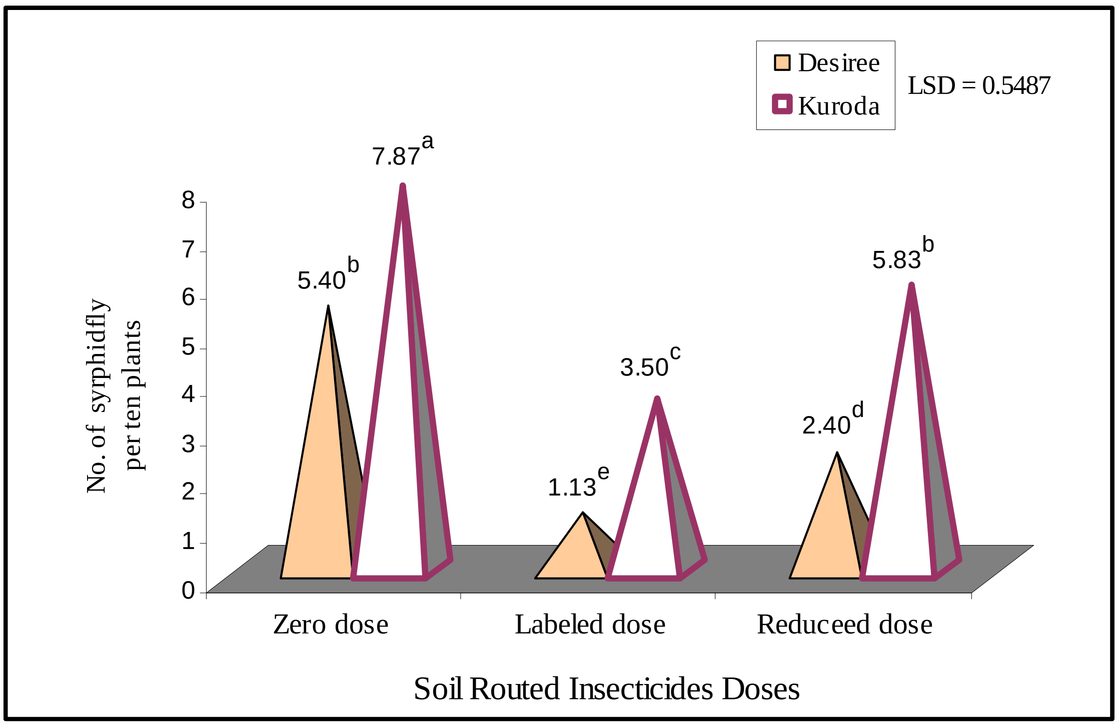


Fig 7.9 Interaction effect of potato varieties x soil routed insecticide doses (V x D) on the population means of syrphidae 'syrphidfly' in potato crop (averaged over insecticides)

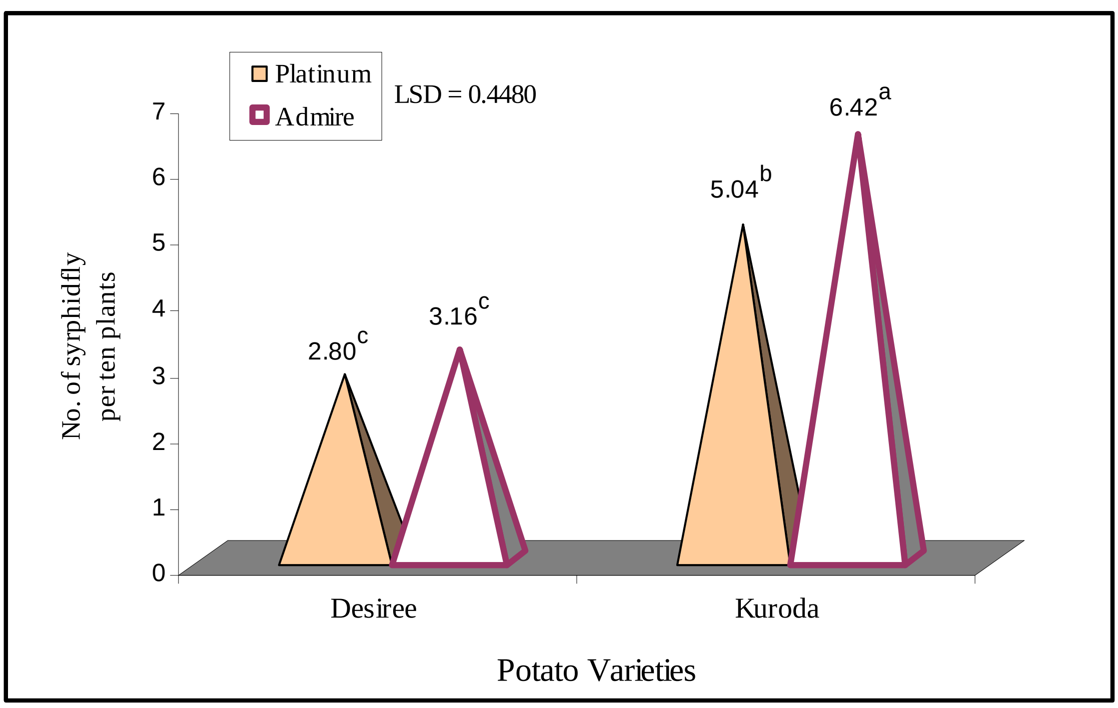


Fig 7.10 Interaction effect of potato varieties x soil routed insecticides (V x I) on the population means of syrphidae 'syrphidfly' in potato crop (averaged over insecticide doses)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

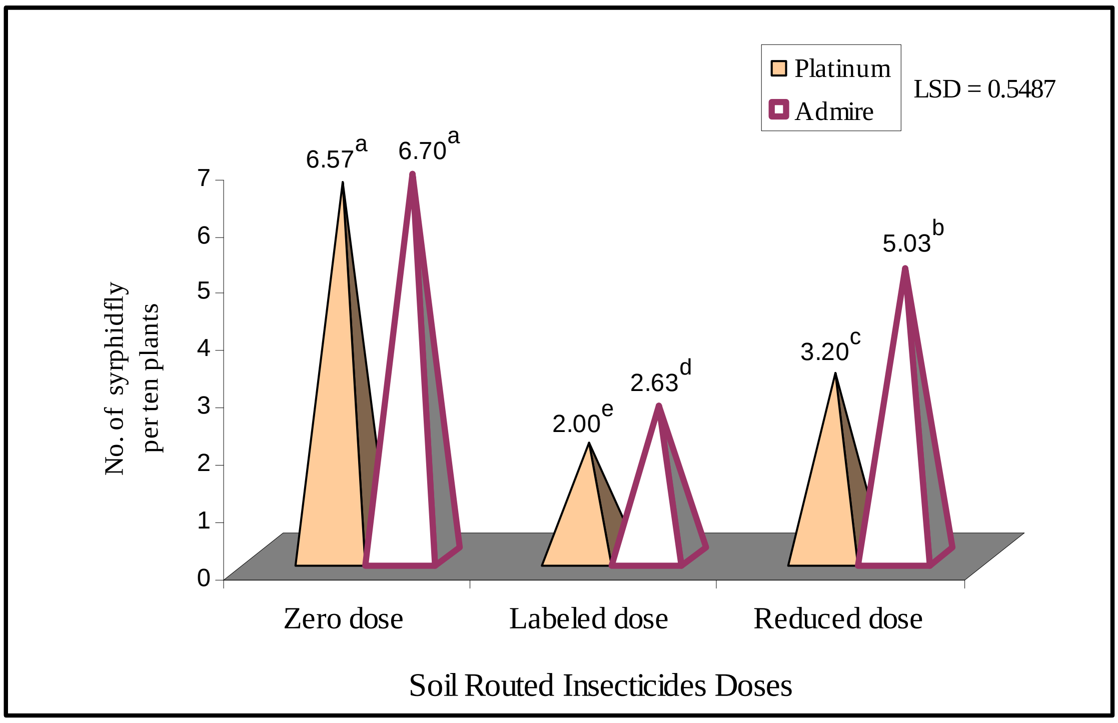


Fig 7.11 Interaction effect of soil routed insecticides x insecticide doses (I x D) on the population means of syrphidae 'syrphidfly' in potato crop (averaged over potato varieties)

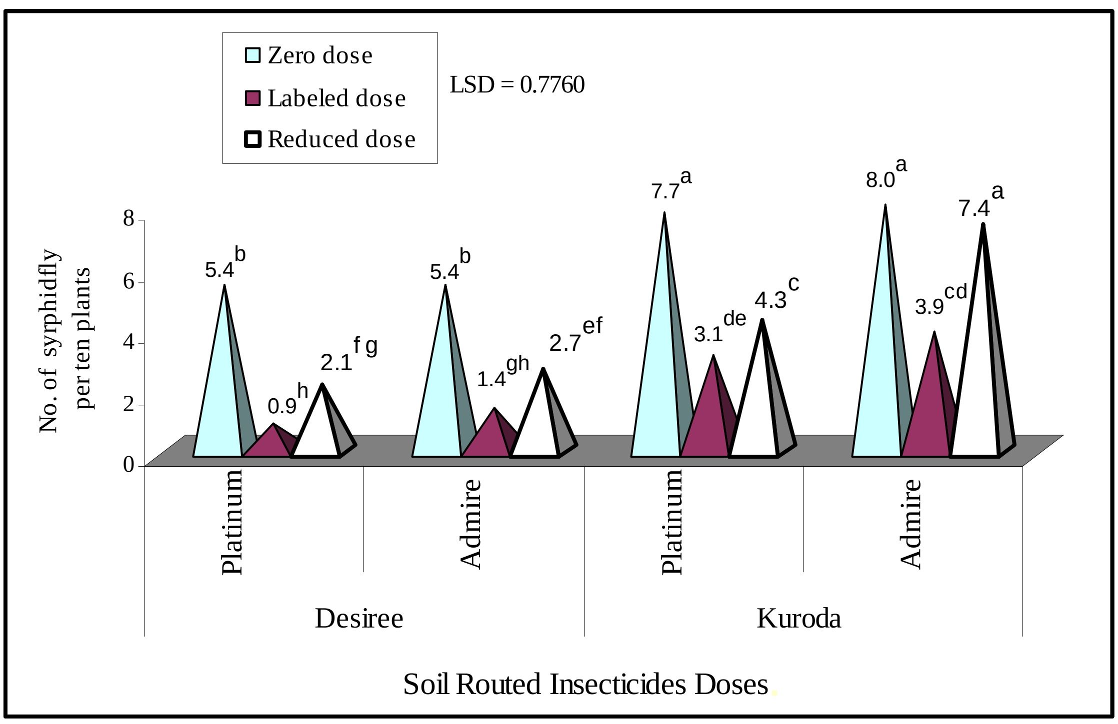


Fig 7.12 Interaction effect of potato varieties x soil routed insecticides x insecticide doses (V x I x D) on the population means of syrphidae 'syrphidfly' in potato crop

7.4.4 Effect of the soil routed insecticides on green lacewing population per ten plants

The analysis of variance for green lacewing population showed significant effect ($P<0.05$) due to soil routed insecticides, dosage rates and the potato varieties (Appendix-D Table-D4). All interactions were also significant ($P<0.05$). The results of main factors are shown in Fig 7.13. The mean values for varieties showed significant effect being green lacewing population higher on Kuroda as compared to Desiree. Similarly population on Admire treated plants was significantly higher than Platinum. Insecticides dosage rates also showed significant effect with respect to green lacewing population being maximum on control plants and minimum on plants treated with labeled doses of insecticides.

Averaged over insecticides, interaction between varieties and insecticides doses (V x D) in respect of green lacewing population was significant, Fig 7.14. Maximum population was recorded on Kuroda control followed by Desiree control plants. Among treated plants, Kuroda plants treated with labeled and reduced doses of insecticides had significantly maximum numbers of green lacewing as compared to Desiree plants treated with same doses of insecticides. As such, maximum population was recorded on Kuroda plants treated with reduced doses followed by Kuroda plants treated with labeled doses of insecticides. Minimum population of green lacewing was recorded on Desiree treated with labeled doses of insecticides.

Interaction between varieties and soil routed insecticides (V x I) on green lacewing population, averaged over doses, was significant (Fig 7.15). Maximum population was recorded on Kuroda plants treated with Admire followed by Platinum treated Kuroda plants. Admire and Platinum effects on green lacewing populations did not differ significantly on Desiree.

Both insecticides interacted significantly different at various doses in respect of green lacewing, effect averaged over varieties, (Fig 7.16). Insecticide at both doses significantly reduced green lacewing population as compared to control plants. Labeled doses of insecticides were significantly toxic (being smaller population) than reduced doses. Among treated plants, maximum population was recorded on plants treated with Admire reduced doses followed by Platinum reduced doses. Minimum number of green lacewing was recorded on plants treated with Platinum labeled doses followed by Admire labeled doses.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

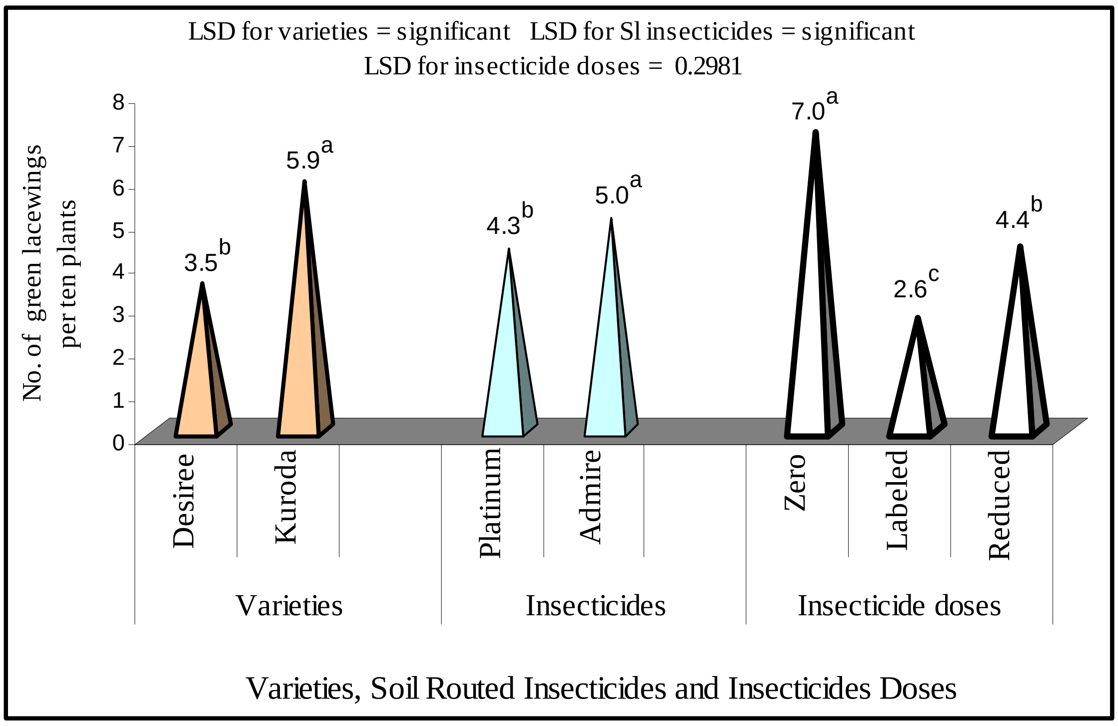


Fig 7.13 Effect of potato varieties, soil routed insecticides and insecticide doses on the population means of *Chrysoperla spp* “green lacewing” in potato crop

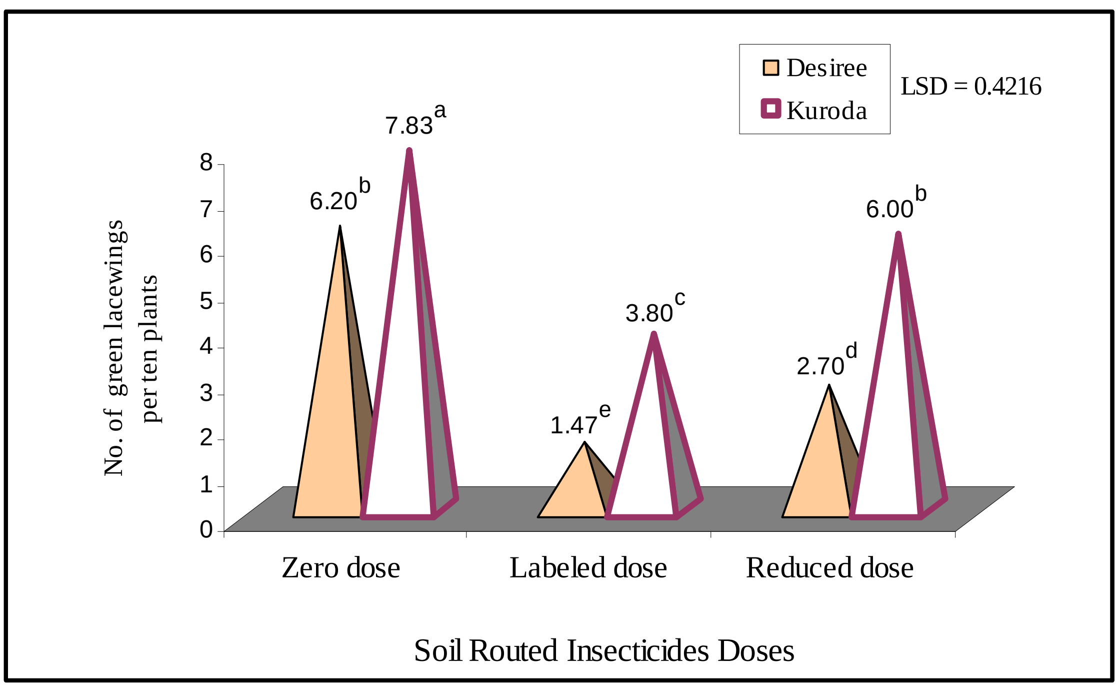


Fig 7.14 Interaction effect of potato varieties x soil routed insecticide doses (V x D) on the population means of *Chrysoperla spp* “green lacewing” in potato crop (averaged over insecticides)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

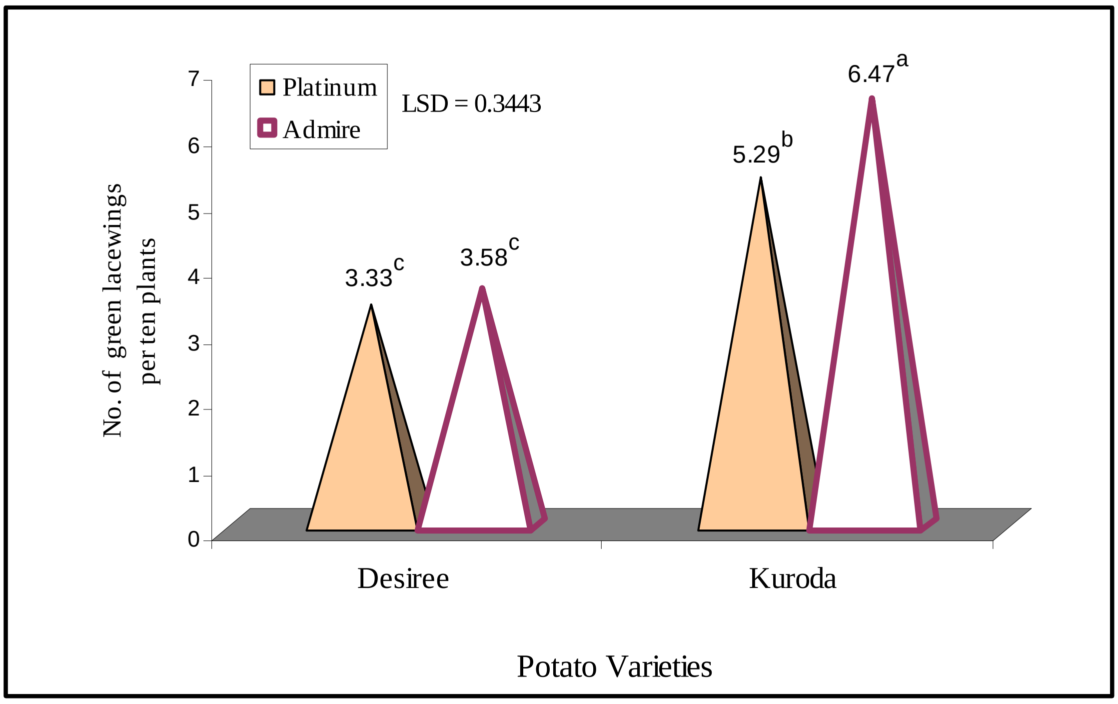


Fig 7.15 Interaction effect of potato varieties x soil routed insecticides (V x I) on the population means of *Chrysoperla spp* “green lacewing” in potato crop (averaged over insecticide doses)

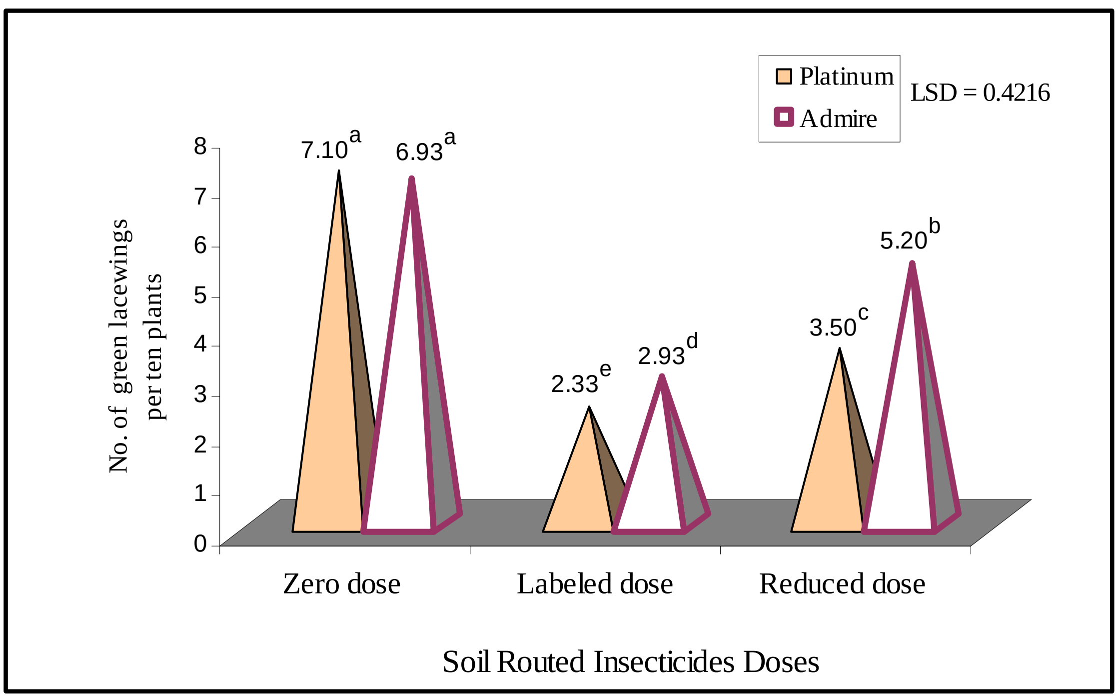


Fig 7.16 Interaction effect of soil routed insecticides x insecticide doses (I x D) on the population means of *Chrysoperla spp* “green lacewing” in potato crop (averaged over potato varieties)

Interaction effect of potato varieties x soil applied insecticides x insecticide doses (V x I x D) on green lacewing populations was significant, Fig 7.17. Kuroda control plants and Kuroda plants treated with Admire reduced dose did not differ statistically and had significantly maximum population of green lacewing as compared to all other treatments including Desiree control plants. It was followed by Kuroda plants treated with Platinum reduced dose and Admire labeled dose (both of which did not differ statistically). All insecticides treated Desiree plants had significantly smaller population of green lacewing as compared to Kuroda treated plants, except that Desiree plants treated with Admire reduced dose did not differ statistically from Kuroda plants treated with Platinum labeled dose. Minimum population of green lacewing was recorded on Desiree plants treated with Platinum labeled dose.

7.4.5 Effect of the soil routed insecticides on the population of parasitized *M. persicae* mummies per ten plants

The analysis of variance for population of parasitized *M. persicae* mummies showed significant effect ($P<0.05$) due to soil routed insecticides, dosage rates and the potato varieties (Appendix-D Table-D5). Interactions effect for varieties x insecticide doses (V x D) and soil routed insecticides x insecticide doses (I x D) were also significant ($P<0.05$). The results of main factors are shown in Fig 7.18. The mean values for varieties showed significant effect being population of parasitized *M. persicae* mummies higher on Kuroda as compared to Desiree. Similarly population on Admire treated plants was significantly higher than Platinum. Insecticides dosage rates also showed significant effect with respect to population of parasitized *M. persicae* mummies being significantly maximum on control and minimum on plants treated with labeled doses of insecticides.

Averaged over insecticides, interaction between varieties and insecticides doses on population of parasitized *M. persicae* mummies was significant (Fig 7.19). Significantly maximum number of the parasitized *M. persicae* mummies was recorded on Kuroda control plants. It was followed by Kuroda plants treated with Admire reduced dose and Desiree control (both did not differ statistically). Desiree plants treated with reduced doses and Kuroda treated with labeled doses of insecticides also did not differ in respect of the populations of parasitized *M. persicae* mummies. Significantly minimum number of the parasitized *M. persicae* mummies was recorded on Desiree plants treated with labeled doses of insecticides.

Averaged over varieties, both insecticides interacted significantly different at various doses (I x D), Fig 7.20. Numbers of the parasitized *M. persicae* mummies on control plants were significantly higher than insecticides treated plants. Among treated plants, maximum population was recorded on plants treated with Admire reduced doses as compared to minimum on plants treated with Platinum labeled doses. Plants treated with Admire labeled doses and Platinum reduced doses did not differ in respect of the populations of parasitized *M. persicae* mummies.

7.4.6 Effect of the soil routed insecticides on the PPA*A*

The analysis of variance for PPA*A* showed significant effect (P<0.05) due to soil routed insecticides, dosage rates and the potato varieties (Appendix-D Table-D6). Interactions between varieties x doses (V x D) and insecticides doses x insecticides (D x I) were significant (P < 0.05). The results of main factors are shown in Fig 7.21. The mean values for varieties showed significant effect being maximum PPA*A* on Kuroda as compared to Desiree. Similarly the PPA*A* on Admire treated plants was significantly higher than Platinum. Insecticides dosage rates also showed significant effect with respect to PPA*A* being significantly maximum on control plants and minimum on plants treated with labeled doses of insecticides.

Averaged over insecticides, interaction effect of varieties x doses (V x D) on PPA*A* was significant (Fig 7.22). Maximum PPA*A* was recorded on Kuroda control followed by Desiree control. PPA*A* on plants treated with reduced doses of insecticides was significantly higher as compared to labeled doses. However, the varieties did not differ significantly from each other in respect of PPA*A* on reduced doses of insecticides as well as labeled doses of insecticides.

Averaged over varieties, both insecticides interacted significantly different at various doses (D x I), Fig 7.23. Both insecticides significantly reduced PPA*A* as compared to control plants. However, PPA*A* on plants treated with reduced doses of insecticides was significantly higher as compared to labeled doses. Among treated plants, the maximum PPA*A* was recorded on plants treated with Admire reduced doses followed by plants treated with Platinum reduced doses. Minimum PPA*A* was recorded on plants treated with Platinum labeled doses.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

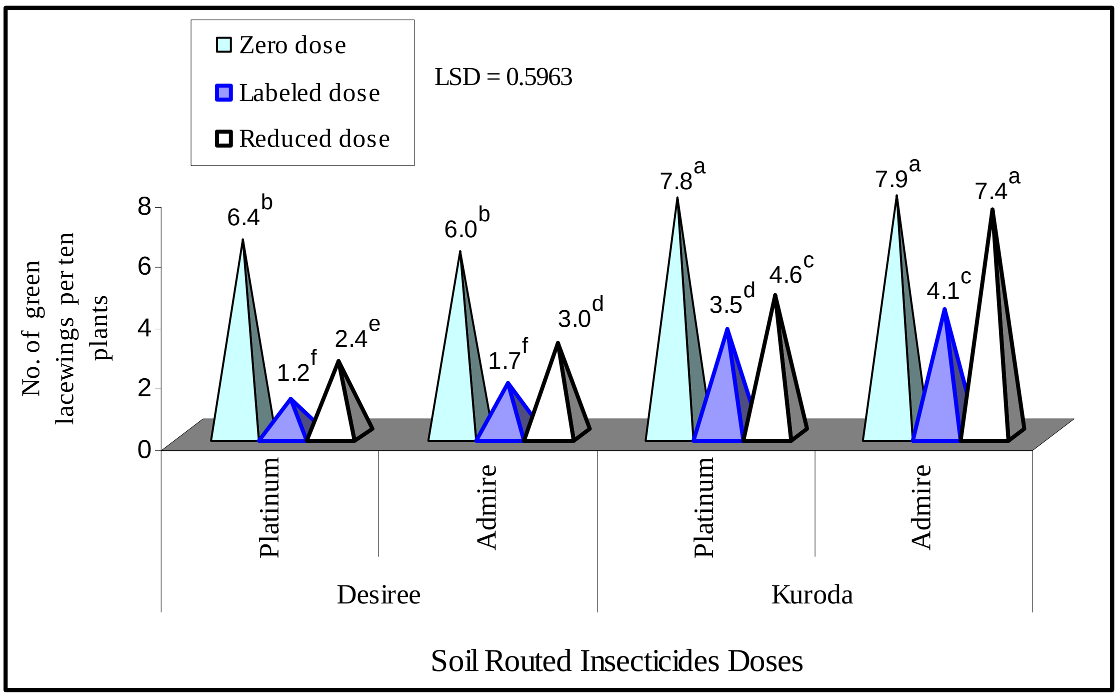


Fig 7.17 Interaction effect of potato varieties x soil routed insecticides x insecticide doses (V x I x D) on the population means of *Chrysoperla spp* "green lacewing" in potato crop

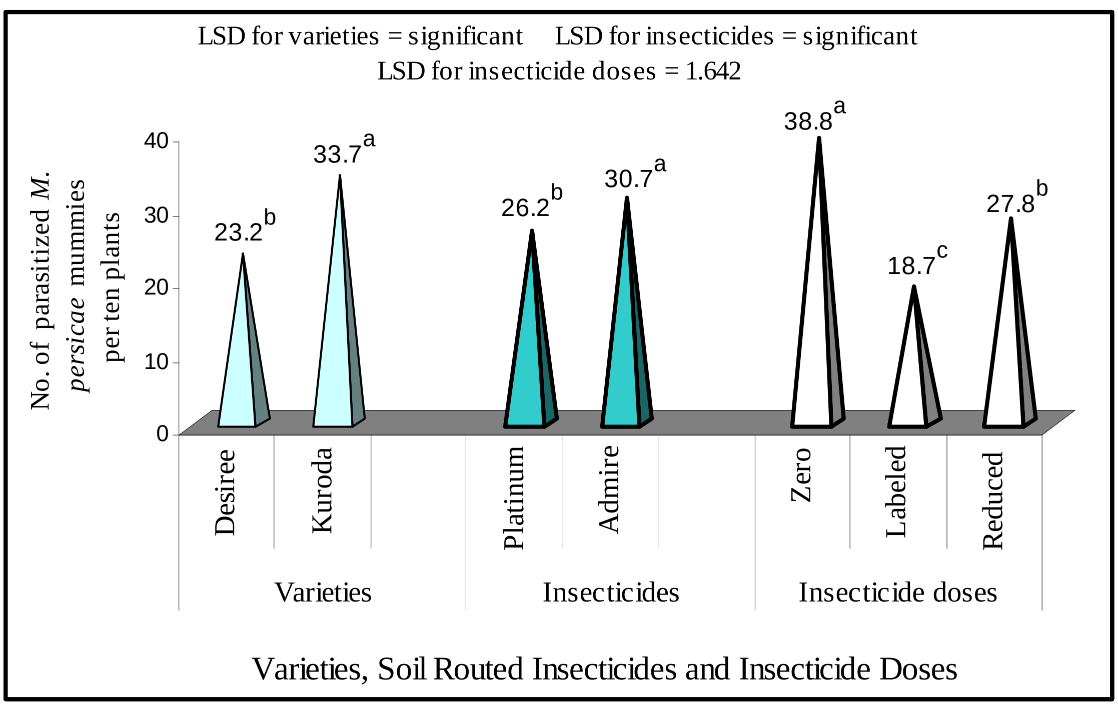


Fig 7.18 Effect of potato varieties, soil routed insecticides and insecticide doses on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PAM) in potato crop

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

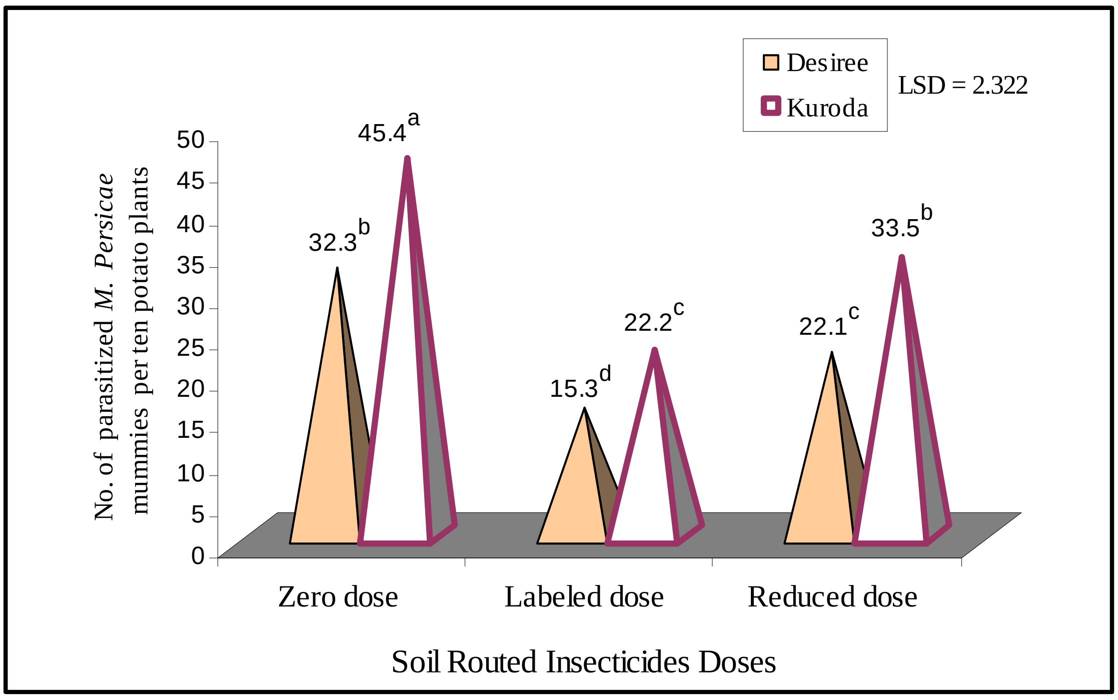


Fig 7.19 Interaction effect of potato varieties x soil routed insecticide doses (V x D) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PAM) in potato crop (averaged over insecticides)

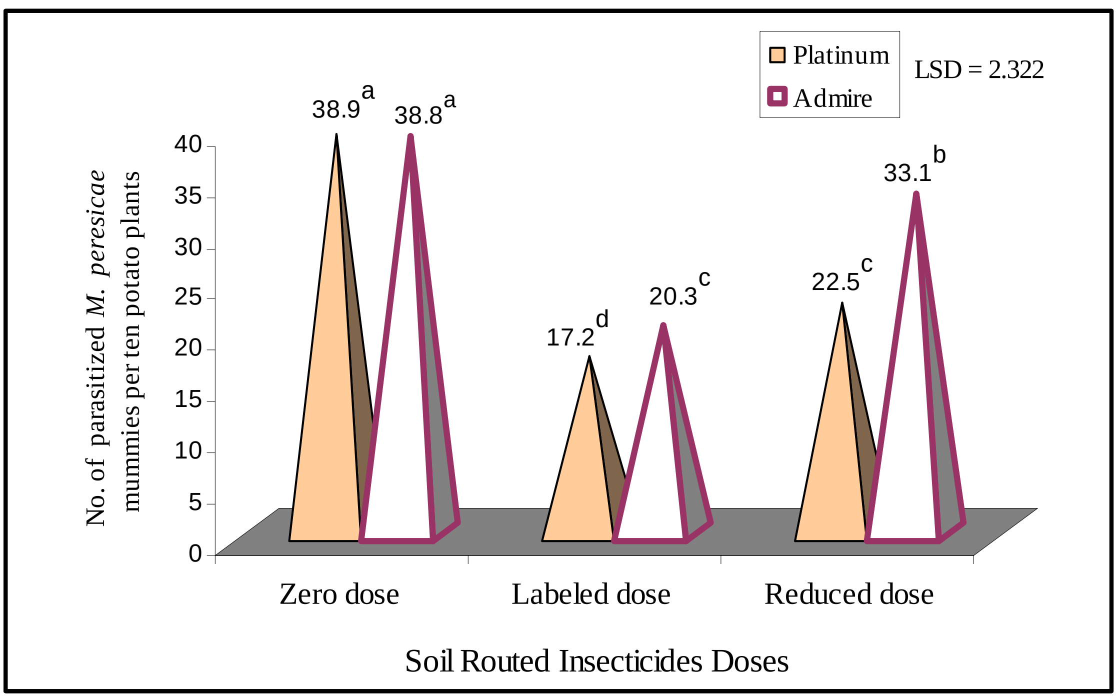


Fig 7.20 Interaction effect of soil routed insecticides x insecticide doses (I x D) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PAM) in potato crop (averaged over potato varieties)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

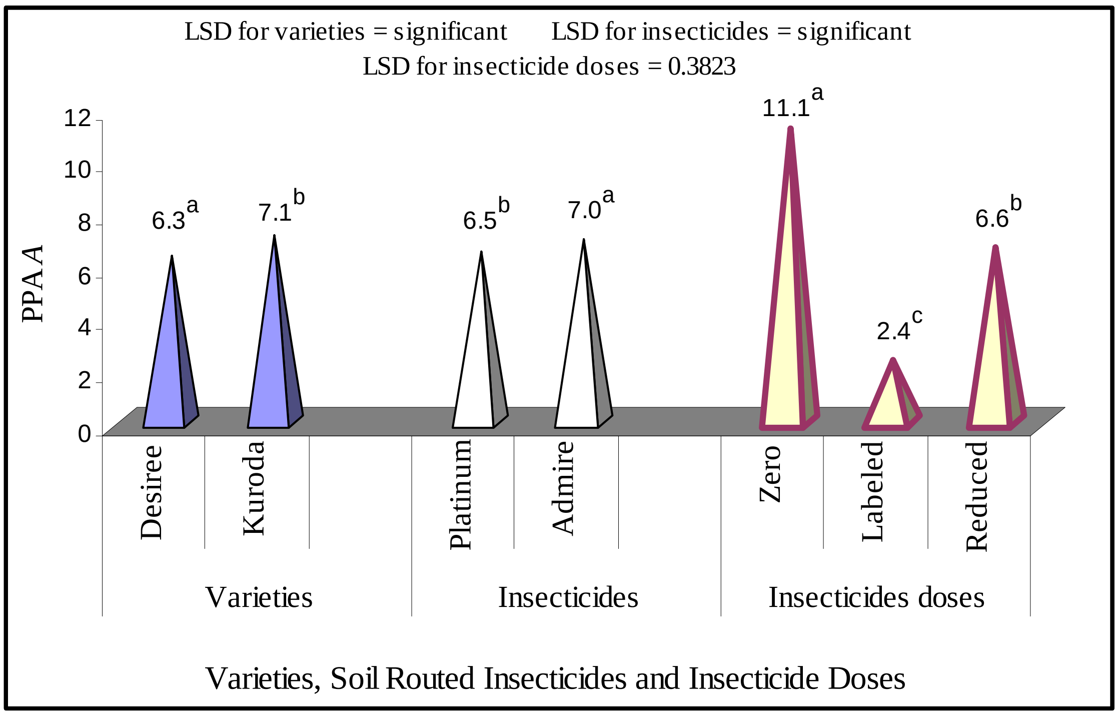


Fig 7.21 Effect of potato varieties, soil routed insecticides and insecticide doses on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp*.' (PPA*A*) in potato crop

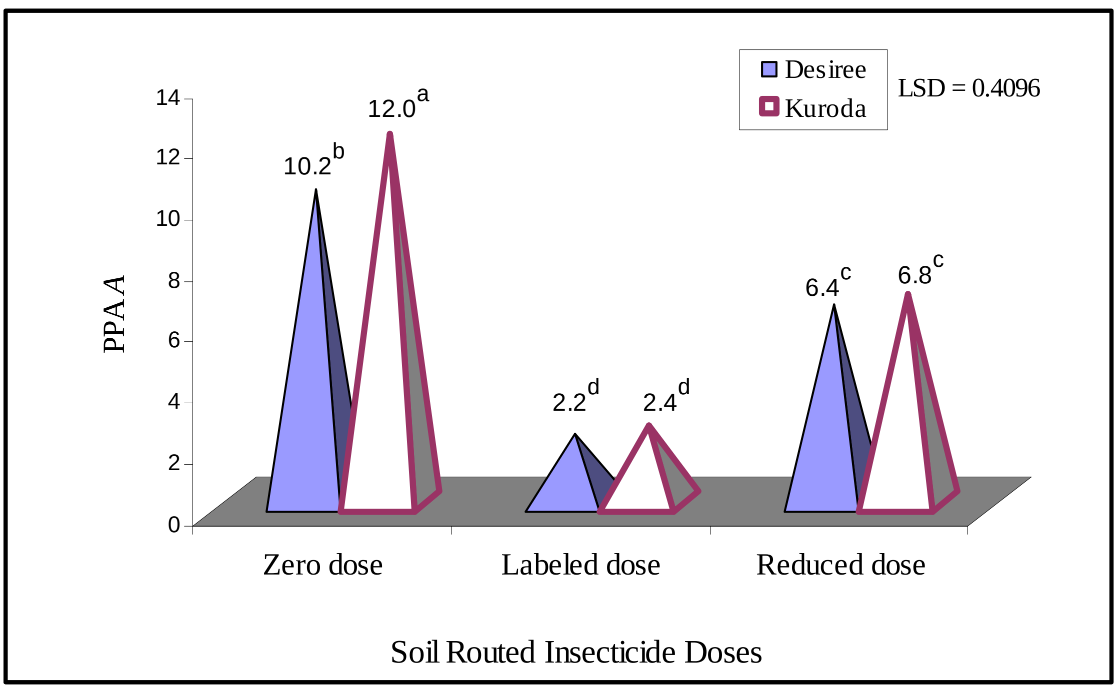
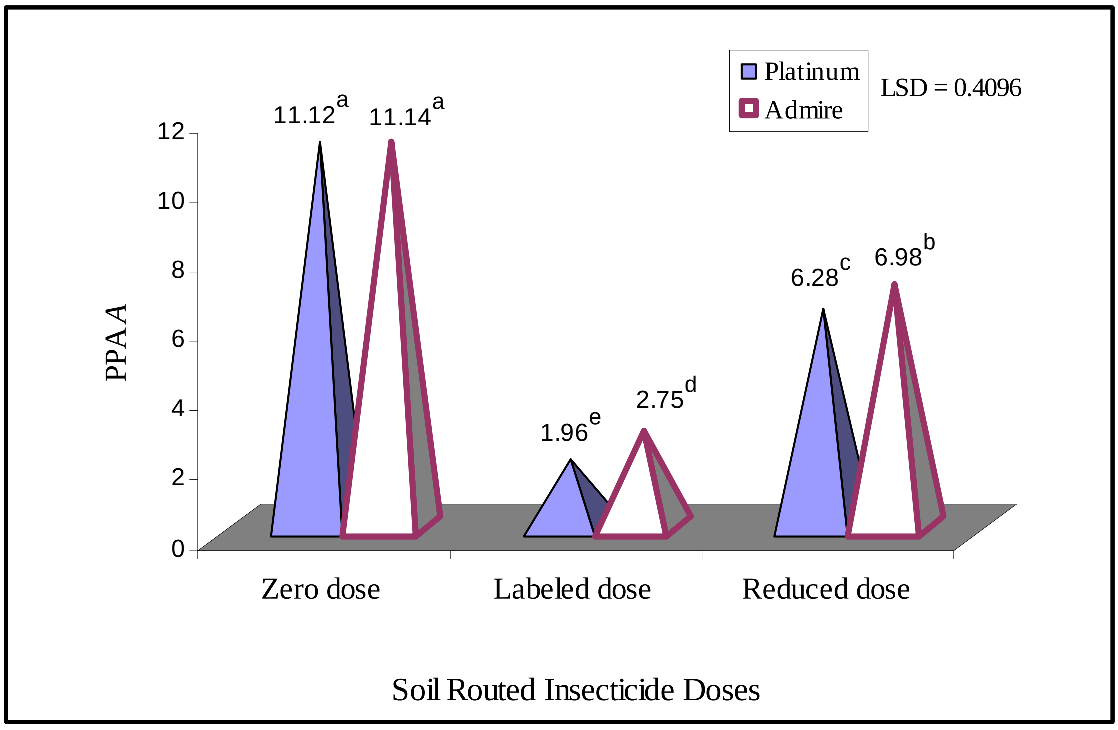


Fig 7.22 Interaction effect of potato varieties x soil routed insecticide doses (V x D) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp*.' (PPA*A*) in potato crop (averaged over insecticides)



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

Fig 7.23 Interaction effect of soil routed insecticides x insecticide doses (I x D) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp*.' (PPA*A*) in potato crop (averaged over potato varieties)

7.4.7 Effect of the soil routed insecticides on the PER*A*

The analysis of variance for PER*A* showed significant effect (P<0.05) due to soil routed insecticides, dosage rates and the potato varieties (Appendix-D Table-D7). One interaction i.e. soil routed insecticides x insecticides doses (I x D) was significant (P<0.05). The results of main factors are shown in Fig 7.24. The mean values for varieties showed significant effect being PER*A* higher on Kuroda as compared to Desiree. Similarly PER*A* on Admire treated plants was significantly higher than Platinum. Insecticides dosage rates also showed significant effect with respect to PER*A* being significantly maximum on control plants and minimum on plants treated with labeled doses of insecticides.

Both the insecticides interacted significantly different at various doses (Fig 7.25). PER*A* recorded on control plants was significantly higher than insecticides treated plants. Among treated plots, maximum PER*A* was recorded on plants treated with Admire reduced doses followed by Platinum reduced doses. Minimum emergence rate was recorded on plants treated with Platinum labeled doses.

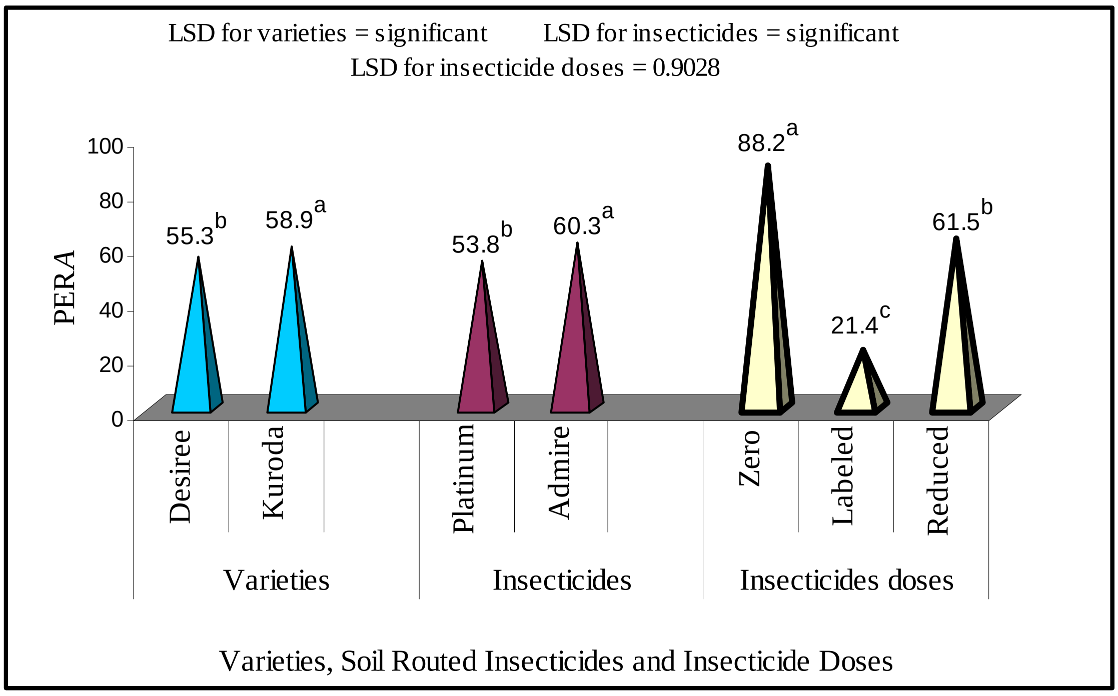


Fig 7.24 Effect of potato varieties, soil routed insecticides and insecticide doses on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PERA) in potato crop

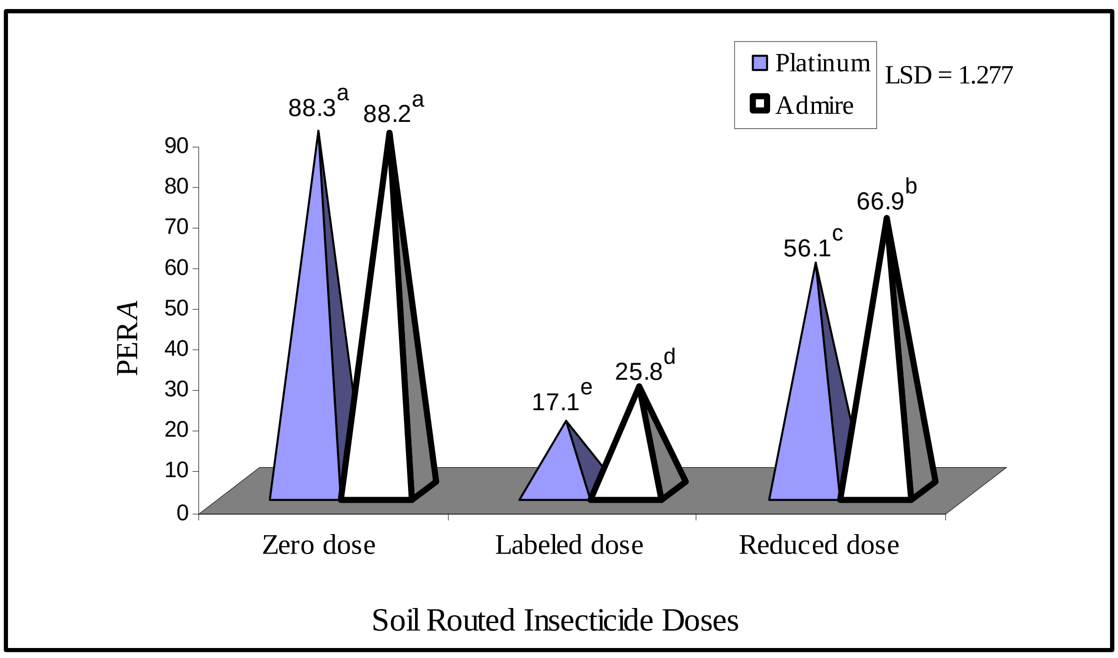


Fig 7.25 Interaction effect of soil routed insecticides x insecticide doses (I x D) on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PERA) in potato crop (averaged over potato varieties)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

7.4.8 Effect of the soil routed insecticides on the FR*A*

The analysis of variance for FR*A* showed significant effect due to dosage rates and the potato varieties (P<0.05), whereas the effect of insecticides on FR*A* was not significant (P>0.05), Appendix-D Table-D8. Only one interaction i.e. varieties x insecticides doses (V x D) was significant (P<0.05). The results of main factors are shown in Fig 7.26. The mean values for varieties showed significant effect being higher FR*A* on Kuroda as compared to Desiree. Insecticides dosage rates showed significant effect with respect to FR*A* being significantly maximum on control plants and minimum on plants treated with labeled doses of insecticides.

Interaction between varieties and insecticides doses on FR*A* was significant (Fig 7.27). Maximum FR*A* was recorded on Kuroda control followed by Desiree control. Among treated plants, FR*A* was significantly higher on plants treated with reduced doses of insecticides as compared to labeled doses. Kuroda and Desiree did not show significant difference in respect of FR*A* when treated with reduced doses of insecticides. Kuroda plants treated with labeled doses had higher FR*A* as compared to Desiree plants treated with labeled doses.

7.4.9 Effect of the soil routed insecticides on the yield of potato varieties

The analysis of variance for yields showed significant effect (P<0.05) due to soil routed insecticides, dosage rates and the potato varieties (Appendix-D Table-D9). Only one interaction i.e. soil routed insecticides x insecticide doses (I x D) was significant (P<0.05). The results of main factors are shown in Fig 7.28. The mean values for varieties showed significant effect being Kuroda yield higher as compared to Desiree. Similarly yield of plants treated with Admire was significantly higher than Platinum. Insecticides dosage rates also showed significant effect with respect to yield being significantly minimum from control plants and maximum from plants treated with reduced doses of insecticides. However, reduced and labeled doses did not differ significantly in respect of yield.

Averaged over varieties, both insecticides interacted significantly different at various doses on potato yield, Fig 7.29. Potato yields obtained from insecticides treated plants were significantly higher than control plants. Yields obtained from Admire treated plants were significantly higher as compared to Platinum treated plants. However, Admire as well as Platinum did not show significant difference for yields at labeled and reduced doses.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

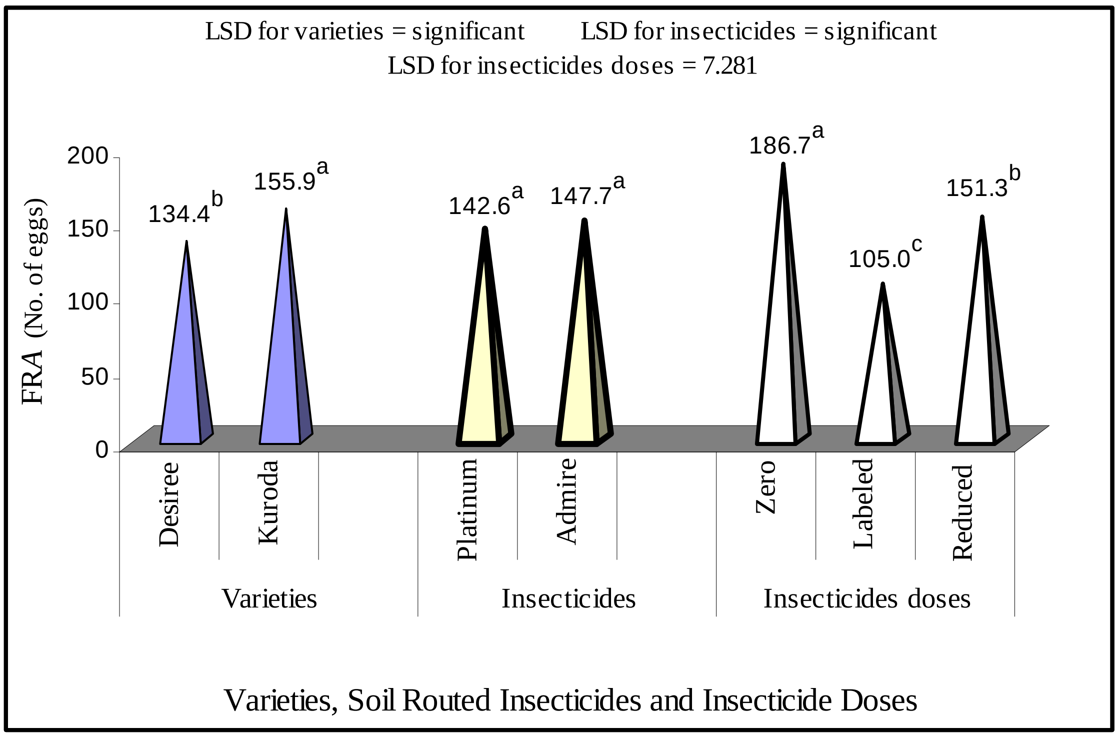


Fig 7.26 Effect of potato varieties, soil routed insecticides and insecticide doses on the mean fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop

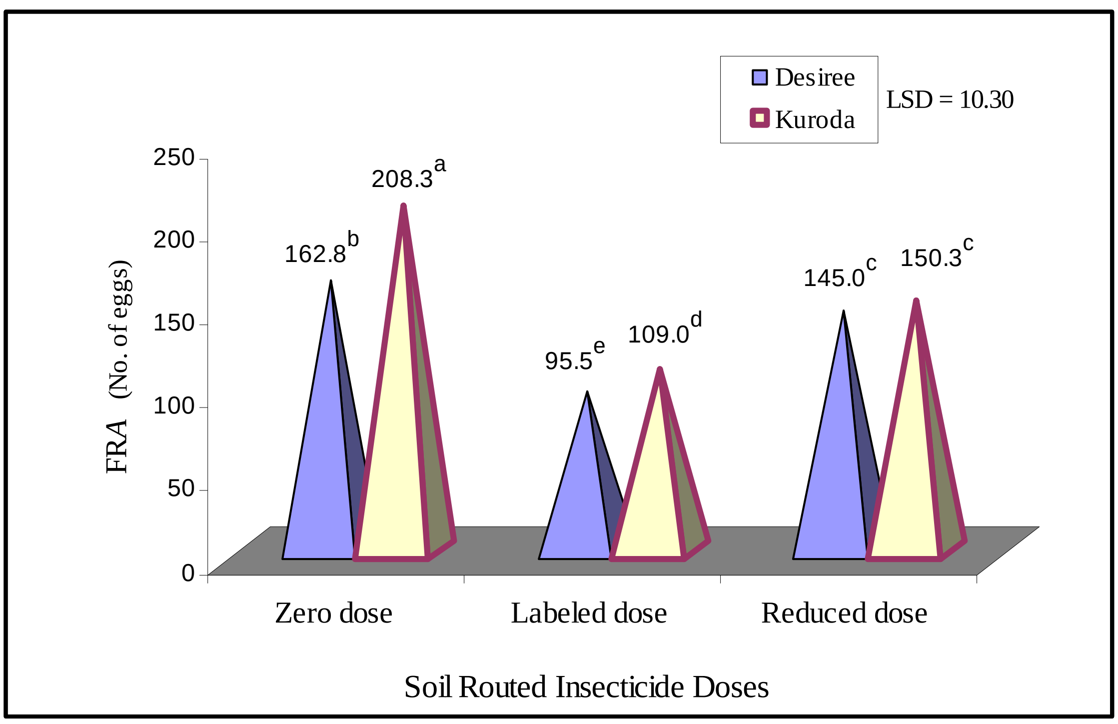


Fig 7.27 Interaction effect of potato varieties x soil routed insecticide doses (V x D) on the mean fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop (averaged over insecticides)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

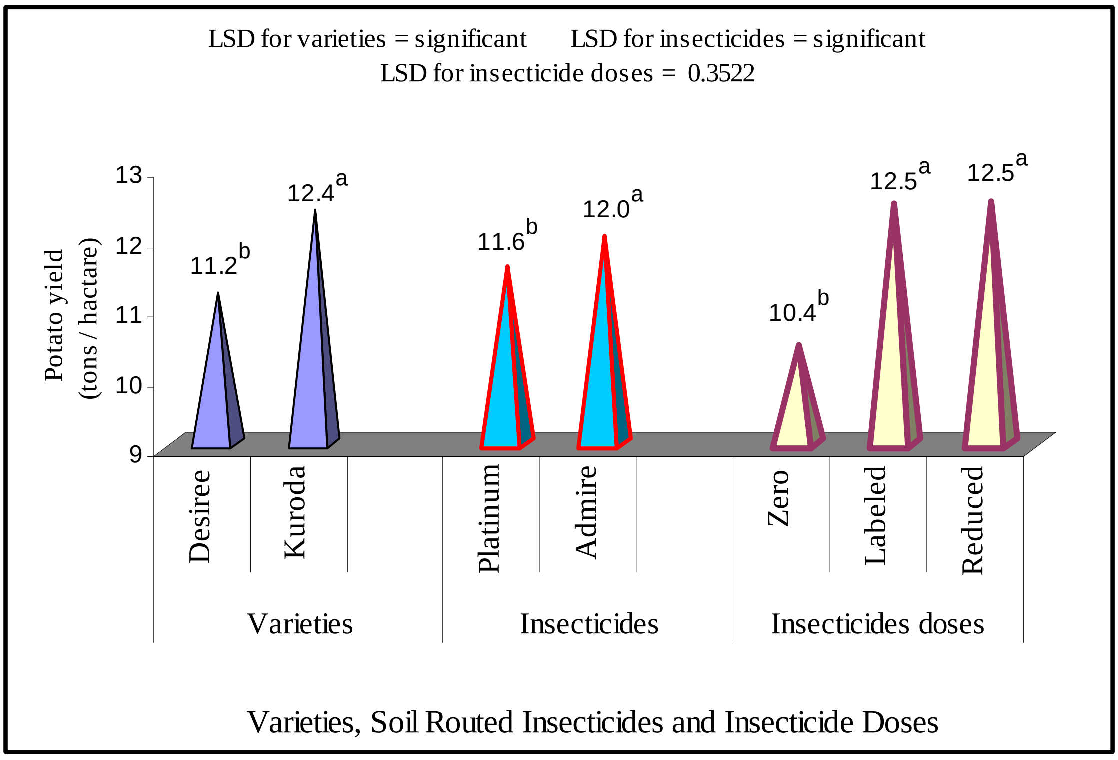


Fig 7.28 Effect of potato varieties, soil routed insecticides and insecticide doses on the yield means of potato tubers in tons/hectare

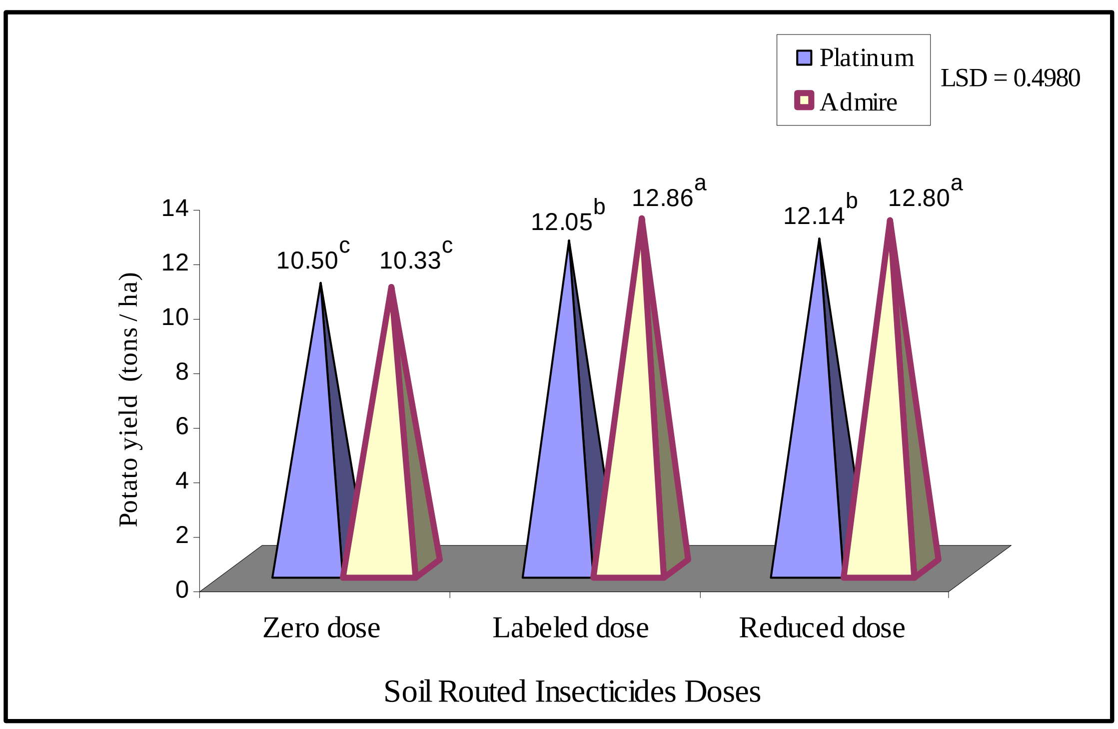


Fig 7.29 Interaction effect of soil routed insecticides x insecticide doses (I x D) on the yield means of potato tubers in tons/hectare (averaged over potato varieties)

7.5 DISCUSSION

In localities where periodic severe infestation of *M. persicae* is a serious problem either due to climatology or abundance of alternate hosts and when the spread of viral diseases due to this pest are common then the soil routed insecticides become necessary. Moreover, it also reduces the numbers of foliar sprays in later stages if required. (Wyman, 2005) in press release quoted Dr. Wale as witness to an unexpected increase in virus levels before aphids associated with virus spread were caught in monitoring and thus recommended the use of soil routed insecticides at planting. In light of these important aspects of pest management the soil routed insecticides were tested.

The results indicated that Admire was significantly more effective than Platinum by being more toxic (in terms of reducing the populations) to *M. persicae* and less toxic to natural enemies. Admire reduced *M. persicae* population higher by 4.8% than Platinum and had higher populations of ladybird beetle, parasitized *M. persicae* mummies, syrphidfly, green lacewing, PPA*A*, PER*A* and FR*A* by 17.2, 18.2, 15.6, 20.0, 6.4, 11.3, 2.6 and 8.4%, respectively. The reasons for higher toxicity of imidacloprid to *M. persicae* and lesser to the natural enemies than thiamethoxam and other traditional insecticide groups are already discussed in Section 6.6, whereby they were applied as foliar spray. In accordance with the above findings, imidacloprid (soil routed insecticide) was reported superior than pirimicarb, acetamiprid, thiamethoxam, and oxydemeton-methyl due to no or less resistance in pests/*M. persicae* (Drinkwater, 2003; Nauen and Elbert, 2003) and lower toxicity of Admire to predators and parasites (Kidd and James, 1994; James and Coyle, 2001; UC Publication, 2008). However, Koch *et al*. (2005) achieved better and similar results from imidacloprid and thiamethoxam when applied as seed dresser to manage bean leaf beetle, *Cerotoma trifurcata* Forster. According to Mowry (2001) imidacloprid applied at planting reduced the number of methamidophos applications from nine to five in the insecticide-at-detection treatments. Difference in efficacy among various granular insecticides against *M. persicae* was confirmed by Misra and Agrawal (1998a). No detrimental effect of imidacloprid on parasitoid was recorded by Kramarz and Stark (2003); however, adverse impacts were reflected in areas contaminated with cadmium. Reduced parasitism, varied response among species and less susceptibility in mummy stages of parasitoids to various soil applied insecticides was determined (Shean and Ranshaw, 1991; Singh *et al.*, 1994).

The labeled dose of each insecticide (Admire and Platinum) was more toxic than the reduced dose to *M. persicae* and all the natural enemies. The difference between the labeled and reduced doses in reducing *M. persicae* for Admire was 4.7 % while for Platinum was 4.6 %. The granular insecticides being highly toxic to *M. persicae* at labeled doses than reduced doses was also recorded by Saljoqi and van Emden (2003b). Reference to the persistency of insecticides, *M. persicae* population was at increase from Day 27 till the last day of data recording i.e. Day 55 of seed germination; however, the treated plants had consistently quite lower populations than control. The difference between labeled and reduced doses was significant only on Day 34 and 55. It was in conformity with the recommendations that the higher rate of imidacloprid is used for lengthened control and for resistance management especially where incidence of *M. persicae* is periodic (Kramarz and Stark, 2003; Bayer Crop Science, 2008). Provision of season-long aphid control by maximum labeled rate of Admire was also confirmed by test conducted at the University of Minnesota (Radcliffe, 1998). Moreover, it is reported that the toxicity of soil routed imidacloprid to *M. persicae* remained high for 5 weeks with reduction in population of 97-100% within 72 and 96 hours of the post treatment (Diaz and Mcleod, 2005), and for 62-65 days when applied at 0.03 g (AI)/m after plant emergence (Boiteau and Osborn, 1997). Admixture of seed dresser imidacloprid with fungicides is compatible and broadens the effective control pests (Ahmed *et al.*, 2001).

The difference between labeled and reduced doses in reducing populations of ladybird beetle, parasitized *M. persicae* mummies, syrphidfly, green lacewing, PPA*A*, PER*A* and FR*A* for Admire was 32.7, 33.2, 35.8, 32.8, 38.0, 46.7 and 24.0%, respectively; whereas, for Platinum it was 19.5, 13.7, 18.3, 16.5, 38.9, 44.2 and 24.8%, respectively. Admire reduced doses and Platinum labeled doses were the least and most toxic (in terms of reducing the population), respectively, to ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A* and PER*A*. Admire labeled and Platinum reduced dose did not differ for ladybird beetle and parasitized *M. persicae* mummies while for other corresponding parameters Platinum reduced dose was more toxic than Admire labeled dose. For FR*A* this interaction was not significant (Saljoqi and van Emden, 2003b). Toxicity of insecticides to natural enemies was expressed by Rogers *et al*. (2007) as that survival rate of adult green lacewing after feeding on flowers of plants treated with soil applied imidacloprid was: 79% for the untreated flowers, 14% for the labeled rate and 6% for twice the labeled rate. The lesser infected *M. persicae* on plant treated with reduced doses of insecticides might be the reason for attracting higher populations of natural enemies as compared to plant treated with labeled doses. Moreover, feeding on lesser infected prey might cause detrimental effect on natural enemies and thus became a reason for their higher population (Coll and Guershon, 2002; Wäckers, 2005; Lundgren, 2009; Lundgren *et al*., 2009).

Varieties comparison on control plants showed that *M. persicae* population was lesser by 45.5% on Kuroda than Desiree variety while ladybird beetle, parasitized *M. persicae* mummies, syrphidfly, green lacewing, PPA*A*, PER*A* and FR*A* were higher by 13.2, 40.8, 45.7, 26.3, 17.8, 4.3 and 27.9%, respectively. Some of the possible reasons for these differences are discussed in Section 6.6. It may be added that the presence of lectins plays a defensive role in plants against herbivores due to its feeding deterrent quality (Shi *et al.,* 1994; Powell *et al.,* 1995; Peumans *et al*., 1995; Kanrar *et al.,* 2002) and intoxication (Sauvion *et al.,* 2004). In aphids, lectins appear to reduce growth, development, and fecundity rather than to cause mortality as such the predators and parasitoid feeding on these intoxicated prey are adversely effected (van Emden, 1990; Sauvion *et al.,* 2004). The aphids from favorable hosts are bigger in size, heavier in weight and show higher growth rates and fecundity as compared to unfavorable hosts (Agarwala *et al*., 2009); and may account for the reasons for higher population of *M. persicae* on Desiree. Higher number of parasitized *M. persicae* mummies on Kuroda plant was due to an increase in the PPA*A* that occurred at the time of intense feeding by the predators, which were abundant too on Kuroda (Kindlmann and Ruzicka, 1992).

The insecticides (at an average) reduced the mean population of *M. persicae* per nine compound leaves of plants from 12.02 to 4.9 on Kuroda and 22.05 to 7.3 on Desiree i.e. lesser by 7.3 % on Kuroda as compared to Desiree; however, in spite of this difference the *M. persicae* population was still significantly lower than Desiree (Saljoqi and van Emden, 2003b). Maximum percent reduction of *M. persicae* on susceptible Desiree was due to extensive feeding by very high population that all received toxic dose and got killed; while on resistant Kuroda variety reduction in *M. persicae* population was smaller may be due to lesser feeding and thus received less toxic dose due to certain traits that made Kuroda resistant. The populations of ladybird beetle, parasitized *M. persicae* mummies, syrphidfly, green lacewing, PPA*A*, PER*A* and FR*A* were reduced lesser by 9.3, 3.3, 26.5, 29.0, -3.8, 5.8, and -11.6, respectively, on Kuroda as compared to Desiree. As discussed earlier, the lesser intoxicated prey (*M. persicae*) may be one of the reasons that attracted the natural enemies to Kuroda. Other aspects of this phenomenon are discussed in detail in Section 6.6.

Kuroda vs Desiree comparison in reference to various doses (as per significant interactions) showed that Kuroda plants treated with reduced doses was next to Kuroda treated with labeled doses of insecticides in reducing *M. persicae* and had smaller population even than the Desiree treated with labeled doses of insecticides (Saljoqi and van Emden, 2003b). Kuroda treated with reduced dose of Admire had significantly highest population of ladybird beetle than all other treatments except Kuroda control and Desiree control. Kuroda treated with Admire reduced dose and Kuroda control (being statistically equal) had significantly highest populations of syrphidfly and green lacewing than all other treatments including Desiree control. Population of parasitized *M. persicae* mummies on Kuroda plants treated with reduced doses of insecticides was statistically smaller than Kuroda control but significantly highest than all other treatments including Desiree control.

Kuroda and Desiree plants treated with reduced doses of insecticides (being statistically equal) had significantly higher PPAA and PERA than Kuroda and Desiree treated with labeled doses of insecticides; however, maximum PPAA was recorded on Kuroda control followed by Desiree control. Minimum numbers of ladybird beetle, syrphidfly and green lacewing were recorded on Desiree treated with Platinum labeled dose. The difference in efficacy between the insecticides for either reason is already discussed in detail in the initial portions of this discussion. Similarly, the result achieved in this experiment in reference to the interaction effect of varieties x insecticides x doses were the same as for foliar experiment (Section 6.6). So, the discussion in this context would be the duplication. However, in few words it may be discussed as that certain traits of resistant varieties like Kuroda in this research might slow the *M. persicae* probing/feeding, made them restless and stressed their behavior that forced them to smaller size and low reproductive potential (Agarwala *et al.,* 2009). All these changes made *M. persicae* susceptible to even lower concentration of insecticides on resistant as compared to susceptible varieties (van Emden, 1990; Saljoqi and van Emden 2003a; Saljoqi and van Emden, 2003b).). The weaker, restless and lesser intoxicated *M. persicae* (as of lesser intake due to difficulties in probing/feeding) on Kuroda as compared to Desiree might attract the higher population of natural enemies.

Potato yields obtained from untreated check plots were significantly lower than the insecticides treated plots. Plots treated with Admire gave more yields than Platinum. Reduced and labeled doses of Admire did not differ for yield. Similarly reduced and labeled doses of Platinum did not differ for yield. The reasons for higher yields (just like foliar insecticides experiment) may be linked with healthy plants as of higher population of natural enemies that in return suppressed the *M. persicae* population and injury to plants. Moreover, the viral diseases that were not assessed in this study might not develop. Higher yield (30-90%) than control by application of soil applied insecticides (including imidacloprid admixed with fungicides) against aphid in wheat crop was recorded by Ahmed *et al.* (2001) and in potato by Saljoqi and van Emden (2003b).

7.6 CONCLUSIONS

Similar to foliar insecticides experiment, *M. persicae* population was significantly lower and populations of the natural enemies (ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A*) were consistently higher in all the treatments on Kuroda than Desiree. Insecticides significantly reduced *M. persicae* infestation as compared to control, however, at the same time significantly reduced the populations of the natural enemies. As such minimum yield was obtained from control. Admire was more effective than Platinum. Admire reduced dose was less effective in reducing *M. persicae* infestation as compared to Admire labeled dose; however, it was the least toxic to natural enemies (as of significantly higher populations) as compared to other insecticides treatments. As such, maximum yield was obtained from Kuroda treated with Admire reduced and labeled doses (both of which did not differ statistically).

7.7 RECOMMENDATIONS

The above findings lead to the following recommendations.

1) The comparison on susceptible ‘Desiree’ and resistant ‘Kuroda’ potato varieties provides solid and valuable basis to study the impact of soil routed insecticides on *M. persicae* and its natural enemies.
2) Kuroda is comparatively more resistant to the *M. persicae* infestation as compared to Desiree and more promising for higher population of the natural enemies even after soil routed insecticides applications.
3) Among the soil routed insecticides, Admire is more effective than Platinum.
4) Soil routed insecticides has negative impact on natural enemies of *M. persicae*; however, natural biological control agents alone fail to suppress the *M. persicae*

population below threshold level, as the yield obtained from control was significantly lower than the insecticide treated plants.

5) Reduced dose of soil routed insecticides may effectively control the *M. persicae* as it was lesser toxic to the natural enemies as compared to labeled dose and the potato yield of the two did not differ.

6) Since the reduced doses of foliar (in previous experiment) and soil routed insecticides in this experiment successfully controlled the *M. persicae* with minimum adverse/detrimental impact on natural enemies, it would be appropriate to compare these two in the next experiment in addition to one or two other components of IPM.

Chapter 8

EVALUATION OF VARIOUS IPM STRATEGIES CONDUCTED ON POTATO VARIETIES AGAINST GREEN PEACH APHID, *M. PERSICAE* (SULZER), WITH MINIMUM ADVERSE IMPACTS ON NATURAL EMEMIES

8.1 INTRODUCTION

The management of insect pests rarely relies on a single control tactic; usually, a number of tactics are integrated to maintain pests at acceptable levels. Some pests are tolerable and are kept at acceptable level by their natural enemies present in particular crop (Adkisson and Smith, 2007). IPM in agriculture is a strategy that focuses on long-term prevention and suppression of pest populations with a minimum impact on human health, the environment and non-target organisms. Preferred pest management techniques include an array of complementary methods including encouraging natural enemies, using alternate plant species or varieties that resist pests, selecting pesticides with a lower toxicity to humans and non-target organisms, cultural management, mechanical and physical devices, and changing the habitat to make it incompatible to pest development. These methods are done in three stages i.e. prevention, observation, and intervention (Dufour, 2003.). IPM system is designed around six basic components. (i) Determine acceptable pest levels and apply controls if those levels (action thresholds) are exceeded. (ii) Application of preventive cultural practices like usage of varieties best for local conditions; maintaining healthy crops together with plant quarantine and cultural techniques such as crop sanitation. (iii) Regular monitoring of pest levels by visual inspection, insect and spore traps or any other method. (iv) Mechanical control methods like hand-picking, erecting barriers, using traps, vacuuming, and tillage to disrupt breeding prevent the pest from reaching unacceptable levels. (v) Natural biological processes and materials can provide control with minimal environmental impact and often at low cost; mainly promoting beneficial insects that eat target pests. (vi) Application of synthetic pesticides as last remedy at specific time when careful monitoring indicates that they are needed according to pre-established guidelines (Adkisson and Smith, 2007).

After screening potato varieties, foliar insecticides and soil applied insecticides, it was decided to include one mechanical control measure as parts of IPM strategy against *M. persicae*. The mechanical control that may be logical, suitable, applicable, sustainable and socially acceptable to farmers was prioritized as the use of yellow water pan trap (Yp-trap). Yp-traps are actually used to monitor the population dynamics, the aphid species landing in the crop and determining the threshold (Halbert *et al.*, 1986; Labonne *et al*, 1989; Boiteau, 1990; Avinent *et al.*, 1991; Difonzo *et al*, 1997; Hamm, 2001; Mitchell *et al*, 2001; Alan *et al*, 2003). However, in this experiment it was tried as an individual treatment and in combination with other management tools, scrutinized in previous trails of this study, to determine the best IPM techniques against *M. persicae* with least adverse effect on natural enemies. And, enhance potato yield.

The study envisaged the following **objectives**:

1. To devise acceptable IPM strategies for *M. persicae* on potato crop with minimum adverse/detrimental impact on its natural enemies (ladybird beetle, Syrphidfly green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A*, FR*A*)
2. To analyze the interaction of partially resistant Kuroda and susceptible Desiree potato varieties with different IPM strategies against *M. persicae* with minimum adverse/detrimental impact on its natural enemies including: (i) ladybird beetle, (ii) syrphidfly, (iii) green lacewing (iv) parasitized *M. persicae* mummies (v) percent parasitism of *M. persicae* by the *Aphidius* (PPA*A*), (vi) percent emergence rate of the *Aphidius* from *M. persicae* mummies (PER*A*), (vii) fecundity rate of the *Aphidius* (FR*A*).
3. To determine the magnitudes of difference in yield of Kuroda and Desiree varieties due to the various treatments.

8.2 MATERIALS AND METHODS

Potato varieties Kuroda and Desiree were raised at Malakandair Research Farm, Khyber Pakhtunkhwa Agricultural University Peshawar during spring 2009. Provado reduced dose, Admire reduced dose and Yp-trap were compared as individual treatments and in combinations. Both the insecticides were applied at reduced dosage (by 20% of the labeled doses) as of better results, see Section 6.5 and 7.4. Methods for application of Provado and Admire insecticides were as described in Sections 6.3 and 7.2, respectively. One Yp-trap was installed in the middle of the experimental unit, where required as per experimental design/concerned treatments. Each trap was 17.5 cm in diameter and 10 cm deep. Traps were positioned just above plant heights. A mixture of water, liquid detergent (surfactant), and benzoic acid (preservative) was filled in the traps to a depth of 5 cm. Traps were emptied weekly (Mohamed *et al.*, 2000).

Split-split plot experimental design was applied. Total number of experimental units was 36 representing two varieties, six treatments including control and three replications as per detail given in Table 8.I. Size of experimental units and other agronomic practices were applied as described in Section 3.3.

Table 8.I Treatments detail; dosage rates for Admire was based on 75cm row spacing

Variety	Treatment		
	Abbre-viations	Nature/Type	Amount/rate of Dose
Kuroda	Ct	Control	No insecticide (Control)
	Yp	Yellow water pan trap (Yp-trap)	Single trap
	Pr(R)	Provado 1.6F labeled dose reduced by 20%	222.39 ml of the product/ha
	Adr(R)	Admire 2F labeled dose reduced by 20%	866.50 ml of the product/ha
	Pr(R)+Yp	Provado reduced dose + Yp-trap	222.39 ml/ha + One trap
	Adr(R)+Yp	Admire reduced dose + Yp-trap	866.50 ml/ha + One trap
Desiree	Ct	Control	No insecticide (Control)
	Yp	Yellow water pan trap (Yp-trap)	Single trap
	Pr(R)	Provado 1.6F labeled dose reduced by 20%	222.39 ml of the product/ha
	Adr(R)	Admire 2F labeled dose reduced by 20%	866.50 ml per hectare
	Pr(R)+Yp	Provado reduced dose + Yp-trap	222.39 ml/ha plus One trap
	Adr(R)+Yp	Admire reduced dose + Yp-trap	866.50 ml/ha + One trap

8.2.1 Data Collection /Population Estimates

Parameters studied were the population of pest *M. persicae* (winged and wingless) and its natural enemies (ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A*, and FR*A*). The methods for data collection on all of these parameters are described in Section 3.4.1 to 3.4.5. However, data on population of these parameters was recorded on day 20, 34, 48, 64 and 78 of seeds germination. The potato tuber yield for each treatment was determined in tons per hectare and analyzed.

8.3 DATA ANALYSIS

The data was analyzed using MSTATC package by analysis of variance of 'factorial randomized complete block design for varieties, with treatments as split on varieties and time interval as split on treatments'. Means were compared using LSD Test at 5% level of significance ($P<0.05$).

8.4 RESULTS

8.4.1 Effect of various IPM strategies on *M. persicae* population per nine compound leaves

The analysis of variance for *M. persicae* population per nine compound leaves showed significant effect ($P<0.05$) due to treatments and plant growth stages (Pgs: days after seeds germination) on two potato varieties (partially resistant Kuroda and susceptible Desiree), Appendix-E Table-E1. All interactions were also significant ($P<0.05$). The results of main factors are shown in Fig 8.1. The mean values for varieties showed significant effect being Kuroda significantly resistant than Desiree to *M. persicae* population buildup. Treatments also showed significant effect with respect to *M. persicae* population being significantly highest on control and lowest on plants treated with Provado reduced dose + Yp-trap. The *M. persicae* population trend also showed significant variations due to various plant growth stages being maximum on Day 64 and minimum on Day 78.

Interaction between varieties and treatments (V x T) for *M. persicae* population, averaged over plant growth stages, was significant (Fig 8.2). The potato varieties responded significantly different due to various treatments. *M. persicae* development on Desiree was significantly higher than Kuroda on all treatments. However, the trend of reduction in *M. persicae* population due to various treatments remained the same on both varieties. Provado reduced dose + Yp-trap was the most effective treatment in reducing *Myzus* population on both varieties. Maximum number of *M. persicae* (19.05) was recorded on Desiree control and minimum (2.41) on Kuroda plants treated with Provado reduced dose + Yp-trap.

Averaged over treatments, interaction between varieties and plant growth stages (V x Pgs) showed that both varieties responded significantly different to *M. persicae* population buildup at various plant growth stages (Fig 8.3). During each plant growth stage the *M. persicae* populations on Kuroda was significantly smaller than Desiree. Minimum number of *M. persicae* was recorded on Kuroda Day 78 as compared to maximum on Desiree Day 64 of the seeds germination.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

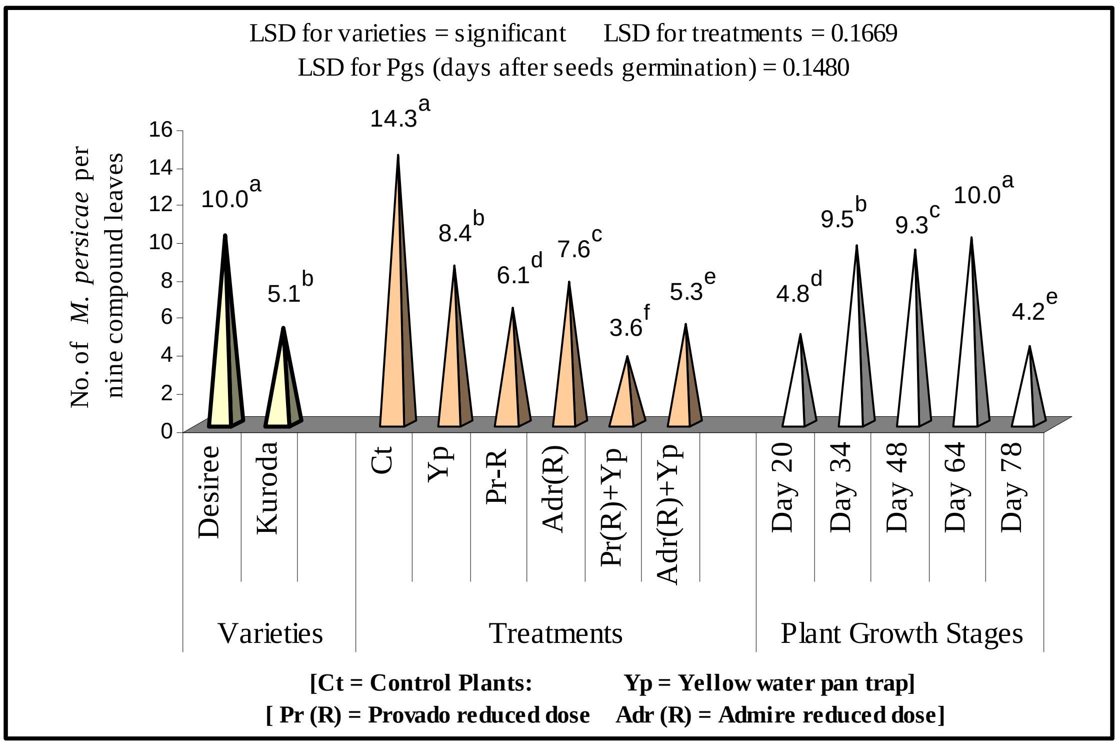


Fig 8.1 Effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop

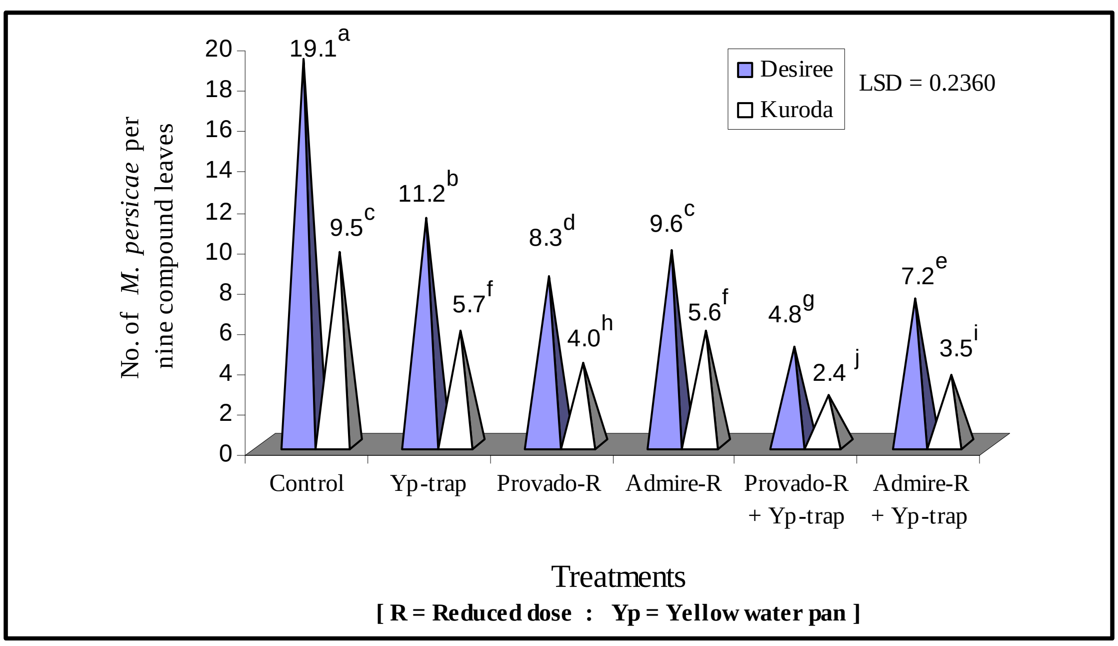


Fig 8.2 Interaction effect of treatments x potato varieties (T x V) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over plant growth stages 'Pgs')

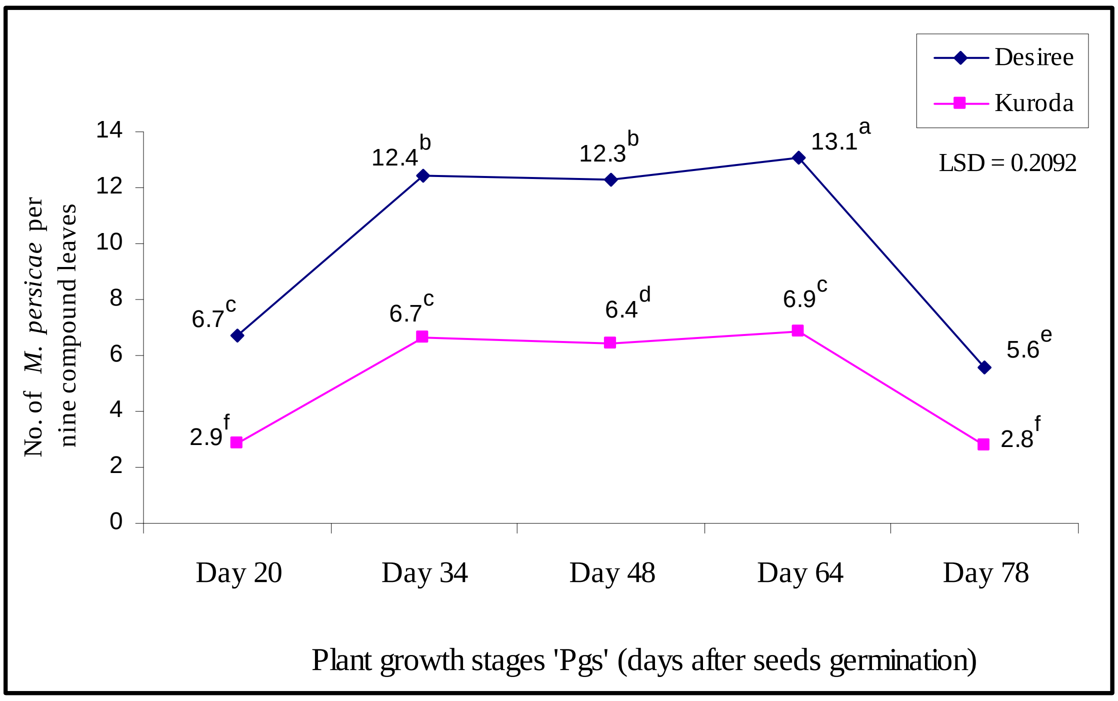


Fig 8.3 Interaction effect of plant growth stages ‘Pgs’ x potato varieties (Pgs x V) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over treatments)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Averaged over varieties, interaction effect between treatments and plant growth stages (T x Pgs) for mean *M. persicae* population showed significant effect (Fig 8.4). On all plant growth stages, the treated plants had significantly smaller *M. persicae* population as compared to control. However, due to big difference in treatment natures especially the application timing of foliar and soil routed insecticides, the *M. persicae* population trends varied significantly at various plant growth stages on each treatment. The *M. persicae* population trends on control and Yp-trap treatments were profoundly greater on successive plant growth stages till Day 48 from where onward it decreased significantly on Day 64 and 78 of seeds germination. However, on Yp-trap treatment the population trend was consistently lower as compared to control. The *M. persicae* population trends on Admire reduced dose and Admire reduced dose + Yp-trap treatments were at increase on successive plant growth stages till Day 64 and thereafter decreased significantly on Day 78 of seeds germination. However, on Admire reduced dose + Yp-trap it was consistently lower as compared to Admire reduced dose treatment. Population trend on Provado reduced dose and Provado reduced dose + Yp-trap was at increase until it reached to maximum on Day 34 and thereafter it decreased significantly; however, on Provado reduced dose + Yp-trap it was consistently lower as compared to Provado reduced dose treatment. The maximum *M.*

persicae population (20.15) was recorded on control plants Day 48 followed by control Day 64 (19.15). The minimum *M. persicae* population (0.97) was recorded on Provado reduced dose + Yp-trap Day 48 followed by Provado reduced dose + Yp-trap -Day 64 (1.20).

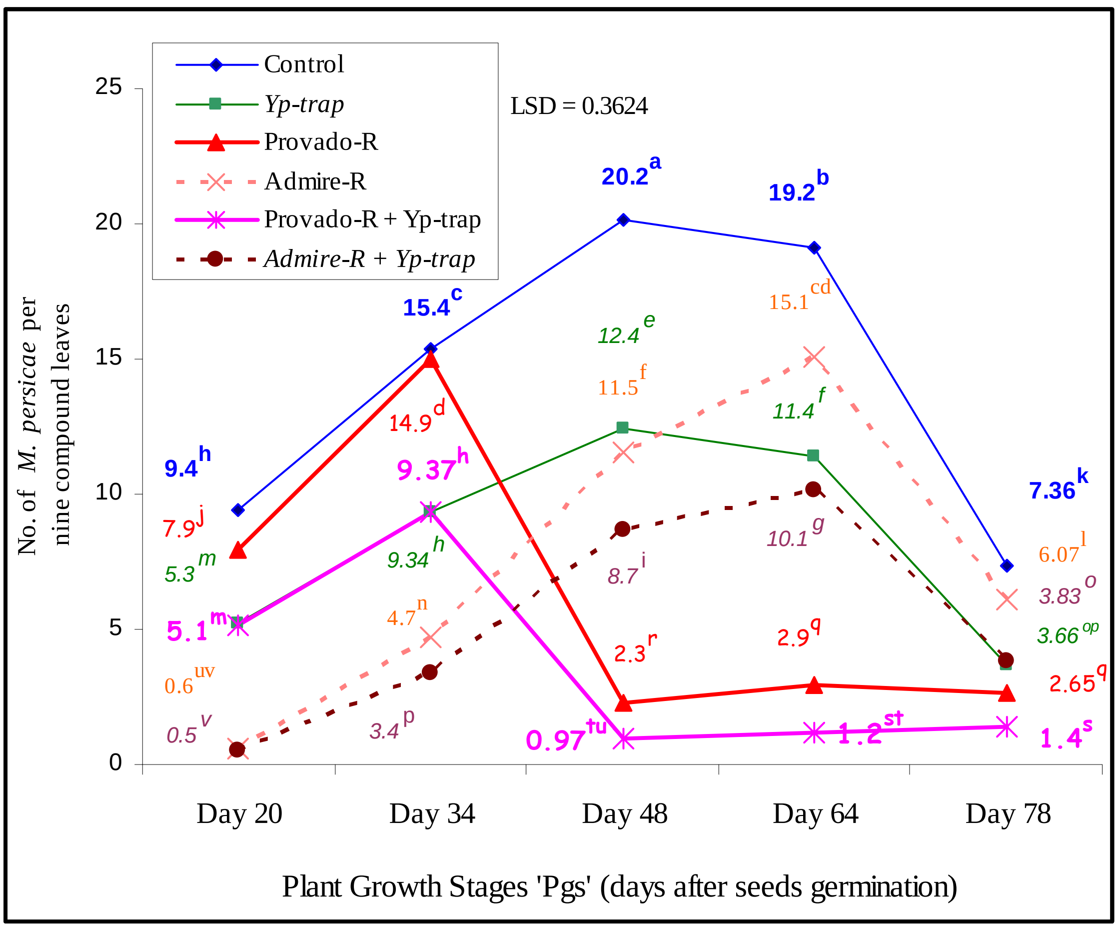
Interaction effect of varieties x plant growth stages x treatments (V x Pgs x T) was significant (Table 8.II). Response of *M. persicae* population development due to different treatments at various plant growth stages on each variety was similar as presented in Fig 8.4. However, the *M. persicae* population on Kuroda was significantly smaller than Desiree on all plant growth stages of each treatment. On Kuroda, maximum number of the *M. persicae* (13.55) was recorded on Kuroda-Day 48 control plants as compared to minimum (0.20) on Kuroda-Day 20 treated with Admire reduced dose + Yp trap. On Desiree, maximum number of the *M. persicae* (26.76) was recorded on Desiree-Day 48 control plants as compared to minimum (0.85) on Desiree-Day 20 treated with Admire reduced dose + Yp trap.

8.4.2 Effect of various IPM strategies on the ladybird beetle population per ten potato plants

The analysis of variance for ladybird beetle population showed significant effect ($P<0.05$) due to various treatments and plant growth stages on the two potato varieties (Appendix-E Table-E2). Only one interaction i.e. between treatments and plant growth stages (T x Pgs) was significant ($P<0.05$). The results of main factors are shown in Fig 8.5. The mean values for varieties showed significant effect being maximum population of ladybird beetle on Kuroda as compared to Desiree. Similarly, treatments showed significant effect with respect to ladybird beetle population being highest on Yp-trap treatment followed by Control plants. Lowest population was recorded on plants treated with Admire reduced dose + Yp-trap followed by Admire reduced dose. Plant growth stages also showed significant effect with respect to ladybird beetle population; being highest on Day 64 and minimum on Day 20 of the seeds germination.

Interaction effect between treatments and plant growth stages (T and Pgs) showed significant effect (Table 8.III). Different nature of treatment types were instrumental in the ladybird beetle population, fluctuating at various plant growth stages. Population trends of ladybird beetle on control plants, Yp-trap, Admire reduced dose and Admire reduced dose + Yp-trap were at increase on successive plant growth stages from Day 20 till Day 64; however, on control and Yp-trap treatments it were significantly higher as compared to

Admire reduced dose and Admire reduced dose + Yp-trap till Day 48. In contrast, ladybird beetle population on Provado reduced dose and Provado reduced dose + Yp-trap was at significant increase till Day 34, dropped significantly on Day 48, and increased again on Day 64. On Day 64 and Day 78 the ladybird beetle populations did not differ significantly on all treatments. The maximum population (7.83) was recorded on control on Day 64 followed by Yp-trap treatments on Day 64 (7.67). The minimum population (0.50) was recorded on Admire reduced dose-Day 34 followed by Admire reduced dose and Admire reduced dose + Yp-trap on Day 20 and 34, respectively.



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

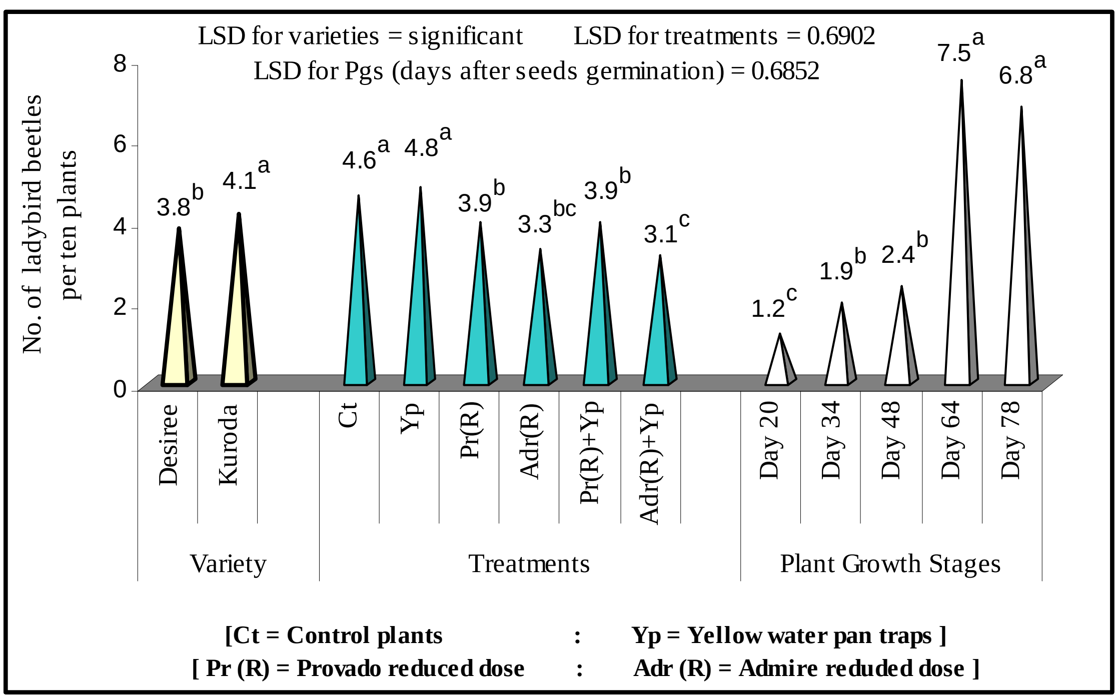
Fig 8.4 Interaction effect of plant growth stages ‘Pgs’ x treatments (Pgs x T) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), in potato crop (averaged over varieties)

Table 8.II Interaction effect of varieties x plant growth stages x treatments (V x Pgs x T) on the population means of green peach aphid (GPA), *Myzus persicae* (Sulzer), per nine compound leaves of potato plants

Variety	Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
		Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Desiree	Day 20	12.34 [h]	6.94 [m]	12.39 [h]	0.96 [\]	6.97 [m]	0.85 [\]
	Day 34	20.36 [c]	12.39 [h]	19.62 [d]	5.43 [o]	12.43 [h]	4.23 [qr]
	Day 48	26.76 [a]	16.43 [e]	2.49 [v-x]	14.64 [f]	1.17 [[\]	12.14 [h]
	Day 64	25.81 [b]	14.93 [f]	3.26 [tu]	19.14 [d]	1.47 [z[]	13.92 [g]
	Day 78	9.99 [j]	5.13 [op]	3.56 [st]	7.92 [kl]	2.09 [w-y]	4.70 [pq]
Kuroda	Day 20	6.50 [mn]	3.56 [st]	3.45 [tu]	0.27 []^]	3.28 [TU]	0.20 [^]
	Day 34	10.42 [j]	6.29 [n]	10.33 [j]	4.05 [rs]	6.31 [N]	2.54 [v-x]
	Day 48	13.55 [g]	8.41 [k]	2.04 [xy]	8.39 [k]	0.77 [\]]	5.24 [o]
	Day 64	12.49 [h]	7.83 [l]	2.60 [vw]	11.01 [i]	0.92 [\]	6.34 [n]
	Day 78	4.72 [pq]	2.18 [w-y]	1.75 [yz]	4.23 [qr]	0.75 [\]]	2.97 [uv]

LSD value for interaction (treatments x Pgs x varieties) = 0.5125

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test; (P < 0.05)



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

Fig 8.5 Effect of potato varieties x treatments and plant growth stages 'Pgs' (days after seeds germination) on the population means of coccinellids "ladybird beetles" in potato crop

Table 8.III Interaction effect of plant growth stages x treatments (Pgs x T) on the population means of Coccinellids "ladybird beetles" per ten potato plants

Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
	Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Day 20	1.50 [c-f]	1.50 [c-f]	1.50 [c-f]	0.50 [f]	1.67 [c-f]	0.50 [f]
Day 34	2.50 [c-e]	2.83 [cd]	3.00 [c]	0.33 [f]	2.50 [c-e]	0.50 [f]
Day 48	4.83 [b]	4.83 [b]	0.67 [f]	1.67 [c-f]	1.00 [ef]	1.17 [d-f]
Day 64	7.83 [a]	7.67 [a]	7.50 [a]	7.17 [a]	7.50 [a]	7.17 [a]
Day 78	6.50 [ab]	7.33 [a]	7.00 [a]	6.67 [a]	7.00 [a]	6.33 [ab]

LSD value for interaction (treatments x Pgs) = 1.678
Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test; ($P < 0.05$)

8.4.3 Effect of various IPM strategies on syrphidfly population per ten plants

The analysis of variance for syrphidfly population showed significant effect ($P<0.05$) resulting due to treatments and plant growth stages on the two potato varieties (Appendix-E Table-E3). Interactions effect of varieties x plant growth stages (V x Pgs) and treatments x plant growth stages (T x Pgs) were also significant ($P<0.05$). The results of main factors are shown in Fig 8.6. The mean values for varieties showed significant effect being greater number of syrphidfly on Kuroda as compared to Desiree. Similarly treatment showed significant effect with respect to number of syrphidfly being highest on Yp-trap treatment followed by control. Lowest population of syrphidfly was recorded on Admire reduced dose + Yp-trap followed by Admire reduced dose. Plant growth stages also showed significant effect with respect to syrphidfly population being significantly maximum on Day 64 and minimum on Day 20 of seeds germination.

Interaction between varieties and plant growth stages (V x Pgs) showed that both varieties responded significantly different at various plant growth stages (Fig 8.7). The syrphidfly population increases significantly, on both the varieties, on various plant growth stages till Day 64 of seeds germination. However, on Kuroda the population was significantly higher as compared to Desiree on all plant growth stages except on Day 20 and 34. The maximum number of syrphidfly (7.11) was recorded on Kuroda Day 64 as compared to minimum (0.89) on Desiree Day 20 of the seeds germination.

Interaction effect between various plant growth stages and treatments (Pgs x T) showed significant effect, Table 8.1V. Due to different nature of treatments, the population trends of syrphidfly were varied at various plant growth stages. The syrphidfly populations were at significant increase in all treatments on successive plant growth stages till Day 64 and declined on Day 78 when crop maturity was achieved. Treatments effect on syrphidfly population was not significantly different on plant growth stages except on Day 34 wherein the populations were significantly smaller on Admire reduced dose and Admire reduced dose + Yp-trap; and on Day 48 the populations were smaller on Provado reduced dose and Provado reduced dose + Yp-trap as compared to control and Yp-trap treatments. However, Admire reduced dose from Admire reduced dose + Yp-trap treatment on Day 34 and Provado reduced dose from Provado reduced dose + Yp-trap treatment on Day 48 did not differ significantly. The maximum number of syrphidfly (6.67) was recorded on Yp-trap treatment on Day 64 followed by Provado reduced dose + Yp-trap treatment on Day 64 (6.50). The minimum number of syrphidfly (0.50) was recorded on Admire reduced dose + Yp-trap and Admire reduced dose treatments on Day 20.

8.4.4 Effect of various IPM strategies on the green lacewing population per ten potato plants

The analysis of variance for green lacewing population showed significant effect ($P<0.05$) due to treatments and plant growth stages of the two potato varieties (Appendix-E Table-E4). Interactions effect of varieties x plant growth stages (V x Pgs), and treatments x plant growth stages (T x Pgs) were also significant ($P<0.05$). The results of main factors are shown in Fig 8.8. The mean values for varieties showed significant effect being maximum green lacewing on Kuroda than Desiree. Similarly, treatments showed significant effect with respect to green lacewing population being highest on Yp-trap followed by control. Lowest populations of green lacewing were recorded on Admire reduced dose + Yp-trap followed by Admire reduced dose treatment. The plant growth stages showed significant effect ($P<0.05$) with respect to green lacewing population being significantly highest on Day 64 and minimum on Day 20 of seeds germination.

Interaction between varieties and plant growth stages (V x Pgs) showed that both varieties responded significantly different at various plant growth stages, Fig 8.9. The green lacewing populations were at significant increase on both varieties on successive plant growth stages till Day 64. However, the populations of green lacewing on Kuroda were significantly higher as compared to Desiree on all plant growth stages except Day 20 of the seeds germination. The highest population of green lacewing (7.72) was recorded on Kuroda Day 64 as compared to lowest (1.11) on Desiree Day 20 of the seeds germination.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

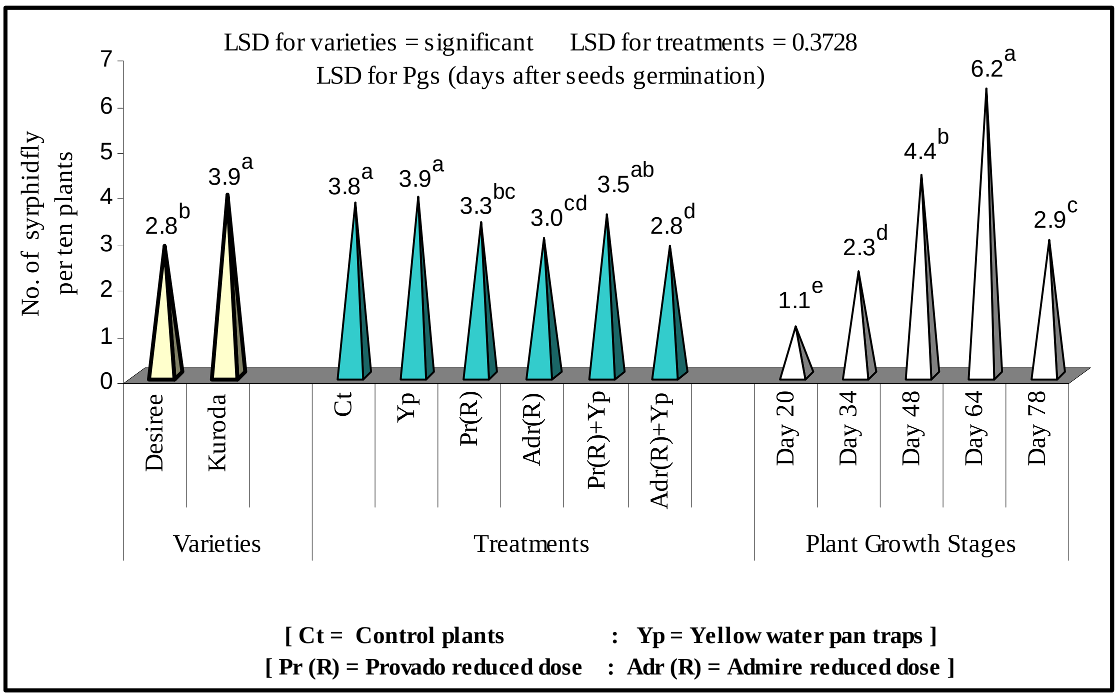


Fig 8.6 Effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the population means of syrphidae 'syrphidfly' in potato

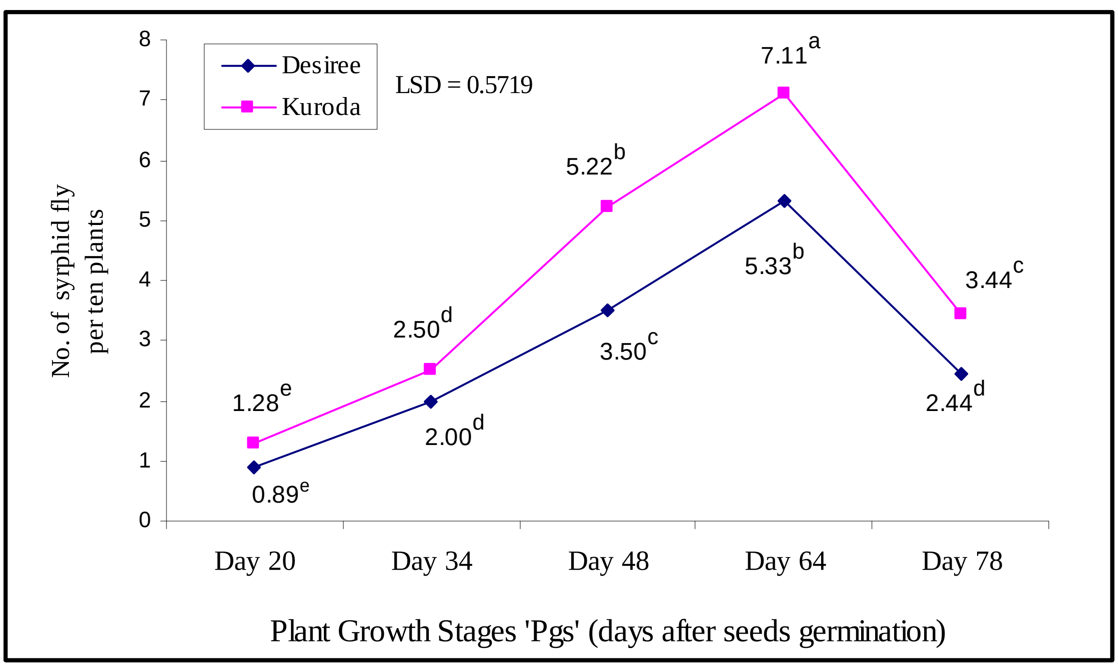
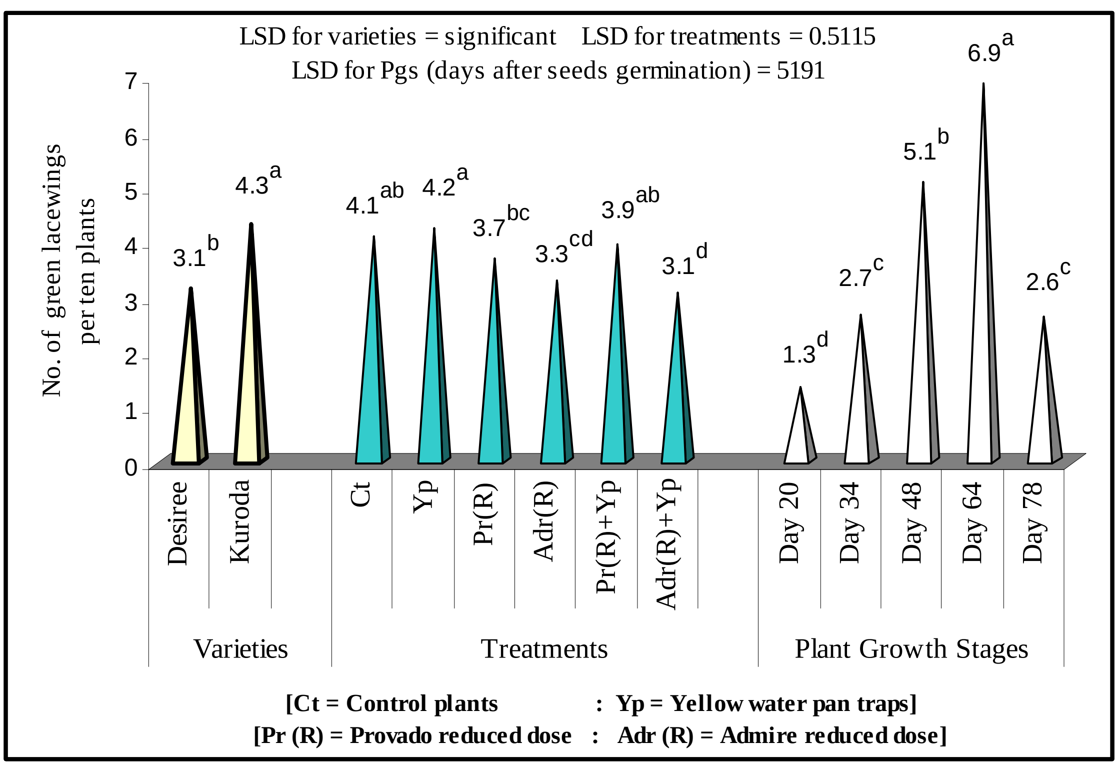


Fig 8.7 Interaction effect of plant growth stages 'Pgs' x potato varieties (Pgs x V) on the population means of syrphidae 'syrphidfly' in potato crop (averaged over treatments)

Table 8.IV Interaction effect of plant growth stages x treatments (Pgs x T) on the population means of Syrphidae ‘syrphidfly’ per ten potato plants

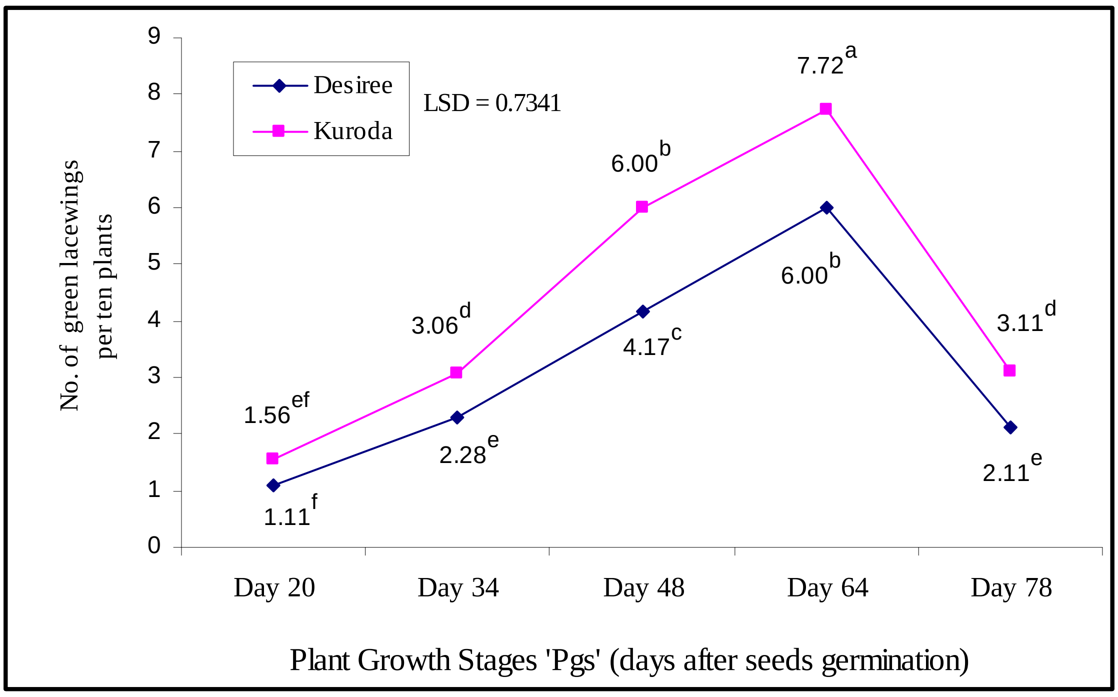
Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
	Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Day 20	1.33 hi	1.33 hi	1.33 hi	0.50 i	1.50 h	0.50 i
Day 34	3.00 g	2.67 g	3.17 fg	0.83 hi	3.00 g	0.83 hi
Day 48	5.33 cd	5.50 b-d	3.17 fg	4.67 de	3.50 fg	4.00 ef
Day 64	6.33 ab	6.67 a	6.17 a-c	5.83 a-c	6.50 a	5.83 a-c
Day 78	2.83 g	3.17 fg	2.83 g	3.00 g	3.00 g	2.83 g

LSD value for interaction (treatments x Pgs) = 0.9905
Means followed by same letter(s) are not significantly different at 5% level of significance; ($P < 0.05$)



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Fig 8.8 Effect of potato varieties, treatments and plant growth stages ‘Pgs’ (days after seeds germination) on the population means of *Chrysoperla spp* “green lacewing” in potato crop



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Fig 8.9 Interaction effect of plant growth stages 'Pgs' x potato varieties (Pgs x V) on the population means of *Chrysoperla spp* "green lacewing" in potato crop (averaged over treatments)

Interaction effect of plant growth stages x treatments (Pgs x T) was significant, Table 8.V. Variations in treatments nature put the population trends of green lacewing quite different at various plant growth stages. Treatments effect on green lacewing populations due to treatments was similar to syrphidfly. The green lacewing populations were at significant increase in all treatments on successive plant growth stages till Day 64 before it finally crashed on Day 78 i.e. crop maturity. Treatments effect on green lacewing was not significantly different on plant growth stages except Day 34 wherein the populations were significantly smaller on Admire reduced dose and Admire reduced dose + Yp-trap; and on Day 48 the populations were smaller on Provado reduced dose and Provado reduced dose + Yp-trap as compared to control and Yp-trap treatments. However, Admire reduced dose from Admire reduced dose + Yp-trap treatment on Day 34; and Provado reduced dose from Provado reduced dose + Yp-trap treatment on Day 48 did not differ significantly. The maximum number of green lacewing (7.33) was recorded on Yp-trap treatment on Day 64 followed by Provado reduced dose + Yp-trap treatment on Day 64 (7.17). The minimum numbers green lacewing i.e. 0.50 and 0.67 were recorded on Admire reduced dose + Yp-trap treatment on Day 20 and Admire reduced dose treatment on Day 20, respectively.

8.4.5 Effect of various IPM strategies on the population of parasitized *M. persicae* mummies per ten potato plants

The analysis of variance for parasitized *M. persicae* mummies population showed significant effect ($P<0.05$) occurring due to various treatments and plant growth stages on the two potato varieties (Appendix-E Table-E5). All interactions were also significant except varieties x treatment x plant growth stages (V x T x Pgs). The results of main factors are shown in Fig 8.10. The mean values for varieties showed significant effect being maximum parasitized *M. persicae* mummies on Kuroda as compared to Desiree. Similarly treatments showed significant effect with respect to number of parasitized *M. persicae* mummies being numerous on Yp-trap treatment followed by control plants. Minimum parasitized *M. persicae* mummies were recorded on Admire reduced dose followed by Admire reduced dose + Yp-trap treatment. Plant growth stages showed significant effect with respect to population of parasitized *M. persicae* mummies being significantly highest on Day 64 and lowest on Day 20 of seeds germination.

Interaction effect of varieties x treatments (V x T) on parasitized *M. persicae* mummies was significant (Fig 8.11). Significantly maximum number of parasitized *M. persicae* mummies was recorded in all treatments on Kuroda as compared to Desiree. Control from Yp-trap, Admire reduced dose from Admire reduced dose + Yp-trap, and Provado reduced dose from Provado reduced dose + Yp-trap treatments on Kuroda did not differ significantly for the populations of parasitized *M. persicae* mummies. Whereas; Control from Yp-trap, and insecticide applied treatments among each other (Admire reduced dose, Provado reduced dose, Admire reduced dose + Yp-trap and Provado reduced dose + Yp-trap) on Desiree did not show significant difference among each other in respect of the populations of parasitized *M. persicae* mummies. The highest number of parasitized *M. persicae* mummies (27.07) was recorded on Kuroda treated with Yp-trap treatment followed by Kuroda control (26.73). The lowest population of parasitized *M. persicae* mummies (13.00) was recorded on Desiree treated with Admire reduced dose followed by Desiree treated with Admire reduced dose + Yp-trap (13.13).

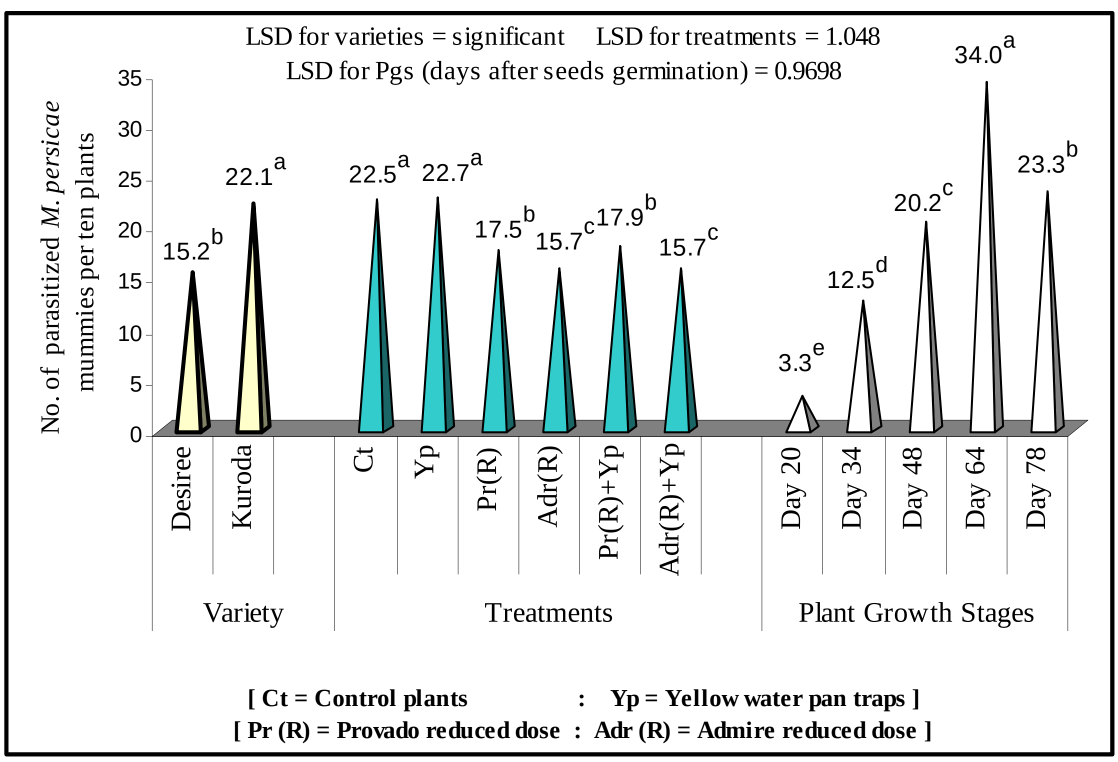
Interaction between varieties and plant growth stages (V x Pgs) showed that both varieties responded significantly different at various plant growth stages, Fig 8.12. The populations of parasitized *M. persicae* mummies were at significant increase on both varieties on successive plant growth stages till Day 64 before it crashed on Day 78 of seeds germination. However, the populations of parasitized *M. persicae* mummies on Kuroda were significantly higher as compared to Desiree on all plant growth stages. The maximum number of parasitized *M. persicae* mummies (40.00) was recorded on Kuroda Day 64 as compared to the minimum (2.33) on Desiree Day 20 of the seeds germination.

Table 8.V Interaction effect of plant growth stages x treatments (Pgs x T) on the population of C*hrysoperla spp* "green lacewing" per ten potato plants

Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
	Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Day 20	$1.67^{\text{i-k}}$	$1.67^{\text{i-k}}$	$1.67^{\text{i-k}}$	0.67^{jk}	1.83^{ij}	0.50^{k}
Day 34	$3.33^{\text{f-h}}$	$3.17^{\text{f-h}}$	$3.50^{\text{e-h}}$	1.17^{jk}	$3.67^{\text{e-h}}$	1.17^{jk}
Day 48	6.00^{bc}	$6.17^{\text{a-c}}$	$4.00^{\text{e-g}}$	5.33^{cd}	$4.33^{\text{d-f}}$	4.67^{de}
Day 64	7.00^{ab}	7.33^{a}	6.67^{ab}	$6.50^{\text{a-c}}$	7.17^{ab}	$6.50^{\text{a-c}}$
Day 78	2.50^{hi}	$2.83^{\text{g-i}}$	2.50^{hi}	2.67^{hi}	2.67^{hi}	2.50^{hi}

LSD value for interaction (treatments x Pgs) = 1.272

Means followed by same letter(s) are not significantly different at 5% level of significance; ($P<0.05$)



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Fig 8.10 Effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

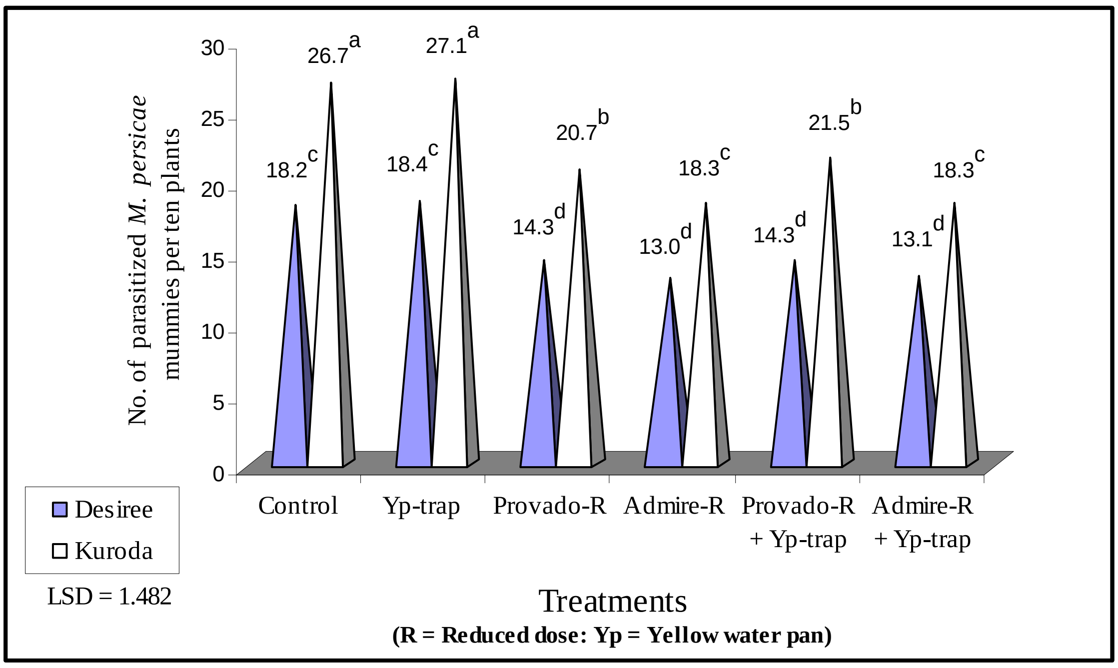


Fig 8.11 Interaction effect of treatments x potato varieties (T x V) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop (averaged over plant growth stages 'Pgs')

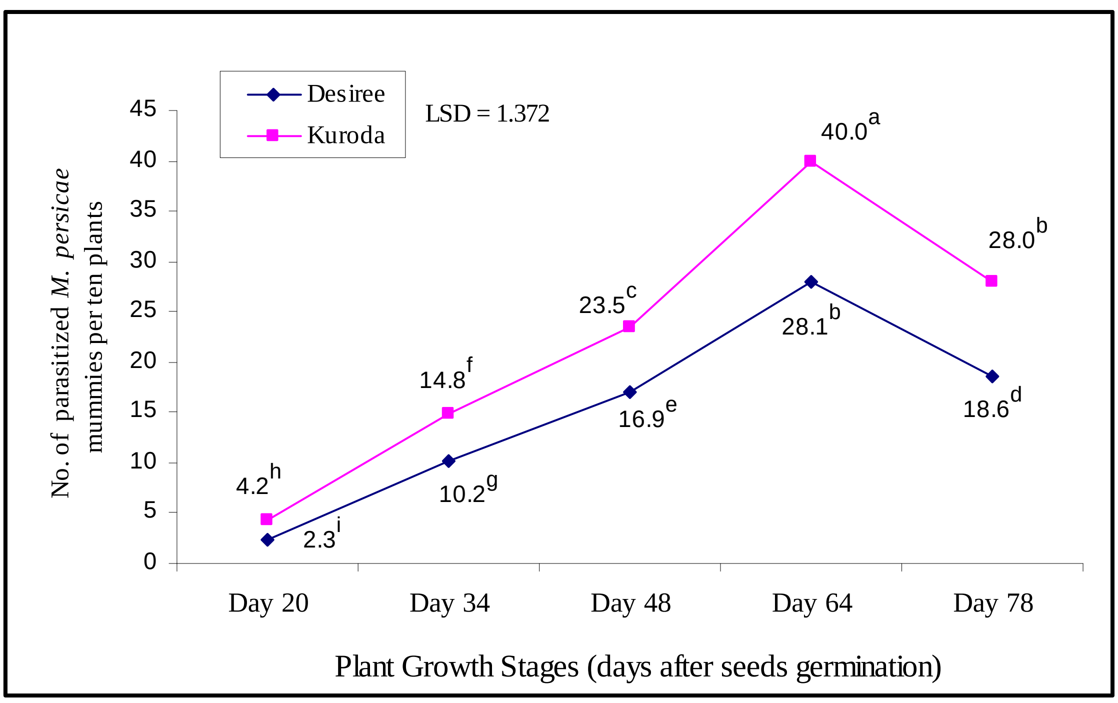


Fig 8.12 Interaction effect of plant growth stages 'Pgs' x potato varieties (Pgs x V) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies in potato crop (averaged over treatments)

Interaction effect of plant growth stages x treatments (Pgs x T) was significant, Table 8.VI. Different nature of treatments made the population trends of parasitized *M. persicae* mummies to fluctuate quite differently during various plant growth stages. Population trends of the parasitized *M. persicae* mummies on control plants, Yp-trap, Admire reduced dose and Admire reduced dose + Yp-trap treatments were at increase on successive plant growth stages from Day 20 till Day 64; however, on control and Yp-trap it were significantly high as compared to Admire reduced dose and Admire reduced dose + Yp-trap treatments. Control from Yp-trap, and Admire reduced dose from Admire reduced dose + Yp-trap treatments did not show significant difference on each plant growth stage. In contrast, populations of the parasitized *M. persicae* mummies on Provado reduced dose and Provado reduced dose + Yp-trap were at increase till Day 34, dropped significantly on Day 48 and went up again on Day 64 before it finally crashed on Day 78 i.e. at crop maturity. Provado reduced dose and Provado reduced dose + Yp-trap treatments did not show significant difference on each plant growth stage. Populations of parasitized *M. persicae* mummies on Provado reduced dose and Provado reduced dose + Yp-trap treatments did not differ statistically from control and Yp-trap treatments on plant growth stages except Day 48 and 64 of the seeds germination. The population of parasitized *M. persicae* mummies did not differ significantly on Day 78 of the seeds germination on all the treatments. The highest number parasitized *M. persicae* mummies (42.50) was recorded on Yp-trap treatment on Day 64 followed by control plants on Day 64 (42.17). The lowest number of parasitized *M. persicae* mummies (0.83) was recorded on Admire reduced dose + Yp-trap on Day 20 followed by Admire reduced dose on Day 20 (1.00) of the seeds germination.

8.4.6 Effect of various IPM strategies on PPA*A*

The analysis of variance for PPA*A* showed significant effect ($P<0.05$) due to various treatments and plant growth stages on the two potato varieties (Appendix-E Table-E6). All interactions were also significant ($P<0.05$). The results of main factors are shown in Fig 8.13. The mean values for varieties showed significant effect being maximum PPA*A* on Kuroda than to Desiree. Similarly, treatments showed significant effect with respect to the PPA*A* being highest on Yp-trap treatment followed by Provado reduced dose + Yp-trap treatment. Minimum PPA*A* was recorded on Admire reduced dose followed by Admire reduced dose + Yp-trap treatment. The plant growth stages showed significant effect with respect to PPA*A* being significantly maximum on Day 64 and minimum on Day 78.

Table 8.VI Interaction effect of treatments x plant growth stages (T x Pgs) on the population means of parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies per ten potato plants

Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
	Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Day 20	4.33 g	4.67 g	4.50 g	1.00 h	4.33 g	0.83 h
Day 34	15.17 f	15.83 ef	15.67 ef	6.33 g	15.83 ef	6.17 g
Day 48	27.00 c	26.83 c	16.50 ef	16.50 ef	17.83 e	16.67 ef
Day 64	42.17 a	42.50 a	27.50 c	32.33 b	27.33 c	32.33 b
Day 78	23.67 d	23.83 d	23.33 d	22.17 d	24.17 d	22.67 d

LSD value for interaction (treatments x Pgs) = 2.376
Means followed by same letter(s) are not significantly different at 5% level of significance; (P<0.05)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

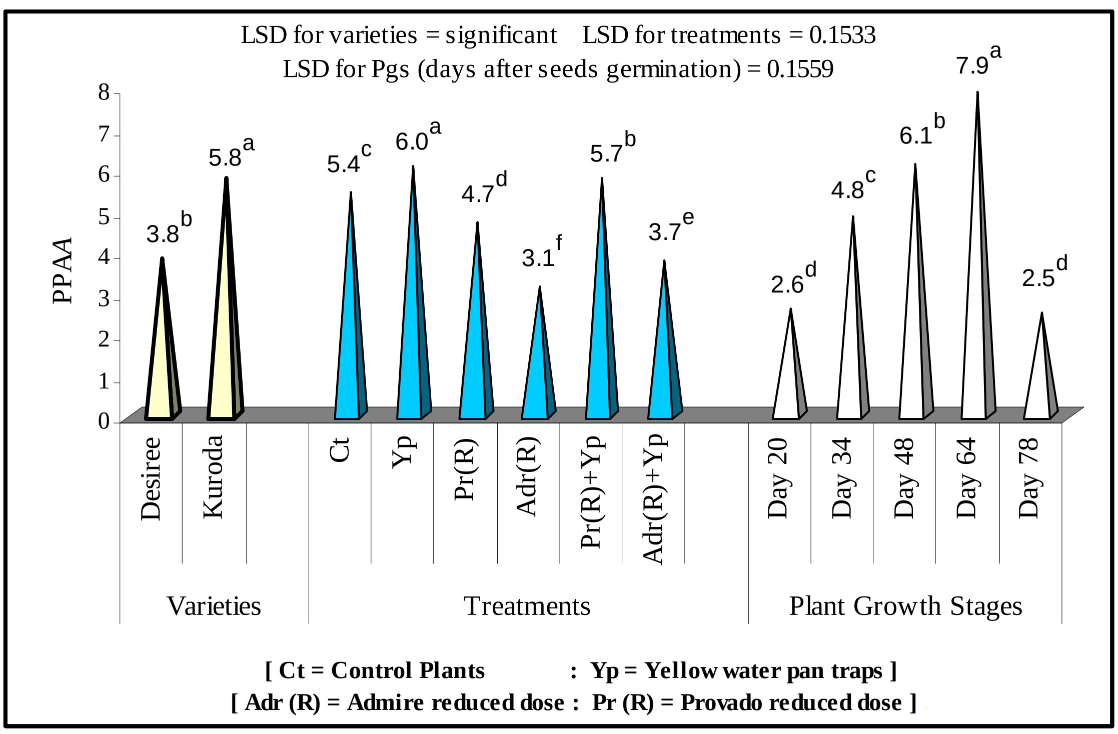


Fig 8.13 Effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp.*' (PPAA) in potato crop

Interaction effect of varieties x treatments (V x T) on PPA*A* was significant, Fig 8.14. On each individual treatment, significantly maximum PPA*A* was recorded on Kuroda as compared to Desiree. On Kuroda, significantly maximum PPA*A* (7.18) was recorded on Yp-trap treatment; whereas control treatment and Provado reduced dose +Yp-trap treatment (being statistically equal) followed it. The minimum PPA*A* (3.84) on Kuroda was recorded on plants treated with Admire reduced dose. On De, the maximum PPA*A* was recorded on plants treated with Yp-traps (4.90) and Provado reduced dose + Yp-trap (4.73), both of which did not differ statistically. The minimum (2.36) PPA*A* on Desiree was recorded on Admire reduced dose treated plants.

Interaction between varieties and plant growth stages (V x Pgs) showed that both the varieties responded significantly different at various plant growth stages, Fig 8.15. On both varieties, the PPA*A* was at significant increase on successive plant growth stages till Day 64 before it crashed on Day 78 of the seeds germination. However, significantly maximum PPA*A* was recorded on Kuroda than Desiree on each plant growth stage. The maximum PPA*A* was recorded on Kuroda on Day 64 and minimum on Desiree on Day 20 of the seed germination.

Interaction effect of plant growth stages x treatments (Pgs x T) was also significant, Table 8.VII. Difference in treatments nature made the trend of PPA*A* quite different on various plant growth stages. The PPA*A* on control, Yp-trap, Admire reduced dose and Admire reduced dose + Yp-trap treatments was at increase on successive plant growth stages till Day 64 of the seeds germination. However, among these treatments it was significantly highest on Yp-trap followed by control and lowest on Admire reduced dose followed by Admire reduced dose + Yp-trap treatment. In contrast, PPA*A* on Provado reduced dose and Provado reduced dose + Yp-trap treatments were at increase till Day 34, declined significantly on Day 48 and increased again on Day 64 before it crashed on Day 78 i.e. at crop maturity. However, the PPA*A* on Provado reduced dose + Yp-trap was significantly higher than Provado reduced dose treatment on all plant growth stages. On all treatments, the PPA*A* significantly decreased on Day 78; however on Provado reduced dose + Yp-trap it sustained as significantly highest and Provado reduced dose treatment followed it while the other treatments did not differ statistically. The highest PPA*A* (9.19) was recorded on Yp-trap treatment on Day 64 followed by control on Day 64 (8.71). The lowest PPA*A* (0.06) was recorded on Admire reduced dose on Day 20 followed by Admire reduced dose + Yp-trap treatment on Day 20 (0.40) of the seeds germination.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

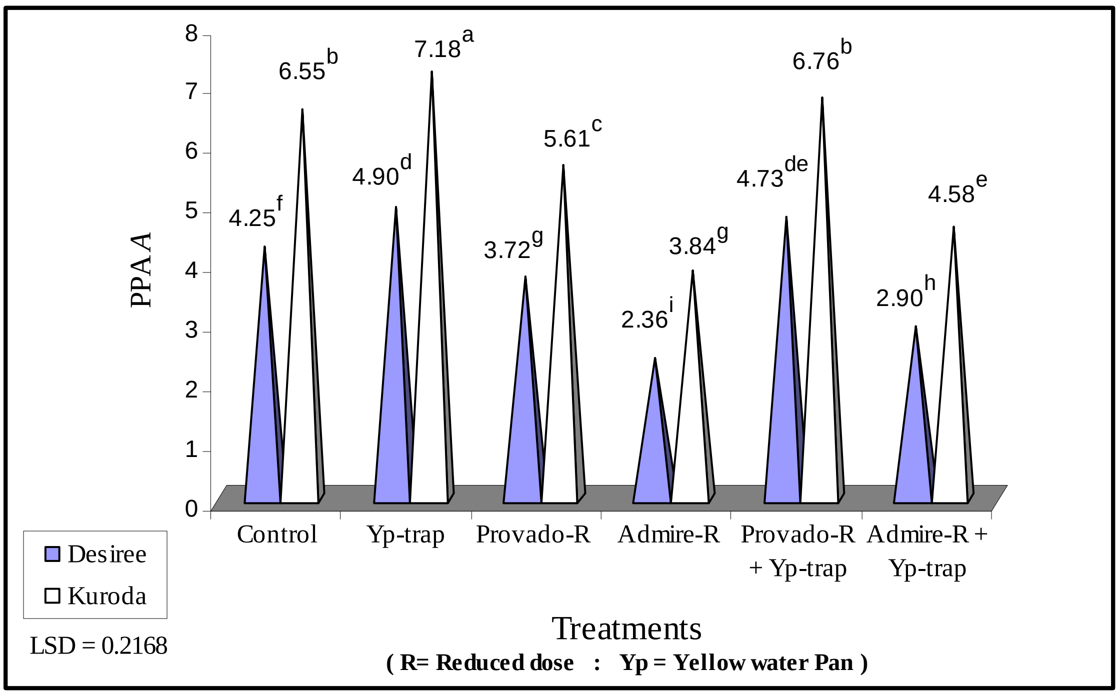


Fig 8.14 Interaction effect of treatments x potato varieties (T x V) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp.*' (PPA*A*) in potato crop (averaged over plant growth stages 'Pgs')

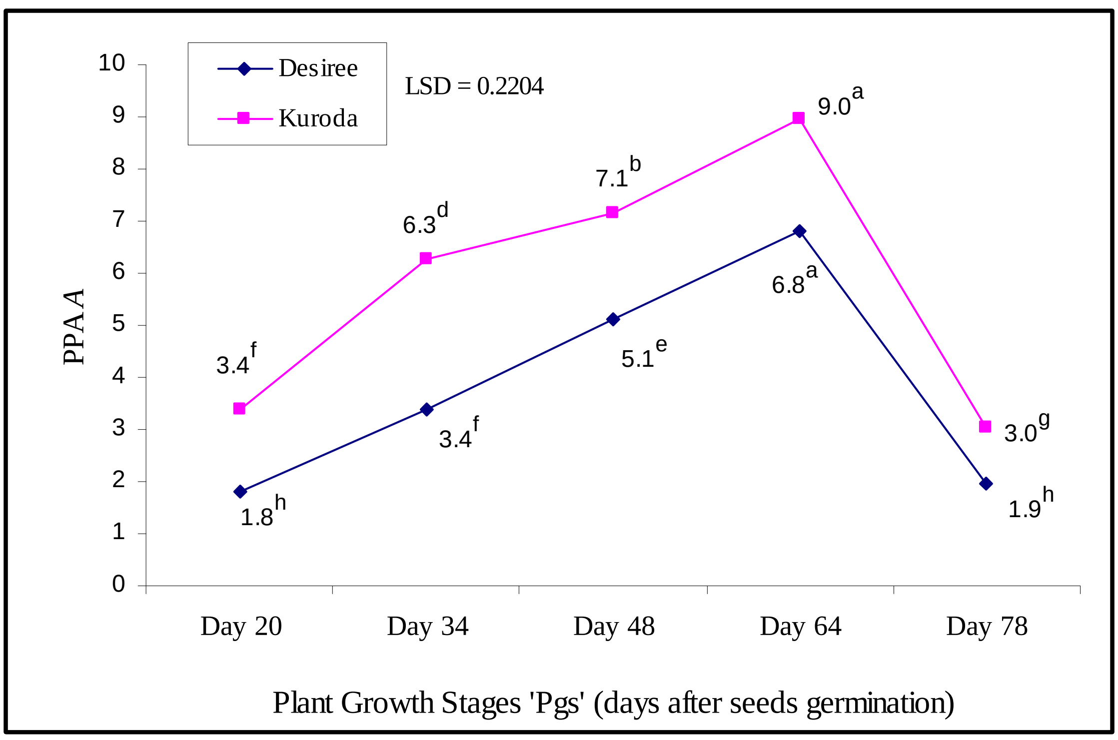


Fig 8.15 Interaction effect of potato varieties x plant growth stages 'Pgs' (V x Pgs) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp.*' (PPA*A*) in potato crop (averaged over treatments)

Table 8.VII Interaction effect of plant growth stages x treatments (Pgs x T) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp*' (PPA*A*) in potato crop

Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
	Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Day 20	3.25 j	4.35 h	3.39 ij	0.06 m	4.42 h	0.40 m
Day 34	5.89 e	6.58 d	5.87 ef	1.51 l	6.58 d	2.52 k
Day 48	7.71 c	8.46 b	3.65 i	5.50 fg	4.67 h	6.74 d
Day 64	8.71 b	9.19 a	6.77 d	6.94 d	7.90 c	7.74 c
Day 78	1.43 l	1.60 l	3.66 i	1.48 l	5.15 g	1.60 l

LSD value for interaction (treatments x Pgs) = 0.3818
Means followed by same letter(s) are not significantly different at 5% level of significance; (P<0.05)

Interaction effect of potato varieties x plant growth stages x treatments (V x Pgs x T) on PPA*A* was significant, Table 8.VIII. Treatments effect on PPA*A* at various plant growth stages of Kuroda and Desiree showed similar trend as presented in Table 8.VII. However, PPA*A* on Kuroda was significantly maximum than Desiree on each plant growth stage of all treatments. Highest PPA*A* (10.29) was recorded on Kuroda Day 64 treated with Yp-trap treatment and lowest (0.04) on Desiree Day 20 treated with Admire reduced dose and Admire reduced dose + Yp-trap treatments.

8.4.7 Effect of the various IPM strategies on the PER*A*

The analysis of variance for PER*A* showed significant effect (P<0.05) due to treatments and plant growth stages on the two potato varieties (Appendix-E Table-E7). All interactions were also significant (P<0.05). The results of main factors are shown in Fig 8.16. The mean values for varieties showed significant effect being highest PER*A* on Kuroda than Desiree. Similarly treatments showed significant effect with respect to PER*A* being highest on control followed by Yp-trap treatment. Lowest PER*A* was recorded on Admire reduced dose + Yp-trap treatment followed by Admire reduced dose treatment. The plant growth stages showed significant effect with respect to PER*A* being significantly highest on Day 78 and minimum on Day 20 of the seeds germination.

Interaction between varieties and various treatments (V x T) on PER*A* was significant (Fig 8.17). Significantly more PER*A* was recorded on Kuroda as compared to Desiree in each treatment. On Kuroda, the highest PER*A* (93.6) was recorded on control, and was followed by Yp-trap treatment (92.4). Moreover, on Kuroda, Provado reduced dose from Provado reduced dose + Yp-trap, and Admire reduced dose from Admire reduced dose + Yp-trap did not differ for PER*A*; however, Provado reduced dose and Provado reduced dose + Yp-trap had maximum PER*A* (86.7 and 86.6, respectively) as compared to Admire reduced dose and Admire reduced dose + Yp-trap (63.4 and 62.9, respectively). The pattern of PER*A* due to treatments on Desiree plants was different than Kuroda. On Desiree, the maximum PER*A* was recorded on control and Yp-trap treatments (85.8 and 85.6), both did not differ statistically; all other treatments differed significantly from each other with highest PER*A* on Provado reduced dose treatment (78.4) and lowest on Admire reduced dose + Yp-trap (54.0) treatment.

Interaction between varieties and plant growth stages (V x Pgs) showed that both varieties responded significantly different at various plant growth stages (Fig 8.18). The PER*A* was at significant increase on both varieties on successive plant growth stages till Day 78. However, PER*A* on Kuroda was significantly higher as compared to Desiree on each plant growth stage. The highest PER*A* (91.50) was recorded on Kuroda Day 78 as compared to lowest (64.58) on Desiree Day 20 of the seeds germination.

Interaction effect between various plant growth stages x treatments (Pgs x T) showed significant effect, Table 8.IX. Different nature of treatments made the PER*A* quite different at various plant growth stages. The PER*A* on control and Yp-trap treatments was at increase on successive plant growth stages till Day 64 and then declined on Day 78. On Admire reduced dose and Admire reduced dose + Yp-trap treatments it was continuously at increase till Day 78. However, PER*A* on Admire reduced dose and Admire reduced dose + Yp-trap did not exceed any treatment at any plant growth stage. The PER*A* on control as compared to Yp-trap, and on Admire reduced dose as compared to Admire reduced dose + Yp-trap treatments on Day 20 and 34 were significantly higher whereas on other plant growth stages the difference was not significant. In contrast, the PER*A* on Provado reduced dose and Provado reduced dose + Yp-trap was at increase till Day 34, significantly dropped on Day 48 and was again at significant increase till Day 78 of the seeds germination. However, the PER*A* on Provado reduced dose treatments was significantly higher than Provado reduced dose + Yp-trap treatment only on Day 48 and 78. Highest PER*A* (92.70) was recorded on control Day 64 followed by Yp-trap treatments on Day 64 (92.43). Lowest (31.90) PER*A* was recorded on Admire reduced dose + Yp-trap treatment on Day 20 followed by Admire reduced dose treatment on Day 20 (33.69) of the seeds germination.

Interaction effect of potato varieties x plant growth stages x treatments (V x Pgs x T) on PER*A* was significant, Table 8.X. The PER*A* at various plant growth stages on Kuroda and Desiree showed similar trend on all treatments, as shown in Table 8.IX. However, significantly highest PER*A* was recorded on Kuroda as compared to Desiree on each plant growth stage in all treatments. Highest PER*A* (96.82) was recorded on Kuroda control plants on Day 64 of the seeds germination as compared to lowest (29.23) on Desiree Day 20 treated with Admire reduced dose + Yp-trap.

Table 8.VIII Interaction effect of varieties x plant growth stages x treatments (V x Pgs x T) on the mean percent parasitism of green peach aphid (GPA), *Myzus persicae* (Sulzer), by its parasitoids '*Aphidius spp*' (PPA*A*) in potato crop

Variety	Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
		Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Desiree	Day 20	2.26 r	3.06 q	2.30 r	0.04 t	3.10 q	0.04 t
	Day 34	4.09 op	5.10 lm	4.11 op	0.79 s	5.09 lm	1.18 s
	Day 48	6.46 gh	7.13 ef	3.10 q	4.16 op	3.95 op	5.84 i-k
	Day 64	7.51 de	8.08 c	6.10 hi	5.94 h-j	6.76 fg	6.41 gh
	Day 78	0.92 s	1.11 s	3.01 q	0.87 s	4.75 mn	1.02 s
Kuroda	Day 20	4.25 n-p	5.64 i-k	4.47 no	0.08 t	5.75 i-k	0.15 t
	Day 34	7.69 cd	8.06 c	7.63 c-e	2.23 r	8.08 c	3.86 p
	Day 48	8.95 b	9.80 a	4.21 n-p	6.83 fg	5.39 kl	7.64 c-e
	Day 64	9.91 a	10.29 a	7.44 de	7.95 cd	9.03 b	9.08 b
	Day 78	1.93 r	2.09 r	4.32 n-p	2.09 r	5.55 j-l	2.19 r

LSD value for interaction (treatments x Pgs x varieties) = 0.5400
Means followed by same letter(s) are not significantly different at 5% level of significance; (P<0.05)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

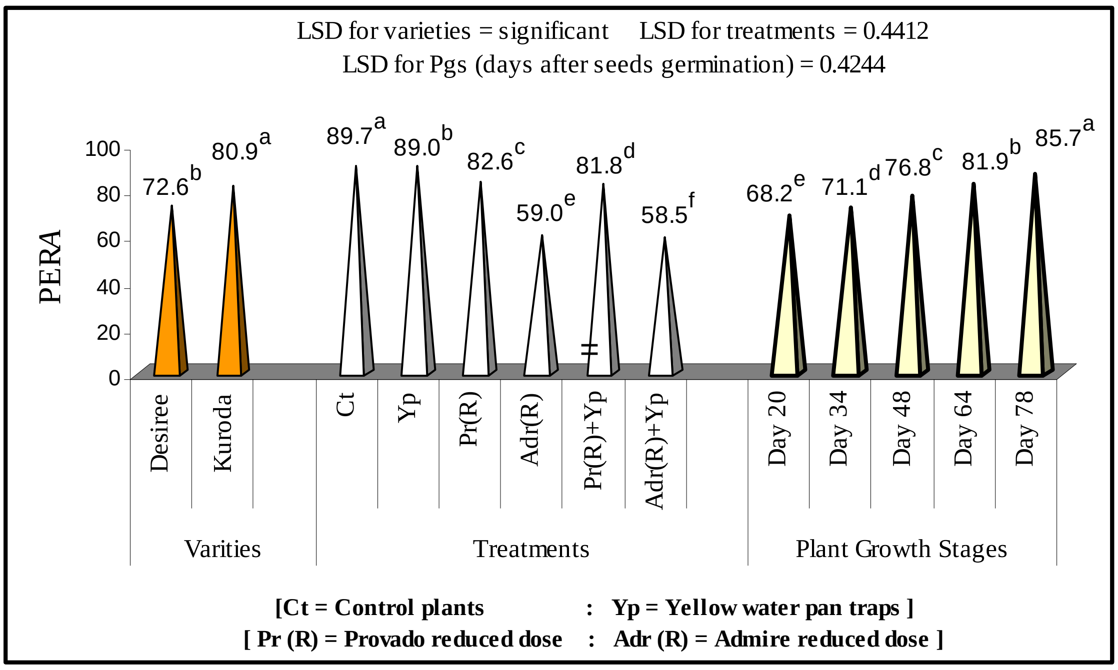


Fig 8.16 Effect of potato varieties x treatments and plant growth stages 'Pgs' (days after seeds germination) on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PER*A*) in potato crop

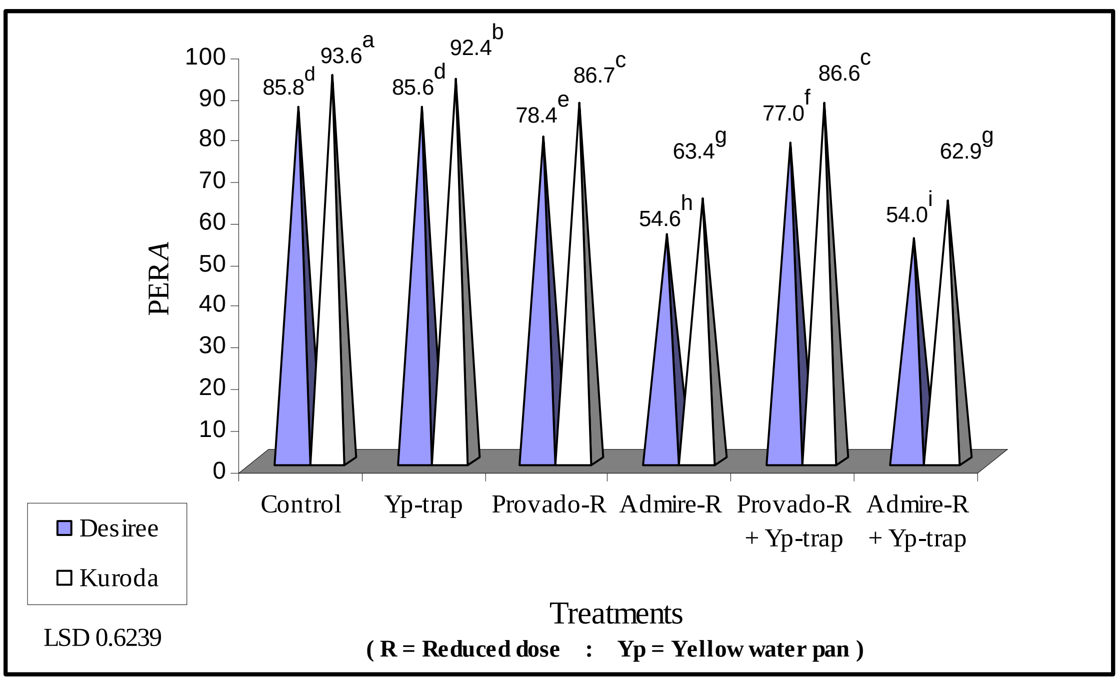
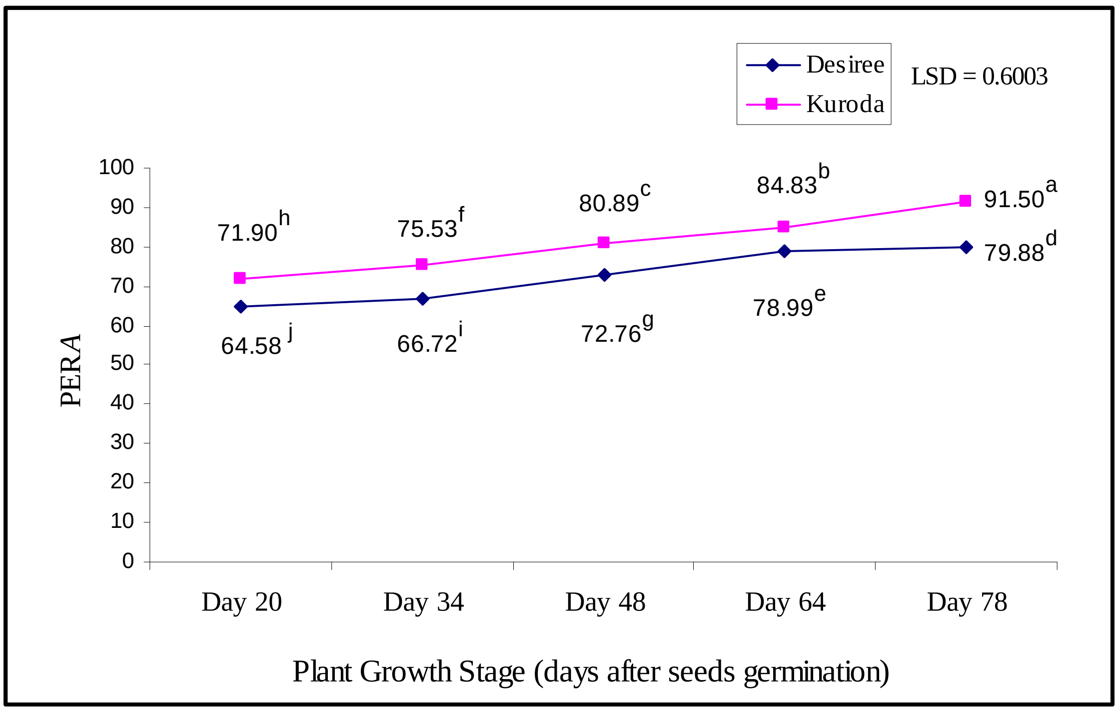


Fig 8.17 Interaction effect of potato varieties x treatments (V x T) on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PER*A*) in potato crop (averaged over plant growth stages 'Pgs')



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

Fig 8.18 Interaction effect of potato varieties x plant growth stages 'Pgs' (V x Pgs) on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PER*A*) in potato crop (averaged over treatments)

Table 8.IX Interaction effect of potato plant growth stages x treatments (Pgs x T) on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PER*A*) in potato crop

Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
	Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Day 20	86.75 ^{de}	85.68 ^{f}	85.93 ^{ef}	33.69 ^{q}	85.49 ^{f}	31.90 ^{r}
Day 34	87.94 ^{c}	86.46 $^{d-f}$	87.48 ^{cd}	40.55 ^{o}	86.81 ^{de}	37.50 ^{p}
Day 48	90.64 ^{b}	89.99 ^{b}	71.86 ^{m}	67.03 ^{n}	73.99 ^{l}	67.44 ^{n}
Day 64	92.70 ^{a}	92.43 ^{a}	77.74 ^{j}	74.53 ^{kl}	78.67 ^{ij}	75.38 ^{k}
Day 78	90.41 ^{b}	90.47 ^{b}	89.75 ^{b}	79.33 ^{hi}	84.11 ^{g}	80.04 ^{h}

LSD value for interaction (treatments x Pgs) = 1.040
Means followed by same letter(s) are not significantly different at 5% level of significance; (P<0.05)

Table 8.X Interaction effect of varieties x plant growth stages x treatments (V x Pgs x T) on the mean percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *Myzus persicae* (Sulzer), mummies (PER*A*) in potato crop

Variety	Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
		Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Desiree	Day 20	83.06 ^{pq}	81.94 $^{q-s}$	80.68 ^{s}	31.00 ^{b}	81.56 ^{rs}	29.23 ^{c}
	Day 34	84.15 ^{p}	82.97 $^{p-r}$	83.59 ^{p}	36.29 `	81.98 $^{q-s}$	31.31 ^{b}
	Day 48	87.74 $^{k-m}$	87.56 $^{l-m}$	67.76 \	60.56 ^	70.53 [	62.38]
	Day 64	88.58 $^{j-l}$	89.19 $^{i-k}$	74.27 $^{w-y}$	72.41 ^{z}	75.73 $^{u-w}$	73.76 $^{x-z}$
	Day 78	85.63 ^{o}	86.26 ^{no}	85.86 ^{o}	72.93 ^{yz}	75.19 $^{v-x}$	73.39 ^{yz}
Kuroda	Day 20	90.45 $^{g-i}$	89.42 ^{ij}	91.18 $^{f-h}$	36.39 `	89.42 ^{ij}	34.56 ^{a}
	Day 34	91.73 $^{e-g}$	89.96 $^{h-j}$	91.37 $^{f-h}$	44.81 –	91.64 $^{e-g}$	43.68 –
	Day 48	93.54 ^{cd}	92.41 $^{d-f}$	75.96 ^{uv}	73.50 ^{yz}	77.44 ^{t}	72.50 ^{z}
	Day 64	96.82 ^{a}	95.66 ^{ab}	81.21 ^{s}	76.64 $^{t-w}$	81.61 $^{q-s}$	77.01 ^{tu}
	Day 78	95.20 ^{b}	94.69 ^{bc}	93.63 ^{cd}	85.74 ^{o}	93.03 ^{de}	86.69 $^{m-o}$

LSD value for interaction (treatments x Pgs x varieties) = 1.470
Means followed by same letter(s) are not significantly different at 5% level of significance; ($P<0.05$)

8.4.8 Effect of various IPM strategies on the FR*A*

The analysis of variance for FR*A* showed significant effect ($P<0.05$) due to treatments and plant growth stages on the two potato varieties (Appendix-E Table-E8). All interactions were also significant ($P<0.05$). The results of main factors are shown in Fig 8.19. The mean values for varieties showed significant effect being highest FR*A* on Kuroda than Desiree. Similarly, treatments showed significant effect with respect to FR*A*, being highest on control followed by Yp-trap treatment. Lowest FR*A* was recorded on Admire reduced dose followed by Admire reduced dose + Yp-trap treatment. The plant growth stages showed significant effect with respect to FR*A* being significantly highest on Day 78 and minimum on Day 20 of the seeds germination.

Interaction between varieties and treatments (V and T) on FR*A* was significant, Fig 8.20. The control plants from Yp-trap treatment, Admire reduced dose from Admire reduced dose + Yp-trap treatment, and Provado reduced dose from Provado reduced dose + Yp-trap treatment, on both varieties, did not differ significantly in respect of the FR*A*. However, on each treatment significantly highest FR*A* was recorded on Kuroda as compared to Desiree. The maximum FR*A* (194.9) was recorded on Kuroda control plants followed by Kuroda plants treated with Yp-traps (193.3) whereas minimum FR*A* (114.0) was recorded on Desiree treated with Admire reduced dose followed by Desiree treated with Admire reduced dose + Yp-trap (117.6).

Interaction effect of varieties x plant growth stages (V x Pgs) showed that both varieties responded significantly different at various plant growth stages (Fig 8.21). On both varieties, the FR*A* was at significant increase on successive plant growth stages till Day 78, except that Kuroda did not differ for FR*A* on Day 34 and 48 of the seeds germination. However, the FR*A* on Kuroda was significantly higher than Desiree on each plant growth stage. Maximum FR*A* (218.4) was recorded on Kuroda Day 78 as compared to minimum (94.52) on Desiree Day 20 of the seeds germination.

Interaction between plant growth stages and treatments (Pgs x T) in respect of FR*A* was significant, Table 8.XI. The FR*A* due to treatments showed quite different trends as of difference in treatments nature. The FR*A* on control, Yp-trap, Admire reduced dose and Admire reduced dose + Yp-trap treatments were at significant increase on successive plant growth stages till Day 78 of the seeds germination. However, FR*A* was significantly higher on control plants and Yp-trap treatments as compared to Admire reduced dose and Admire reduced dose + Yp-trap treatments on each plant growth stage till Day 64. The FR*A* on control plants from Yp-trap treatment, and Admire reduced dose from Admire reduced dose + Yp-trap treatment did not differ statistically on each plant growth stage. In contrast, FR*A* on Provado reduced dose and Provado reduced dose + Yp-trap treatments was at significant increase till Day 78 except on Day 48 wherein it dropped significantly. However, Provado reduced dose did not differ from Provado reduced dose + Yp-trap treatment on each plant growth stage. Treatments effect on FR*A* was not significant on Day 78 of the seeds germination. Maximum FR*A* (199.7) was recorded on Admire reduced dose + Yp-trap treatment on Day 78 followed by Provado reduced dose + Yp-trap treatment on Day 78 (198.0). The minimum FR*A* (38.08) was recorded on Admire reduced dose + Yp-trap treatment on Day 20 followed by Admire reduced dose treatment on Day 20 (40.09) of the seeds germination.

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test (P < 0.05)

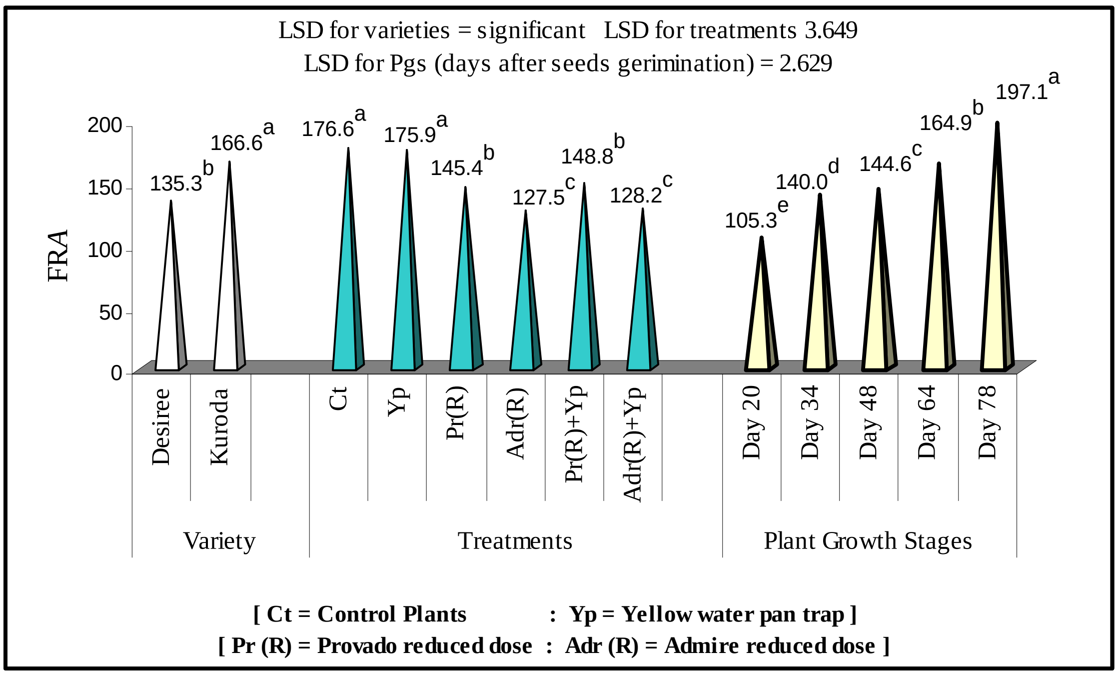


Fig 8.19 Effect of potato varieties x treatments and plant growth stages 'Pgs' (days after seeds germination) on the mean fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop

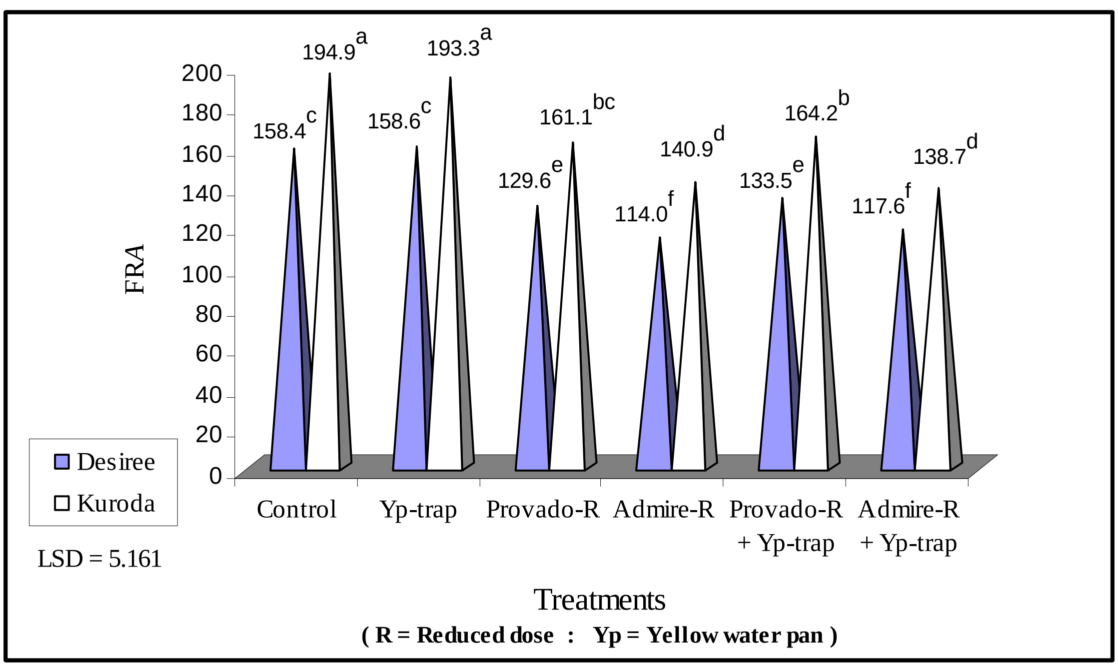
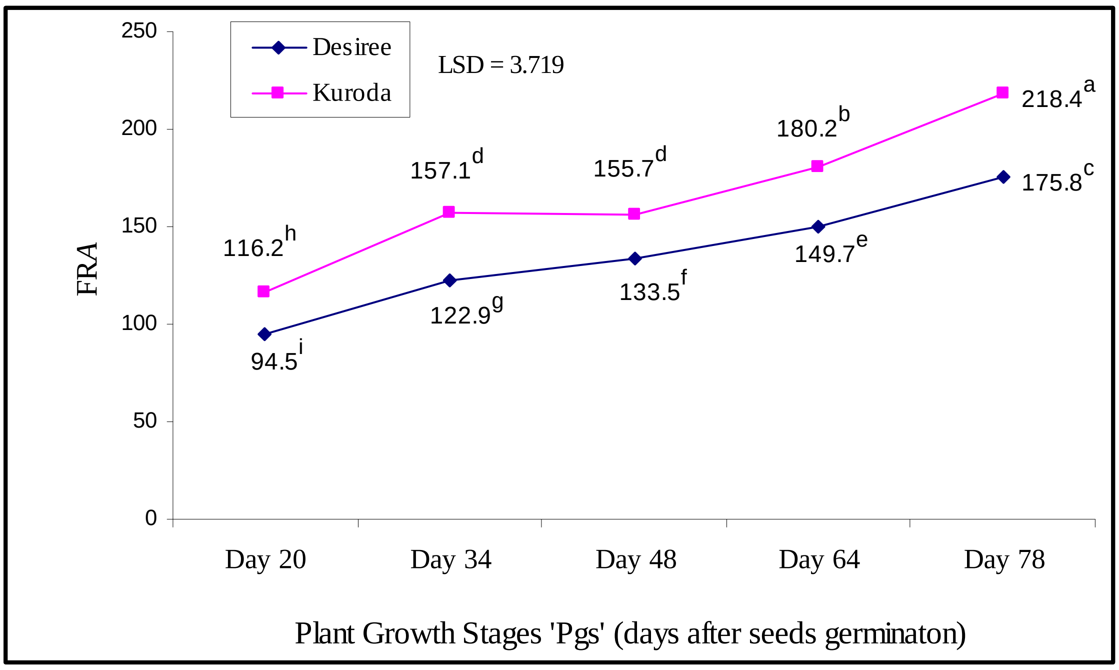


Fig 8.20 Interaction effect of treatments x potato varieties (T x V) on the mean fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop (averaged over plant growth stages 'Pgs')



Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

Fig 8.21 Interaction effect of plant growth stages ‘Pgs’ x potato varieties (V x Pgs) on the mean fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop (averaged over treatments)

Table 8.XI Interaction effect of various plant growth stages x treatments (Pgs x T) on the mean fecundity rates of mature female parasitoid ‘*Aphidius spp*’ (FR*A*) in potato crop

Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
	Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Day 20	138.4 ^{fg}	135.7 ^{gh}	137.4 ^{fg}	40.09 ^{k}	142.4 ^{ef}	38.08 ^{k}
Day 34	164.7 ^{d}	166.2 ^{d}	165.8 ^{d}	88.04 ^{j}	167.4 ^{d}	87.85 ^{j}
Day 48	190.0 ^{bc}	186.5 ^{c}	98.67 ^{i}	142.4 ^{ef}	103.0 ^{i}	147.1 ^{e}
Day 64	193.9 ^{ab}	194.0 ^{ab}	129.7 ^{h}	170.6 ^{d}	133.4 ^{gh}	168.1 ^{d}
Day 78	196.3 ^{ab}	197.2 ^{a}	195.3 ^{ab}	196.2 ^{ab}	198.0 ^{a}	199.7 ^{a}

LSD value for interaction (treatments x Pgs) = 6.441
Means followed by same letter(s) are not significantly different at 5% level of significance; ($P<0.05$)

Interaction effect of varieties x plant growth stages x treatments (V x Pgs x T) on FR*A* was significant, Table 8.XII. Treatments effect in respect of FR*A* on various plant growth stages showed similar trend on both varieties, as presented in Table 8.XI. However, significantly maximum FR*A* was recorded on Kuroda than Desiree on each plant growth stage. Maximum FR*A* (221.1) was recorded on Provado reduced dose + Yp-trap treatment on Day 78 as compared to minimum (26.10) on Admire reduced dose + Yp-trap treatment on Day 20 of the seeds germination.

8.4.9 Effect of the various IPM strategies on yield of the potato varieties

The analysis of variance for yields showed significant effect ($P<0.05$) due to treatments and potato varieties (Appendix-E Table-E9). Interaction effect of varieties x treatment (V x T) was also significant ($P<0.05$). The results of main factors are shown in Fig 8.22. The mean values for varieties showed significant effect being maximum potato yield from Kuroda as compared to Desiree. Similarly treatments showed significant effect with respect to yield. Maximum yield (15.22 tons/hectare) was obtained from Provado reduced dose + Yp-trap treatment followed by Provado reduced dose treatment (14.18). Minimum yield was obtained from control (11.08) followed by Yp-trap treatment (11.72).

Interaction between varieties and various treatments (V x T) on potato yield was significant, Fig 8.23. On each treatment, the yield obtained from Kuroda was significantly higher as compared to Desiree. Kuroda responded significantly different to each treatment in respect of yield, except that Admire reduced dose and Yp-trap treatments did not differ statistically. The sequential yield in descending order from Kuroda plant due to various treatments was; Provado reduced dose + Yp-trap > Provado reduced dose > Admire reduced dose + Yp-trap > Admire reduced dose > Yp > Ct. As far as the Desiree is concerned, the maximum yield was obtained from Desiree plant treated with Provado reduced dose + Yp-trap. It was followed by Provado reduced dose and Admire reduced dose + Yp-trap treatments, both of which did not differ statistically. The minimum yield was obtained from Desiree control plants and Yp-traps treated Desiree plants, both of which did not differ statistically.

Table 8.XII Interaction effect of varieties x plant growth stages x treatments (V x Pgs x T) on the mean fecundity rates of mature female parasitoid '*Aphidius spp*' (FRA) in potato

Variety	Plant growth stages (Pgs) i.e. days after seeds germination	Treatments					
		Control/ untreated plants	Yellow water pan trap (Yp-trap)	Provado reduced dose	Admire reduced dose	Provado reduced dose + Yp-trap	Admire reduced dose + Yp-trap
Desiree	Day 20	126.7 ^{no}	125.0 ^{no}	128.3 ^{n}	27.96 ^{v}	133.0 ^{n}	26.10 ^{v}
	Day 34	146.5 ^{m}	147.7 ^{m}	147.0 ^{m}	73.71 ^{t}	147.5 ^{m}	74.74 ^{t}
	Day 48	171.5 ^{hi}	167.7 ^{ij}	87.64 ^{s}	133.6 ^{n}	93.87 ^{rs}	146.6 ^{m}
	Day 64	174.7 $^{f-i}$	175.4 $^{f-I}$	113.0 ^{p}	159.9 ^{jk}	118.0 ^{op}	157.3 ^{kl}
	Day 78	172.5 $^{g-i}$	177.1 $^{e-h}$	172.1 ^{hi}	174.8 $^{f-I}$	175.0 $^{f-i}$	183.3 $^{d-f}$
Kuroda	Day 20	150.0 ^{ml}	146.5 ^{m}	146.5 ^{m}	52.23 ^{u}	151.7 $^{k-m}$	50.05 ^{u}
	Day 34	182.8 $^{d-f}$	184.7 ^{de}	184.6 ^{de}	102.4 ^{qr}	187.3 ^{d}	101.0 ^{qr}
	Day 48	208.5 ^{bc}	205.2 ^{c}	109.7 ^{pq}	151.2 $^{k-m}$	112.1 ^{p}	147.5 ^{m}
	Day 64	213.1 $^{a-c}$	212.6 $^{a-c}$	146.4 ^{m}	181.2 $^{d-g}$	148.8 ^{lm}	179.0 $^{d-h}$
	Day 78	220.0 ^{a}	217.3 ^{ab}	218.4 ^{a}	217.5 ^{ab}	221.1 ^{a}	216.1 ^{ab}

LSD value for interaction (treatments x Pgs x varieties) = 9.108
Means followed by same letter(s) are not significantly different at 5% level of significance; ($P<0.05$)

Means followed by same letter(s) are not significantly different at 5% level of significance using LSD Test ($P < 0.05$)

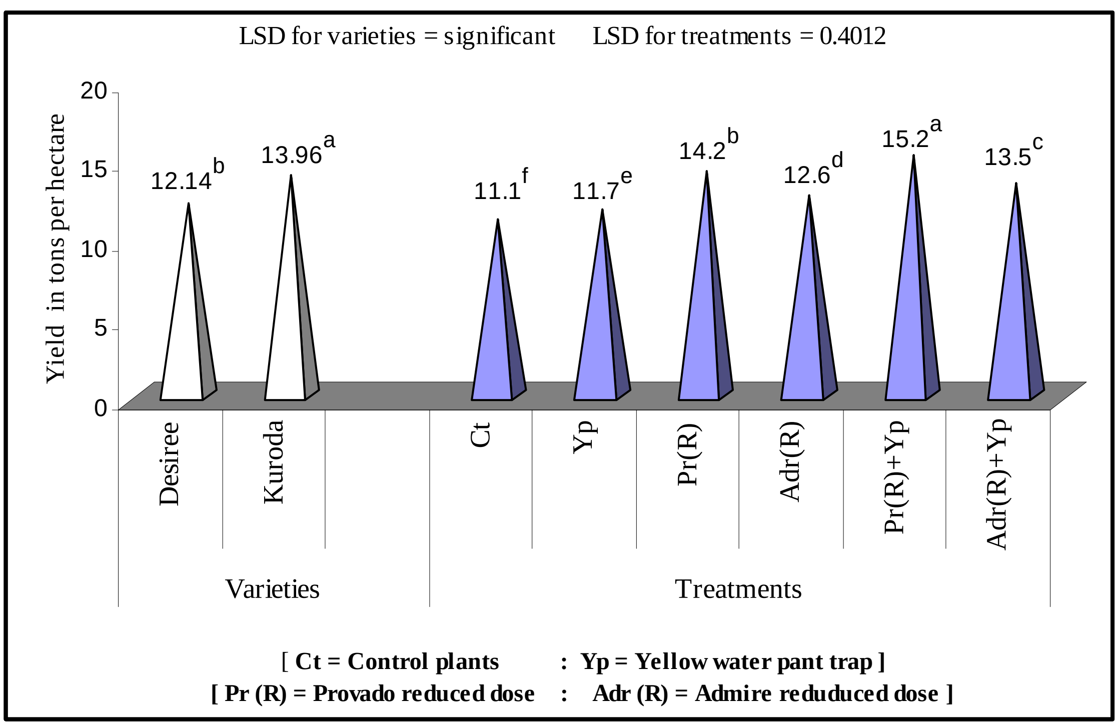


Fig 8.22 Effect of potato varieties and treatments on the yield means of potato tubers in tons/hectare

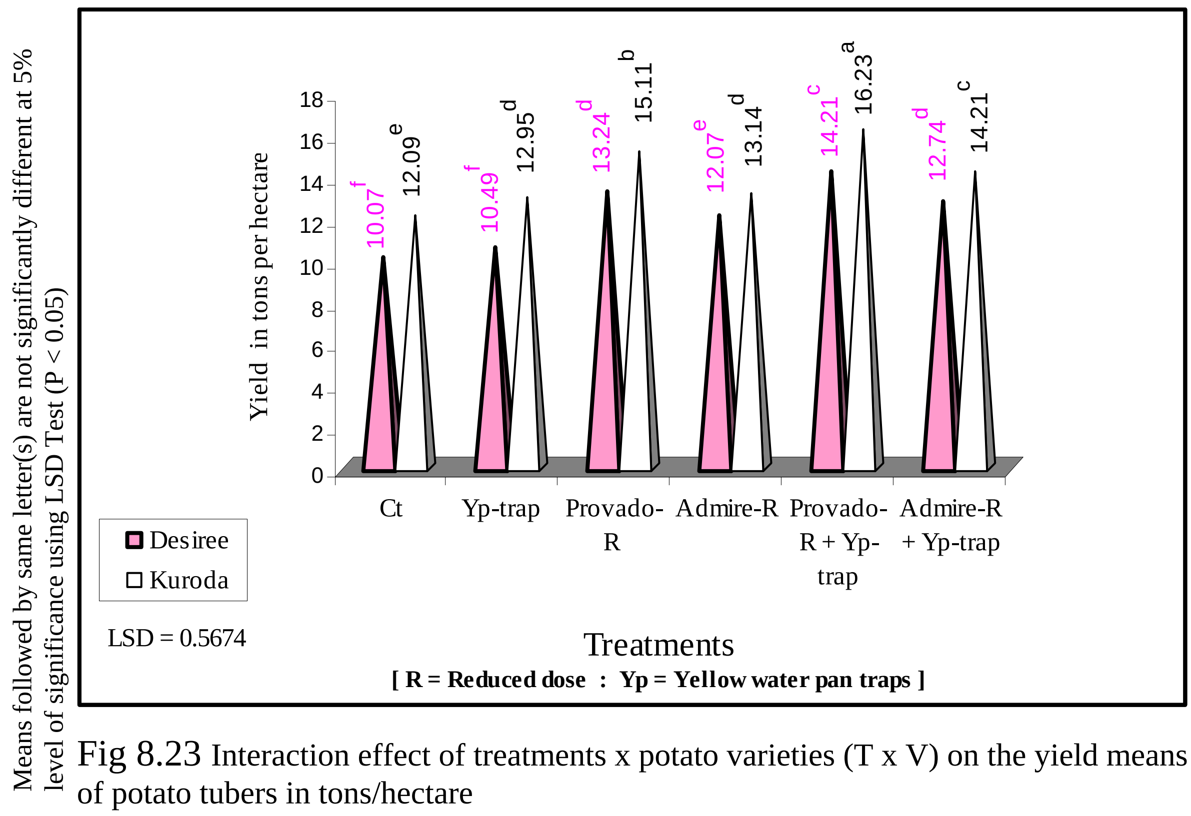


Fig 8.23 Interaction effect of treatments x potato varieties (T x V) on the yield means of potato tubers in tons/hectare

8.5 DISCUSSION

The foundation of IPM strategies is commonly tripartite that includes close monitoring of pest populations, decision rules based on pest density, and application of an integrated suite of management tactics like resistant varieties, attractants/trap crops and the use of selective chemicals. Such strategies also allow native and introduced biological control agents associated with crop pests to survive and replicate easily. It would be appropriate to say that IPM relies (either intentionally or inadvertently) on predators, parasitoids, and pathogens, as fundamental sources of mortality to insect pests (Follas and Bland, 1994; Kogan, 1998; Bates *et al.*, 2005; Bernal, 2008).

The model selection and parameters estimate indicated that the data were consistent with the hypotheses that development of *M. persicae* and its natural enemies (ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A*) were associated with different IPM packages and potato varieties. The varieties comparison on control plants showed that *M. persicae* population was lesser by 49.9% on Kuroda than Desiree variety while the ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A* were higher by 4.4, 35.4, 32.1, 46.9, 54.1, 9.0 and 23.0%, respectively. These findings were in conformity with those of Marvier *et al.* (2007), Walker *et al.* (2007) and Wolfenbarger *et al.* (2008) whereby it was reported that crops with induced resistance had no significant adverse effect on predator populations as compared to conventional crops. Further possible reasons for variation in resistance to *M. persicae* and populations of natural enemies on Kuroda and Desiree varieties are discussed in Section 4.4 and 6.6.

Being higher/crowded population of *M. persicae* and lower/scattered populations of natural enemies on Desiree control than Kuroda control; it was presumed that the treatments would reduce *M. persicae* population in greater quantity and natural enemies in smaller quantity on Desiree as compared to Kuroda. But, the results were otherwise. All the treatments responded significantly different in reducing the populations of *M. persicae* and natural enemies. Saljoqi and van Emden (2003c) found similar results. Only, Yp-trap treatment did not differ with control in respect of natural enemies. Yp-trap, Provado reduced dose, Admire reduced dose, Provado reduced dose + Yp-trap and Admire reduced dose + Yp-trap treatments reduced *M. persicae* populations on Kuroda by 40.7, 57.7, 41.4, 74.8 and 63.8%, respectively, and on Desiree by 41.4, 56.6, 49.5, 74.7 and 62.4%, respectively. The difference in percent reduction between Desiree and Kuroda (Desiree - Kuroda) due to respective treatments for ladybird beetle was 5.6, 5.0, 2.7, 5.0 and 5.7%, respectively; for parasitized *M. persicae* mummies was 0.2, -0.8, -2.9, 1.5 and -3.6%, respectively; for syrphidfly it was 1.0, 5.4, 2.9, -5.1 and 6.1%, respectively; for green lacewing was 5.7, 4.6, 4.1, -0.5 and 5.4%, respectively; for PPA*A* was -5.6, -1.9, 3.0, -8.1 and 1.8%, respectively; for PER*A* was -0.9, 1.3, 4.1, 2.9 and 4.3%, respectively; and for FR*A* was -0.9, 0.9, 0.3, 0.0 and -3.1%, respectively. Higher PPA*A* was also recorded by Saljoqi and van Emden (2003c) in mixed cropping of potato with berseem; however the inclusion yellow sticky plastic sheet in the same treatment was reported as not extra productive.

Statistically, these results (as per significant interactions) are presented as; *M. persicae* population was significantly minimum and maximum on Kuroda plants treated with Provado reduced dose + Yp-trap and Desiree control plants, respectively, as compared to other treatments (Saljoqi and van Emden, 2003c). Provado reduced dose + Yp-trap was next to Yp-trap and control treatments (both statistically equal) in highest population of ladybird beetle; however, it was statically equal to Provado reduced dose and Admire reduced dose treatments. Yp-trap, control and Provado reduced dose + Yp-trap treatments had significantly highest populations of syrphidfly and green lacewing; however, Provado reduced dose + Yp-trap treatment was statically equal to Provado reduced dose treatment. Kuroda plants treated with Provado reduced dose and Provado reduced dose + Yp-trap (being statistically equal) had highest parasitized *M. persicae* mummies, PER*A* and FR*A* than other treatments except Kuroda control plants and Kuroda treated with Yp-trap. Kuroda treated with Provado reduced dose + Yp-trap and Kuroda control plants had significantly highest PPA*A* than all other treatments except Kuroda plants treated with Yp-trap. Minimum numbers of the corresponding parameters for natural enemies were recorded on Desiree plants treated with Admire reduced dose + Yp-trap and Desiree plants treated with Admire reduced dose that were in most cases statistically equal.

These results clearly demonstrated that the existing difference for *M. persicae* population between the Kuroda and Desiree (untreated/control plants) was further increased by each treatment except Yp-trap treatment that gave opposite result but at negligible amount (-0.7%). And, the impact on natural enemies was similar to *M. persicae* in most of the cases. The reduction in population of natural enemies, other than direct effect, may be linked with reduction of available prey/ *M. persicae* due to treatments (Schuler *et al.*, 2003). Impact of Admire reduced dose and Provado reduced dose on *M. persicae* and its natural enemies on Kuroda vs De are discussed in Section 6.6 and 7.5. Yp-traps or yellow sticky strings/boards traps are actually used to monitor/trapping the aphid species flight-activity, landing, diversity or population dynamics and its threshold i.e. 5 winged *M. persicae* caught/trap/week (Halbert *et al.*, 1986; Labonne *et al.*, 1989; Boiteau, 1990; Avinent *et al.*, 1991; Hamm, 2001; Mitchell *et al.,* 2001; Alan *et al.,* 2003, Kuroli and Lantos, 2006). No literature was available for direct usage of these traps as management tool against *M. persicae*. Reduced insecticide usage in association with resistant variety encouraged natural enemies (Walker *et al.*, 2007). Increased populations of natural enemies in IPM package carrying Yp-traps may be linked with chasing of the *M. persicae* that had catalyzed movement/flight towards to Yp-traps; however the literature in this regard is not available. In short, resistant variety, Provado reduced dose (imidacloprid) and addition of Yp-traps was comparatively better IPM package than the others. Kuroda proved better than Desiree to the extent that even Kuroda plants treated with Provado reduced dose + Yp-trap or only Provado reduced dose had highest populations of these natural enemies than Desiree control plants and Desiree treated with Yp-trap. Parker *et al.* (2002) expressed similar views stating that acceptable levels of aphid control could be achieved, provided a full range of treatment options (resistant cultivars, selective insecticides, natural enemies and validated pest forecasts) are utilized. While according to Walker *et al.*, (2007) no consistent difference between conventional and induced resistant crops is documented in numerous studies that provide opportunities for integrating biological control with IPM.

The populations of *M. persicae* were varied at different plant growth stages i.e. days after seeds germination on various treatments as of difference in their application timings especially Provado reduced dose and Admire reduced dose treatments. However, the population of all the parameters on each treatment was significantly lower than control till harvesting. The order thus found for *M. persicae* population on treatments from Day 20-34 was Admire reduced dose + Yp-trap < Admire reduced dose < Yp ≤ Provado reduced dose + Yp-trap < Provado reduced dose; while from Day 48-78 it was Provado reduced dose + Yp-trap < Provado reduced dose < Admire reduced dose + Yp-trap < Yp < Admire reduced dose. These findings demonstrated that the plants treated by Admire reduced dose provided long-lasting protection against *M. persicae* population buildup especially during the critical and susceptible early stages of plant growth (Powell, 1980) and maintained it (lower than control plants) till harvesting (Palumbo and Kerns, 1994); although the toxicity decreased with the passage of time, as the population was at ascend till Day 64 until it declined on Day 78 i.e. at crop maturity (Saljoqi and van Emden, 2003b). The Provado reduced dose treatment on the other hand abruptly suppressed the *M. persicae* population (to the lowest level as compared to other treatments) at its application i.e. Day 34 and sustained it till harvesting to the extent that the average effect was significantly better than Admire reduced dose treatment. The inclusion of Yp-trap fueled the efficacy Provado reduced dose and Admire reduced dose treatments in suppressing *M. persicae* populations. Trapping of unprecedented numbers of *M. persicae* population in yellow water pan traps was also recorded in England by IRAG Resistance Alert (2007) and by yellow sticky plastic sheets by Saljoqi and van Emden (2003c).

The interaction treatments x plant growth stages for ladybird beetle, parasitized *M. persicae* mummies, syrphidfly and green lacewing showed that Yp-trap treatment did not differ from control on all plant growth stages. Admire reduced dose and Admire reduced dose + Yp-trap treatments had quite lesser populations as compared to control till Day 48 and thereafter it became equal to control i.e. the insecticide practically lost its toxicity. On the other side, Provado reduced dose and Provado reduced dose + Yp-trap treatments did not differ from control except for short period i.e. on Day 48 on which the populations of these parameters were statistically smaller than control. The populations of each parameter on all treatments became statistically equal on Day 78 i.e. the insecticides lost their toxicity. These results clearly indicated that Provado reduced dose and Provado reduced dose + Yp-trap treatments were better than Admire reduced dose and Admire reduced dose + Yp-trap as the toxic effect of insecticide either directly or indirectly persisted for short time. While the indirect toxicity of Admire reduced dose and Admire reduced dose + Yp-trap persisted for long time that either may have killed or repelled the natural enemies.

The interaction effect of varieties x treatments x plant growth stages was significant only for PPA*A*, PER*A* and FR*A*; quantitatively all these parameters on each treatment at each plant growth stage were significantly higher on Kuroda than Desiree. PPA*A* and FR*A* on both varieties were significantly lowest on Admire reduced dose + Yp-trap and Admire reduced dose treatments as compared to highest on control and Yp-trap treatments from Day 20-64; while on Provado reduced dose + Yp-trap and Provado reduced dose (Provado reduced dose + Yp-trap > Provado reduced dose) these were lower than control and Yp-trap from Day 48-64 of the seeds germination. PPA*A* on Provado reduced dose and Provado reduced dose + Yp-trap treatments was continuously higher than Admire reduced dose and Admire reduced dose + Yp-trap treatments from Day 20-64 except on Day 48 (closer to Provado application time), and higher than control and Yp-trap on Day 78. While FR*A* on Provado reduced dose + Yp-trap/Provado reduced dose treatments as compared to Admire reduced dose + Yp-trap/Admire reduced dose treatments was higher from Day 20-34 (before Provado application) and lower on Day 48-64. On Day 78 the difference for FR*A* between all treatments including control and Yp-trap became not significant. Stapel *et al.* (2000) explained it as that longevity of parasitoid females fed on nectar was affected for at least 10 days after insecticides treatment while the parasitoid's host foraging ability was severely affected from 2 days (imidacloprid) to 18 days (aldicarb) of post treatments.

The response of PER*A* to treatments at various plant growth stages on Kuroda and Desiree was different. On Kuroda; PER*A* was lowest on Admire reduced dose + Yp-trap and Admire reduced dose as compared to highest control and Yp-trap treatments from Day 20-78; while on Provado reduced dose and Provado reduced dose + Yp-trap it was lowest as compared to highest on control and Yp-trap treatments from Day 48-78. On Desiree; PER*A* was lowest on Admire reduced dose + Yp-trap and Admire reduced dose as compared to highest on control and Yp-trap treatments from Day 20-64 while on Provado reduced dose and Provado reduced dose + Yp-trap treatments it was lowest as compared to control and Yp-trap treatments from Day 48-64 and 34-78, respectively. However, PER*A* on Provado reduced dose and Provado reduced dose + Yp-trap was continuously higher than Admire reduced dose and Admire reduced dose + Yp-trap treatments from Day 20-78. Theses results indicated that the treated hosts (*M. persicae*) on Admire reduced dose and Admire reduced dose + Yp-trap treatments indirectly infected the parasitoids that affected PER*A* even from seedling till harvesting. As such Provado reduced dose + Yp-trap treatment was more beneficial than Admire reduced dose + Yp-trap treatment. No detrimental effect of insecticides (Deltamethrin ‘pyrethroid’) on PER*A* from mummies (Desneux *et al.*, 2006) and development of parasitoid (*Gonatocerus ashmeadi*) in eggs of its host were seen when exposed to imidacloprid (Byrne and Toscano, 2007).

Yield obtained from various treatments was in order of; Kuroda treated with Provado reduced dose + Yp-trap > Kuroda treated with Provado reduced dose > Kuroda treated with Admire reduced dose + Yp-trap ≥ Desiree with Provado reduced dose + Yp-trap ≥ Desiree treated with Provado reduced dose ≥ Kuroda treated with Admire reduced dose ≥ Kuroda treated with Yp-trap ≥ Desiree treated with Admire reduced dose + Yp-trap > Kuroda control plants ≥ Desiree treated with Admire reduced dose > Desiree treated with Yp-trap ≥ Desiree control plants; wherein the symbols ‘>’ and ‘≥’ between two variables denote greater/more than, by significant and not significant difference in yield, respectively. These results were in close conformity with that of Raman and Midmore (1983) according to whom the soil-incorporated insecticides gave protection against *Diabrotica* but not *M. persicae*, and yields were significantly lower with these compared with the foliar-applied insecticide. Moreover, higher yield from potato crop was achieved by Saljoqi and van Emden (2003c) from treatment in which mixed cropping [(potato + berseem (*Trifolium alexandrinum* (L)] was treated with yellow sticky plastic sheets.

From these results one could easily assess that the resistant variety performed better than susceptible variety in respect of reducing *M. persicae* and encouraging population of natural enemies even post IPM package. The addition of Yp-traps enhanced the efficacy of IPM packages not only by trapping *M. persicae* but also by increasing the populations of natural enemies. Moreover, the landing population of *M. persicae* that escaped the Yp-traps trapping got killed easily when fed on treated crop in Admire reduced dose treatments. Similarly, it was easier for Provado reduced dose treatments to kill the aggregated *M. persicae* population, being attracted to crop due to Yp-traps. The other assessment one could measures from these results is that Provado reduced dose treatment was better than

Admire reduced dose treatment in reducing the *M. persicae* population, preserving the natural enemies and producing higher yield.

8.6 CONCLUSIONS

Kuroda responded effectively than Desiree in all treatments to resist *M. persicae* infestation and showed maximum populations of the natural enemies. Plants treated only with Yp-traps reduced the *M. persicae* infestation compared to control plants and had statistically equal population of the natural enemies to control. However, the *M. persicae* population was not suppressed by Yp-traps to a level to get maximum yield of potato than other treatments. Provado reduced dose and Provado reduced dose + Yp-trap treated plants proved better than Admire reduced dose and Admire reduced dose + Yp-trap treated plants. The IPM package in which resistant Kuroda variety was treated with reduced dose of Provado 1.6F (foliar insecticide) in addition to Yp-trap significantly reduced the *M. persicae* population than all the other treatments. At the same time this package was comparatively friendlier to natural enemies than other treatments. For example, in respect of green lacewing population this package did not differ from control plants; for PPA*A* it was better than control plants; for ladybird beetle, syrphidfly, parasitized *M. persicae* mummies, PER*A* and FR*A* it was second to Control plants and Yp-trap treatment. The cumulative effect of all these parameters resulted in maximum potato tuber yield by this treatment than all other treatments. In respect of yield this IPM package was followed by another IPM package wherein Kuroda was treated only with Provado reduced dose.

8.7 RECOMMENDATIONS

The above findings lead to the following recommendations.

1) The comparison on susceptible ‘Desiree’ and resistant ‘Kuroda’ potato varieties provides solid and valuable bases to devise and study the impact of IPM packages on *M. persicae* and its natural enemies.

2) Kuroda is more resistant to *M. persicae* infestation as compared to Desiree and more promising for sustaining higher population of the natural enemies (ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A*); even after insecticidal applications.

3) Yellow water pan traps alone in a resistant cultivar significantly reduce *M. persicae* population without affecting natural biological control agents. However, the potato yield thus obtained is quite less as compared to package in which insecticides are added.

4) Adding insecticides in IPM package has negative impact on the natural enemies; however, IPM package carrying resistant Kuroda variety, yellow water pan traps and naturally occurring biological control agents could not reduce the *M. persicae* population to get higher yield than IPM package with insecticide.

5) Reduced doses of the foliar insecticides (Provado 1.6F) prove better than the reduced doses of soil applied insecticide (Admire 2F).

6) IPM package in which resistant potato variety (Kuroda) is treated with reduced dose of Provado 1.6F (foliar application) in addition to yellow water pan significantly reduce *M. persicae* population with lesser adverse effect on natural enemies and result in achieving the highest yield.

Chapter 9

GENERAL DISCUSSION

This research was an attempt to develop IPM package that would be instrumental in minimizing the *M. persicae* population and conservation of the population of its natural enemies in potato crop. Almost all experiments were conducted in the field; especially the survey regarding the population trends of *M. persicae* and its natural enemies was made in different ecological zones. Though the field experiments have an obvious edge over laboratory tests due to many factors including the natural environment for plants, pests and natural enemies; the natural impediments like unusual weather sometimes disrupted an ongoing smooth running of the experimentation and collection. Elaborate and exhaustive field experimentations were undertaken to makeup for any natural abrupt changes in such varied conditions. The general discussion and recommendations in this chapter are an attempt to appraise the researcher of the different climatic zones and their ecological impacts on the various parameters undertaken in this endeavour.

M. persicae buildup varied along the locations and seasons due to difference in geographical position (the altitudes from sea level; Section 4.3) and consequently climatic changes like rainfall, and rise and fall in temperature (Table 4.I) at different plant growth stages (Bale *et al*., 2002; Capinera, 2005). In all the three different locations/climatic zones viz Malakandair, Abbottabad and Mingora the *M. persicae* population was significantly higher than fall that may be explained by the difference in climate especially the temperature (Cocu *et al.,* 2005). The means for *M. persicae* population during spring was highest at Mingora and lowest at Malakandair while during fall the results were opposite. This indicated that during fall the *M. persicae* at Abbottabad and Mingora moved earlier than Malakandair to *prunus* for depositions of over-wintering eggs as the temperature threshold (16-17°C under field condition) for this act was probably met (Boiteau, 1986; Cocu *et al.,* 2005).

The location comparison for natural enemies indicated that their abundance during spring was interlinked with the abundance of prey/food '*M. persicae*' (Park and Obrycki, 2004; Kalushkov and Hodek, 2005). However, during fall this relation was otherwise and not accordingly higher at Malakandair, which might be due to food/*M. persicae* scarcity that resulted intraguild or extraguild predations (Hindayana *et al.,* 2001; Wiebe and Obrycki, 2002).

The sequence of resistance among all the nine tested potato varieties was similar during spring in each location, Kuroda and Desiree being the most resistant and susceptible, respectively. However, owing to the very small population of *M. persicae* during fall the varieties did not differ statistically during fall in Abbottabad and Mingora while in Malakandair both the varieties responded similar to spring. Using antibiosis test, the lowest percent survival rate of *M. persicae* was lowest on Kuroda and highest on Desiree potato varieties; minimum development time of *M. persicae* was on Desiree and maximum on Kuroda; maximum fecundity rate was of *M. persicae* fed on Desiree and minimum on Kuroda; highest r_m value for *M. persicae* was recorded on Desiree and lowest on Kuroda. All these reading further confirmed the Kuroda and Desiree as the most resistant and susceptible varieties, respectively (Alla *et al.*, 2003). A number of physical and chemical factors are linked with host plant resistance, which include the process of evolution, trichomes, olfactory/visual cues, hard leaf surface/plant tissues, mutation, transgenic event, glycoalkaloids, amino acid, N, P and K composition etc (Lapointe and Tingey, 1986; Sauge and Monet, 1998; Lee *et al.,* 1999; Fragoyiannis *et al.,* 2000; Karley *et al.,* 2003; Alla *et al.*, 2003; Saljoqi *et al.,* 2003; Wurst and Jones, 2003; Margaritopoulos *et al.,* 2005; Vargas *et al.,* 2005; Alvarez *et al.,* 2006). The existence of resistance to *M. persicae* with minimum or no adverse/detrimental effect on natural enemies, among the tested varieties, has opened the window for further investigation on these lines.

Mostly, the inputs required for raising quality crop are very costly that limit the proper management practices (PARC, 2009). The natural biological controls rarely suppress the pests (Natwick *et al*., 2002) and in such cases the usages of pesticides become important (Powell, 1980). In light of these facts it was realized to find ways that are sustainable and could limit the growers to minimum pesticides application in a season, whenever deemed necessary. As such two foliar (Provado 1.6F 'imidacloprid' and Actara 25WG 'thiamethoxam') and two soil routed insecticides (Admire 2F 'imidacloprid' and Platinum 2SC 'thiamethoxam)' at labeled and reduced doses were evaluated in separate experiments on Kuroda and Desiree. Provado and Actara are effective as contact and stomach poison that allows lower concentration than many traditionally used pesticides for *M. persicae* control (Pike *et al,* 1993; Kidd and James, 1994; Jenkins, 1994; Felsot, 2001; Syngenta, 2008a). Applications of Admire and Platinum applied over seed in-furrow before sealing in soil provide acceptable *M. persicae* management (Alan *et al*., 2003). The data revealed that both insecticides at labeled or reduced dose were better than control, and both formulations of imidacloprid were better than thiamethoxam (IRAG Resistance Alert, 2007).

The labeled dose, of each insecticide in the concerned experiments, were better than reduced dose in reducing *M. persicae* populations but at the same time were highly toxic to natural enemies (Saljoqi and van Emden, 2003b; Saljoqi and van Emden, 2003c). Similarly, each insecticide at each dosage in both experiments persistently suppressed the *M. persicae* till harvesting; although, in Admire and Platinum treatments *M. persicae* and natural enemies populations were at increase along the plant growth stages before it crashed at crop maturity; while in Provado and Actara treatments the population of both parameters started increasing on Day 18 of the post treatments. Important findings of these experiments were that Kuroda treated with reduced doses of insecticides had significantly lowest *M. persicae*, highest natural enemies and better yield than Desiree plants treated with labeled or reduced doses of the same insecticides. Another important finding was that the natural enemies including syrphidfly, parasitized *M. persicae* mummies by *Aphidius* and green lacewing populations on Kuroda treated with reduced doses of insecticides were even higher than the Desiree control plants. It may be explained that the increase in the percentage of parasitized *M. persicae* resulted from the intense feeding by the predators (Kindlmann and Ruzicka, 1992; Pineda *et al.,* 2007). The yield obtained from the potato plants treated with reduced dose of imidacloprid (Provado and Admire) in the concerned experiments was significantly higher than all other treatments. These results confirmed those of Saljoqi and van Emden (2003b) and Saljoqi and van Emden (2003c); although the insecticides used by them were of other group.

In the last experiment to widen the IPM package; Provado reduced dose, Admire reduced dose and yellow water pan traps (Yp-traps) treatments, alone (as single individual treatment) and in combination were compared on Kuroda and Desiree. The encouraging findings in this experiment were that yellow water pan traps treatments (without insecticides) significantly reduced *M. persicae* population as compared to control and were able to maintain the highest populations of natural enemies than all the treatments, on both varieties. The overall treatments comparison indicated that Kuroda treated jointly with reduced dose of Provado and yellow water pan traps significantly suppressed the *M. persicae* population than all other treatments, had highest tuber yield and had highest populations of natural enemies; except control plants and yellow water pan trap treatments. Interestingly, this treatment had significantly higher populations of natural enemies even than the Desiree control plants. These results were in conformity with those of Mowry and John (2002) whereby it was reported that reduced doses/sub-lethal concentrations of imidacloprid poisoned, intoxicate and inhibit *M. persicae* feeding that leads to reduction in spread of PLRV.

The crux of this endeavour has been that resistant variety Kuroda treated jointly with reduced dose of Provado and yellow water pan is the best IPM package against *M. persicae* and quite promising in conservations of natural enemies. However, some observations need to be reported. The detection of lady bird beetles, parasitized *M. persicae* mummies by *Aphidius*, syrphidfly, and green lacewings in all the three locations and especially in Abbottabad where they were numerous is very encouraging. Especial care for conservation of these natural enemies needs due importance to avoid their fatalities. Therefore, it is advisable that excessive and unnecessary use of insecticides should be avoided to save the natural enemies (Kassem *et al.,* 2005). Imidacloprid is not a magic bullet. Problem in generalizing compatibility lays in the variation among pest control situations. Directly spraying predators and parasitoids with imidacloprid could be risky (Lowery and Sears, 1986; James and Coyle, 2001). Long term continuous imidacloprid usage is risky for its detrimental effects on natural enemies and resistance development in *M. persicae* (Stapel *et al.,* 2000; Anstead *et al.,* 2005; Boughton *et al.,* 2006; Rogers *et al.,* 2007; Walker *et al.,* 2007; van Toor *et al.,* 2008).

It should be noted that application of yellow water pan traps or yellow sticky string/boards may not be acceptable to the poor farmers, as it requires extra care to avoid damage to the pans or to protect them from stealing by children/thieves; although these were locally made from the discarded oil packing tins. In such cases the yellow flowering herbs as trap crops may be grown around the fields/plots. The potato varieties grown as an intercrop, with onion or garlic plants, had lesser infestation of *M. persicae* compared to grown alone. The average yield of potato was significantly higher in intercropped plots compared to those which contained sole crop of potato (Mogahed, 2003; Saljoqi and van Emden, 2003c. Yellow water pan traps are also useful in scouting the appearance of winged *M. persicae* that needs immediate management due to threats of spreading viral diseases.

M. persicae infestations are mostly in patches at earlier stage of the crop and thus in timely measures can prevent greater damage in the later stages of the crop (Capinera, 2005). In areas where spread of viral diseases due to *M. persicae* are common and early colonization from over-wintering host is likely; Admire application at reduced dose would be judicious to rogue early and top killing as aphid flights begin. This may eliminates the need for further control measures as of its persistency up to 80 days (Palumbo and Kerns, 1994; Edward, 2008; Powell, 1980). Moreover, once Admire at reduced dose is applied then further application of imidacloprid either as foliar or soil treatments are not allowed due to risk of resistant development in *M. persicae* (Florida, 1999); however pesticides of other groups may be applied when found necessary. For example, imidacloprid seed treatment followed by a foliar application of λ-cyhalothrin or pymetrozine at 10 apterous aphids per 150 potato leaves is sufficient to maintain aphid populations below the action threshold, without compromising yields or increasing virus risk in tubers (van Toor *et al.,* 2008). According to Mowry (2001) imidacloprid applied at planting reduce the number of methamidophos applications from nine to five at-detection treatments.

The indigenous technologies are presently under stress due to complex changes in agro-climatic and agro-environmental conditions. The *M. persicae* adopted themselves to these change through process of co-evolutions and mutation. For example, the varieties with endogenous resistance to *M. persicae* become susceptible with the passage of time as of adoption to plant defenses through evasion and/or detoxification (Gatehouse, 2002; Li *et al.*, 2002). Potato varieties that are tolerant to pests are sometimes not commercially acceptable as pest management alternative, primarily because of yield deficiencies (Florida, 1996). Availability of proper variety and certified virus/pest free seeds is another common factor (PARC, 2009).

Research, findings and recommendations become useless unless they are in-depth pickable, affordable, implementable, socially acceptable and sustainable. Most of the land/potato crop in Pakistan is cultivated by tenants. Unluckily, the tenants are mostly illiterate. The high illiteracy rate among the farmers community is always a hurdle in getting in-depth knowledge and in return judicious execution of the technologies. The producers depends on the prescription of the pesticides retailers. The application or utilization of the pesticides is always shouldered by the farmers on the advice of the retailer who are themselves not certified for this job. As such the proper applications of pesticides at proper dosage are hardly met. The application of imidacloprid at reduced dose by 20% of the labeled dose is the other challenging issue. In such circumstances the most important thing to be kept in mind is that seed treatments with imidacloprid and over dosage as foliar spray may have some phytotoxic effects unless only high quality seed are used. The role of varieties/crop may not be ignored too (Kuhar *et al.,* 2002). Moreover, exposure to lower doses/sub-lethal concentrations of imidacloprid could stimulate reproduction in *M. persicae* (Cutler *et al.,* 2008).

FUTURE CHALLENGES

1) Further studies are needed to study the nature of resistance thus imparted by the potato varieties.
2) The *Aphidius species* need to be identified so that the species more effective ones could be further studied on different angles for biological control of *M. persicae* in potato crop.
3) The predators {coccinellids (ladybird beetle)}, {Syrphidae (syrphidfly)}, {*Chrysoperla spp* (green lacewing)} found active in the research study need to be identified up to specie levels so that the specie more effective could be sorted out and studied further on different angles for biological control of *M. persicae* in potato crop.
4) The various management tools studied in this research study needs to be measured for their detrimental impact on *M. persicae* and its natural enemies up to few generation levels.
5) The acceptability, applicability and sustainability of the findings/recommendations of this research study needs to be assessed in joint collaboration with extension workers/departments.
6) Feed back from the farmer community about the hurdles in launching the new technologies is required and would enable us to design experiments as per their approach, vision and ground realities.

SUMMARY

A series of research experiments were conducted in potato crop during 2007-09 to develop an IPM package for the *M. persicae* with minimum adverse/detrimental effect on its associated natural enemies and get maximum tuber yield. The natural enemies included the ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, percent parasitism of *M. persicae* by the *Aphidius* (PPA*A*), percent emergence rates of the *Aphidius* from parasitized *M. persicae* mummies (PER*A*) and fecundity rates of the *Aphidius* (FR*A*).

Initially, impact of three different agro-climatic locations/zones (viz Malakandair, Abbottabad and Mingora), seasons (spring and fall) and nine potato varieties (viz Cardinal, Desiree, Diamant, Kuroda, Santee, Ultimus, Ajax, Raja and Mullta) were compared for the abundance of *M. persicae* population per nine compound leaves; and the ladybird beetle, syrphidfly, green lacewing, parasitized mummies per ten plants (irrespective of varieties). Antibiosis test on the same varieties was conducted during spring at Malakandair. Later, two foliar insecticides [Provado 1.6F (imidacloprid) and Actara 25WG (thiamethoxam] and two soil routed insecticides [Admire 2F (imidacloprid) and Platinum 2SC (thiamethoxam)] in different experiments were tested at labeled and reduced doses (labeled dose reduced by 20%) on resistant Kuroda and susceptible Desiree varieties for their impact on *M. persicae* and the corresponding natural enemies. Lastly, yellow water pan trap (Yp-trap) and two insecticides (foliar and soil routed) at reduced doses, as individual treatments and in combinations, were compared on Kuroda and Desiree for the same parameters.

The populations of *M. persicae* and the natural enemies varied along locations and seasons as per difference in climatology and agro-ecological conditions. In each location, *M. persicae* population during spring was significantly higher than fall. During spring, the *M. persicae* population was highest at Mingora (14.1) and lowest at Malakandair (12.6). During fall, it was highest at Malakandair (2.5) and statistically equal at Mingora (2.2) and Abbottabad (2.1). During spring, the ladybird beetle population was highest at Abbottabad (5.40), lowest at Malakandair (4.43) and statistically equal to both locations at Mingora (5.17). During fall, its population was highest (4.23) at Malakandair statistically equal at Abbottabad (2.67) and Mingora (2.05). Population of parasitized *Myzus* mummies during spring/fall at Abbottabad (33.5/10.3) and Mingora (31.7/10.5) was statistically equal but higher than Malakandair (26.5/7.8). Averaged over seasons, syrphidfly population was maximum at Abbottabad (5.9) and minimum at Malakandair (3.6). Population of green

lacewing at Abbottabad (4.7) was higher than Malakandair (3.8), and at Mingora (4.3) it was statistically equal to both the locations. Parasitized mummies during spring/fall were statistically equal at Abbottabad (33.5/10.3) and Mingora (31.7/10.5) but higher than Malakandair (26.5/7.8). At each location during spring and fall the *M. persicae* population was at significant ascending level till Day 60 and 30, respectively, of the seeds germination and thereafter started decreasing up to crop maturity. Population trend of natural enemies along the plant growth stages was nearly similar to *M. persicae*, during both seasons.

In all the three locations during spring, Desiree and Kuroda were the most susceptible and resistant varieties, respectively, to *M. persicae* population buildup with 48.5% difference. During fall, at Abbottabad and Mingora the varieties did not differ statistically for relative resistance to *M. persicae* while at Malakandair the results were similar to spring. Antibiosis test further confirmed the results wherein the percent survival rate, fecundity in ten days, intrinsic rate of multiplication (r_m) for *M. persicae* were highest (99.0%, 44.3, and 0.55, respectively) on Desiree as compared to lowest on Kuroda (61.1%, 27.3 and 0.24, respectively). Development time of *M. persicae* was minimum (5.1 days) on Desiree and maximum (10.4 days) on Kuroda.

In foliar experiment; considering the population difference as a parameter, Provado was more toxic than Actara to *M. persicae* by 7.1%. Provado labeled dose was more toxic than reduced dose by 4.7% while this difference for Actara was 5.5%. Provado reduced dose was significantly more toxic (by 2%) than the labeled dose of Actara. Both the insecticides reduced the *M. persicae* population till Day 10 of the post treatments and thereafter it started building up; however, the populations remained quite lower than control even on the last day of data i.e. Day 18. Averaged over varieties, Provado reduced dose was significantly less toxic than Actara reduced dose, Provado and Actara labeled doses to ladybird beetle by 30.1, 37.7 and 45.9%, respectively; syrphidfly by 15.6, 17.8 and 28.3%, respectively; green lacewing by 16.7, 15.2, and 29.0 %, respectively; parasitized *Myzus* mummies by 11.4, 10.5, and 16.3%, respectively; PPA*A* by 15.5, 30.6 and 39.6%, respectively; PER*A* by 23.0, 64.6 and 72.0%, respectively; and FR*A* by 28.8, 34.1 and 45.0%, respectively. Whereby, Provado labeled dose and both the doses of Actara were statistically equal in toxicity to ladybird beetle. Similarly Provado labeled dose and Actara reduced dose were equal in toxicity to syrphidfly, green lacewing and parasitized mummies.

Taking into account all the experiments; the mean populations of *M. persicae* on Kuroda control plants were lesser than Desiree by 49.9-45.8% while the ladybird beetle, syrphidfly, green lacewing, parasitized *Myzus* mummies, PPA*A*, PER*A* and FR*A* were higher 13-4.4, 61.6-35.4, 32.1-19.8, 46.9-39.6, 54.1-17.8, 9.0-4.3 and 27.9-13.2%, respectively. Excluding the existed difference between varieties (without insecticides); the insecticides (averaged) were more toxic (0.5%) to *M. persicae* on Kuroda than Desiree. Labeled doses were more toxic to *M. persicae* than reduced doses; on Kuroda by 5.7% and on Desiree by 4.8%. Kuroda treated with reduced doses was significantly more toxic than the Desiree treated with labeled doses. Similarly the insecticides (averaged), on Kuroda as compared to Desiree, reduced the corresponding natural enemies lesser by 4.9, -0.4, 10.6, 12.6, 1.0, 5.8 and 0.0%, respectively. On Kuroda, the difference in toxicity (population reduction) between labeled and reduced doses to the corresponding natural enemies was 27.8, 7.1, 16.5, 14.2, 26.4, 58.7 and 17.5 %, respectively; while on Desiree it was 25.7, 8.6, 13.3, 13.2, 28.6, 54.9, and 18.5 %, respectively. Kuroda treated with reduced doses was the least toxic to the natural enemies. Kuroda and Desiree treated with labeled and reduced doses, respectively, were nearly equal while Desiree treated with labeled doses was the most toxic to all the corresponding natural enemies. Tuber's yield (tons/ha) obtained from plants treated with Provado reduced dose (14.07) and labeled dose (13.95) was significantly higher than Actara reduced dose (12.81) and labeled dose (12.79); however, labeled dose and reduced dose of each insecticide did not differ in respect of potato yield. Lowest yield was obtained from control plants (10.34-10.58). Averaged over all treatments including control; Kuroda (13.2) delivered significantly higher yield than Desiree (11.6).

In the soil routed insecticides experiment; considering the population difference as parameter, Admire was more toxic to *M. persicae* than Platinum by 4.8% and lesser toxic to ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A* by 17.2, 15.6, 20.0, 18.2, 6.4, 11.3 and 2.6%, respectively. Labeled dose of each insecticide was more toxic than its reduced dose with a toxicity difference for Admire on the corresponding parameters as 4.7, 32.7, 35.8, 32.8, 33.2, 38.0, 46.7 and 24.0%, respectively; while for Platinum it was observed to be 4.6, 13.7, 18.3, 16.5, 19.5, 38.9, 44.2 and 24.8%, respectively. Statistically Admire reduced dose was the least toxic and Platinum labeled dose was the most toxic to all the natural enemies; except FRA for which this interaction was not significant. Reference to the persistency of Soil routed insecticides, *M. persicae* population was at ascending magnitude from Day 27 of the seeds germination till the last day of data collection i.e. Day 55; however, the treated plants had consistently quite lower populations as compared to control. The difference between labeled and reduced doses was significant only on Day 34 and 55.

Excluding the population difference between control plants; the Kuroda as compared to Desiree (in response to insecticides treatments) reduced the *M. persicae*, ladybird beetle, syrphidfly, green lacewing, parasitized *M. persicae* mummies, PPA*A*, PER*A* and FR*A* by lesser margin of 7.3, 9.3, 26.5, 29.0, 3.3, -3.8, 5.8, and -11.6%, respectively. The difference between labeled and reduced doses on Kuroda/Desiree for reduction in the population of the corresponding parameters was 8.6/2.6, 29.4/22.6, 29.6/23.3, 28.1/19.8, 24.9/21.3, 36.2/41.0, 58.7/50.9 and 19.8/30.4 %, respectively. As per significant interactions, *M. persicae* population was significantly lowest on Kuroda treated with labeled doses followed by Kuroda treated with reduced doses. Highest population was recorded on Desiree control. Highest population of ladybird beetle, next to Kuroda and Desiree control, was on Kuroda plants treated with reduced dose of Admire as compared to lowest on Desiree treated with Platinum reduced dose. Population of syrphidfly and green lacewing were highest on Kuroda control and Admire reduced dose treatments (both being equal statistically) as compared to lowest on Desiree plants treated with labeled dose of Platinum or Admire (both statistically different for lacewing but equal for syrphidfly). Highest population of parasitized *Myzus* mummies, next to Kuroda control, was recorded on Kuroda treated with reduced doses as compared to lowest on Desiree treated with labeled doses. PPA*A* was highest on Kuroda and Desiree control, intermediate on Kuroda and Desiree treated with reduced doses, and lowest on Kuroda and Desiree treated with labeled doses (each pair being statistically equal). For PER*A* this interaction was not significant. The highest FR*A* was recorded on Kuroda control and lowest on Desiree treated with labeled doses of insecticides. Tuber's yield (tons/ha) obtained from plants treated with Admire labeled dose (12.86) and reduced dose (12.80) doses was significantly higher than Platinum reduced dose (12.14) and labeled dose (12.05); however, labeled and reduced doses of each insecticide did not differ in respect tuber's yield. Averaged over all treatment including control; Kuroda (12.4) delivered significantly higher yield than Desiree (11.2).

In the last experiment, as per significant interactions, *M. persicae* population was lowest (87.4%) on Kuroda treated with Provado reduced dose +Yp-trap as compared to highest on Desiree control. Kuroda control was less by 49.9% in *M. persicae* population. Ladybird beetle population was highest on Yp-trap and control (being statistically equal with 4.1% difference) followed by Provado reduced dose (with or without Yp-traps, both being equal) with 15.1% difference. Admire reduced dose + Yp-trap treatment was lowest by 35.2% in respect of ladybird beetle population. Syrphidfly and green lacewing populations were highest on Yp-trap, control and Provado reduced dose + Yp-traps (being statistically equal) as compared to the lowest (27.6%) on Admire reduced dose + Yp-traps treatment. The population of parasitized *Myzus* mummies was highest on Kuroda Yp and Kuroda control treatments (both being statistically equal with 1.2% difference) as compared to the lowest (52.0%) on Desiree treated with Admire reduced dose. Kuroda treated with Provado reduced dose with and without Yp-traps (being statistically equal) came out second in the peak parasitized *Myzus* mummies by 23.4 and 20.7% difference, respectively.

PPA*A* was highest on Kuroda treated with Yp-trap and lowest on Desiree treated with Admire reduced dose with a difference of 67.1%. Kuroda treated with Provado reduced dose + Yp-trap and Kuroda control (being statistically equal) with 5.8 and 8.8% difference, respectively, were found next to the highest PPA*A*. PER*A* was highest on Kuroda control and lowest on Desiree treated with Admire reduced dose + Yp-trap with a difference of 42.3%. Peak PER*A* was followed by Kuroda Yp-trap treatment with 1.2% difference. Kuroda treated with Provado reduced dose + Yp and Provado reduced dose were next to follow the peak PER*A* with 15.7 and 17.3% difference, respectively. FR*A* on Kuroda control was highest and followed by Kuroda Yp-trap treatment with 0.8% difference (both being statistically equal). Desiree plants treated with Admire reduced dose with and without Yp-trap (being statistically equal) were lowest in FR*A* by 39.7 and 41.5% difference with Kuroda control, respectively. Kuroda treated with Provado reduced dose with and without Yp-traps (being statistically equal) seconded the Kuroda control statistically in relation to FR*A* with 17.3 and 15.7% difference. Highest yield was obtained from Kuroda treated jointly with Provado reduced dose and Yp-trap that was higher than Kuroda treated with Provado reduced dose by 6.9%, Kuroda control by 25.5% and the Desire control (being the lowest in yield) by 38.0%, respectively.

These findings indicated that resistant potato variety ‘Kuroda’ in combination with yellow water pan traps and Provado 1.6F reduced dose was the better IPM package to manage *M. persicae* with minimum adverse/detrimental effects on its natural enemies and getting maximum tuber’s yield.

LITERATURE CITED

Abdalla, M.M.A., M.A.K. Nasser, S.A. Eraky, G. Kuroli, L. Nemeth and K. Pocsai 1995. "Insecticide treatments in relation to the sucking pest populations and yield of some potato cultivars; Influence of primary metabolic products of the food plant on the individual number of aphids; Effect of primary metabolites on the number of aphids." Assiut J. Agric. Sci. 26(1): 233-244.

Adkisson, P and R.F. Smith. 2007. Integrated pest management. Integrated crop and pest management guidelines for commercial vegetable production. pp: 11-15. http://www.nysaes.cornell.edu/hp/2007vegetableguide/2007veg03.pdf.

Agrawal, A.A. 2007. Macroevolution of plant defense strategies. Tren. Ecol. Evol. 22:103–109.

Agarwala, B.K., K. Das and P. Raychoudhury. 2009. Morphological, ecological and biological variations in the mustard aphid, *Lipaphis pseudobrassicae* (Kaltenbach) (Hemiptera: Aphididae) from different host plants. J. Asia-Pacific Entomol. 12(3): 169-173.

Ahmed, N. E., H.O. Kanan, S. Inanaga., Y.Q. Ma and Y. Sugimoto. 2001. Impact of pesticide seed treatments on aphid control and yield of wheat in the Sudan. Crop Protec. 20(10):929-934.

Alan, S., G. Reed, K. Pike and B. Stoltz. 2003. Integrated pest management program for insects in Pacific Northwest potatoes. Agriculture Development Group, Inc. Green peach aphid-potato leaf roll virus control for Pacific Northwest Potatoes.htm.

Alla, S., A. Cherqui, L. Kaiser, H. Azzouz, S.B. Sangwann-Norreel and P. Giordanengo. 2003. Effects of potato plants expressing the nptII-gus fusion marker genes on reproduction, longevity, and host-finding of the peach-potato aphid, *Myzus persicae*. Entomol. Exp. et Appl. 106(2): 95-102

Alvarez, A. E., W. F. Tjallingii, E. Garzo, V. Vleeshouwers, M. Dicke and B. Vosman. 2006. Location of resistance factors in the leaves of potato and wild tuber-bearing *Solanum* species to the aphid *Myzus persicae*. Entomol. Exp. et Appl. 121 (2): 145–157.

Ambrosino, M.D. 2006. Enhancing the predatory potential of hoverflies on aphids in Oregon broccoli fields with floral resources. PhD Thesis.

Anstead, J.A., M.S. Williamson and I. Denholm. 2005. Evidence for multiple origins of identical insecticide resistance mutations in the aphid *Myzus persicae.* J. Insect Bioche. and Mol. Biol. 35(3): 249-256.

Avinent, L., A. Hermoso de Mendoza and G. Llacer. 1991. Comparison of traps for capture of alate aphids (Homoptera, aphidinea) in apricpot tree orchards. Agronomie. 11: 613-618.

Balduf, V.W. 1939. The Bionomics of Entomophagus Insects, reprinted 1974, E.W. Classey, New York.

Bale, J.S., G.J. Masters, I.D. Hodkinson, C. Awmack, T.M. Bezemer, V.K. Brown, J. Butterfield, A. Buse, J.C. Coulson, J. Farrar, J.E.G. Good, R. Harrington, S. Hartley, T.H. Jones, R.L. Lindroth, M.C. Press, I. Symrnioudis, A.D. Watt and J.B. Whittaker. 2002. Herbivory in global climate change: direct effects of rising temperature on insect herbivores. Global Change Biol. 8: 1–16.

Bates, S.L., J. Zhao, R.T. Roush and A.M. Shelton. 2005. Insect resistance management in GM crops: past, present and future. Nat. Biotechnol. 23: 57–62.

Bayer Crop Science. 2008. Application tips, rates and packaging for Admire 2F (Imidacloprid). © 2008 Bayer CropScience Canada. www.admire.htm.

Bernal, J.S. 2008. Genetically modified crops and biological control with egg parasitoids. In: F. Consoli and J.R. Parra, Editors. Egg Parasitoids in Agroecosystems with Emphasis on *Trichogramma*, Elsevier BV, Amsterdam, The Netherlands.

Bezemer, T. M., T. H. Jones, and K.J. Knight. 1998. Long-term effects of elevated CO2 and temperature on populations of the peach potato aphid *Myzus persicae* and its parasitoid *Aphidius matricariae*. Oecologia. 116(1-2): 128-135.

Bhadauria, N.S., N.K.S. Bhadauria and S.S. Jakhmola 1998. Seasonal incidence of potato aphid, *Myzus persicae* (Sulz.). In north-west Madhya Pradesh. Adv. Pl. Sci. 11(2): 59-61.

Birch, L.C. 1948. The intrinsic rate of natural increase of an insect population. J. Anim. Ecol. 17: 15-26.

Blackman, R.L. and V.F. Eastop. 1984. Aphids on the World's Crops: An Identification and Information Guide. John Wiley and Sons, Chichester, England. p 466.

Blackman, R.L and V.F. Eastop. 2000. Aphids on the World's Crops: An Identification Guide, 2nd edn. Wiley-Interscience.

Boiteau, G. 1986. Diurnal flight periodicities and temperature thresholds for three potato-colonizing aphids (Homoptera: Aphididae) in New Brunswick. Ann. Entomol. Soc. Amer. 79(6): 989-993.

Boiteau, G. 1990. Effect of trap color and size on relative efficiency of water-pan traps for sampling alate aphids (Homoptera: Aphididae) on potato. J. Econ. Entomol. 83: 937-942.

Boiteau, G., R.M. Duchesne and D.N. Ferro. 1995. Use and significance of traditional and alternative insect control technologies for potato protection in a sustainable approach. Proceedings of a Symposium, Quebec City, Canada. pp. 169-188.

Boiteau, G., and W.P.L. Osborn 1997. Behavioral effects of imidacloprid, a new nicotinyl insecticide, on the potato aphid, *Macrosiphum Euphorbiae* (Thomas) (Homoptera: Aphididae). Can. Entomol. 129: 241–249.

Boughton, A. J., K. Hoover and G.W. Felton. 2006. Impact of chemical elicitor applications on greenhouse tomato plants and population growth of the green peach aphid, *Myzus persicae*. Entomol. Exp. et Appl. 120 (3): 175–188.

Brodeur, J. and J.N. McNeil. 1989. Biotic and abiotic factors involved in diapause induction of the parasitoid, *Aphidius nigripes* (Hymenoptera: Aphidiidae). J. Insect Physiol. 35(12): 969-974.

Brunissen, L., S. Dugravot, A. Cherqui, C. Vincent and P. Giordanengo. 2006. Effects of a first conspecific or heterospecific infestation of *Solanum tuberosum* on subsequent feeding behavior of *Myzus persicae* and *Macrosiphum euphorbiae* (Hemiptera: Aphididae). The ESA Annual Meeting and Exhibition.

Byrne, F.J. and N.C. Toscano. 2007. Lethal toxicity of systemic residues of imidacloprid against *Homalodisca vitripennis* (Homoptera: Cicadellidae) eggs and its parasitoid *Gonatocerus ashmeadi* (Hymenoptera: Mymaridae). Biological Control. 43(1): 130-135.

Cabral, S., A.O. Soares, R. Moura and P. Garcia. 2006. Suitability of *Aphis fabae*, *Myzus persicae* (Homoptera: Aphididae) and *Aleyrodes proletella* (Homoptera: Aleyrodidae) as prey for *Coccinella undecimpunctata* (Coleoptera: Coccinellidae). J. Biol. Cont. 39(3): 434-440.

Candolfi, M.P., F. Bakker, V. Cañez, M. Miles, C. Neumann, E. Pilling, M. Primiani, K. Romijn, R. Schmuck, S. Storck-Weyhermüller, A. Ufer and A. Waltersdorfer. 1999. Sensitivity of non-target arthropods to plant protection products: Could *Typhlodromus pyri* and *Aphidius* spp. be used as indicator species? J. Chemosphere. 39(8): 1357-1370.

Capinera, J.L. 2001. Handbook of Vegetable Pests. Academic Press, San Diego. pp: 729.

Capinera, J. L. 2005. Featured Creatures. Department of Entomology and Nematology Division of Plant Industry. Electronic Data Information Source. University of Florida. Publication No. EENY-222.

Christiansen-Weniger P. and J. Hardie. 1999. Environmental and physiological factors for diapause induction and termination in the aphid parasitoid, *Aphidius ervi* (Hymenoptera: Aphidiidae). J. Insect Physiol. 45(4): 357-364.

Ciglari, I., B. Baric, P. Cravedi, C. Hartfield, and E. Mazzoni. 1997. Problems related to the control of the peach-potato aphid, *Myzus persicae* Sulz. (Hemiptera: Aphididae) in Croatia. Integrated plant protection in stone fruit. Proceedings of the meeting at Zaragoza, Spain, 24-26 September 1996. Bulletin OILB SROP. 20(6): 71-74.

Cloutier, C., C. Jean, F. Baudin, and U. Laval. 1995. More biological control for a sustainable potato pest management strategy. Proceedings of a Sympo. Quebec City, Canada. pp: 15-52.

Cocu, N., R. Harrington, M.D.A. Rounsevell, S.P. Worner and M. Hullé. 2005. Geographical location, climate and land use influences on the phenology and numbers of the aphid, *Myzus persicae*, in Europe. J. Biogeogr. 32 (4): 615–632.

Coderre, D.L. and J.C. Tourneur. 1986. Synchronization and voracity of aphidophagous insects on maize in Quebec, Canada. In: I. Hodek, Editor, Ecology of Aphidophaga, Dr. W. Junk Publishers, Dordrecht, The Netherlands. pp. 363–368.

Coll, M. and M. Guershon. 2002. Omnivory in terrestrial arthropods: mixing plant and prey diets. Ann. Rev. Entomol. 47: 267–297.

Cortesero, A.M., J.O. Stapel, and W.J. Lewis. 2000. Understanding and manipulating plant attributes to enhance biological control. J. Biol. Cont. 17: 35–49.

Costamagna, A.C. and D.A. Landis. 2007. Quantifying predation on soybean aphid through direct field observations. J. Biol. Cont. 42(1): 16-24.

Cottrell, T.E. 2004. Suitability of exotic and native lady beetle eggs (Coleoptera: Coccinellidae) for development of lady beetle larvae. J. Biological control. 31(3): 362-371.

Cottrell, T.E. 2005. Predation and cannibalism of lady beetle eggs by adult lady beetles. J. Biol. Cont. 34(2): 159-164.

Cottrell, T.E. and K.V. Yeargan. 1998a. Influence of a native weed, *Acalypha ostryaefolia* (Euphobiaceae), on *Coleomegilla maculata* (Coleoptera: Coccinellidae) population density, predation, and cannabalism in sweet corn. Environ. Entomol. 27: 1375–1385.

Cottrell, T.E. and K.V. Yeargan. 1998b. Effect of pollen on *Coleomegilla maculata* (Coleoptera: Coccinellidae) population density, predation, and cannabalism in sweet corn. Environ. Entomol. 27: 1402–1410.

Couty, A., R.E. Down, A.M.R. Gatehouse, L. Kaiser, M-H Pham-Delègue and G.M. Poppy. 2001. Effects of artificial diet containing GNA and GNA-expressing potatoes on the development of the aphid parasitoid *Aphidius ervi* Haliday (Hymenoptera: Aphidiidae) J. Insect Physiol. 47 (12): 1357-1366.

County, M. 2007. Newsletter contents. Potato and Onion. Oregon State University Extension Service. 710 SW 5th Avenue, Ontario, OR 97914. http://extension.oregonstate.edu/malheur/Agriculture/Newsletters/P-O_June%2025.pdf.

Cowgill, S.E., C. Danks and H.J. Atkinson. 2004. Multitrophic interactions involving genetically modified potatoes, nontarget aphids, natural enemies and hyper-parasitoids. Molec. Ecol. 13: 647- 639

Criniti, A., E. Mazzoni, S. Cassanelli, P. Cravedi, A. Tondelli, D. Bizzaro, and G.C. Manicardi. 2008. Biochemical and molecular diagnosis of insecticide resistance conferred by esterase, MACE, *kdr* and super-*kdr* based mechanisms in Italian strains of the peach potato aphid, *Myzus persicae* (Sulzer). Pest. Biochem. & Physiol. 90(3): 168-174.

Cutler, G.C., K. Ramanaidu, T. Astatkie, and M.B. Isman. 2008. Green peach aphid, *Myzus persicae* (Hemiptera: Aphididae), reproduction during exposure to sublethal concentrations of imidacloprid and azadirachtin. Pest Manag. Sci. 65(2): 205-209.

Davidson, M.M., R.C. Butler, S.D. Wratten and A.J. Conner, 2006. Impacts of insect-resistant transgenic potatoes on the survival and fecundity of a parasitoid and an insect predator. J. Biol. Cont. 37(2): 224-230.

Dent, D. 2000. Insect Pest Management, CAB International, Wallingford. p 111.

Desneux, N., H. Rafalimanana, and L. Kaiser. 2004. Dose–response relationship in lethal and behavioural effects of different insecticides on the parasitic wasp *Aphidius ervi*. J. Chemosphere. 54(5): 619-627.

Desneux, N., R. Denoyelle and L. Kaiser. 2006. A multi-step bioassay to assess the effect of the deltamethrin on the parasitic wasp *Aphidius ervi*. J. Chemosphere. 65(10): 1697-1701.

Dewar, A.M. 1977. Assessment of methods for testing varietal resistance to aphids in cereals. Ann. Appl. Biol. 87: 183-190.

Diaz, F.J. and P. Mcleod. 2005. Movement, toxicity, and persistence of imidacloprid in seedling tabasco pepper infested with *Myzus persicae* (Hemiptera: Aphididae). J. Econ. Entomol. 98(6): 2095-2099.

DiFonzo, C. D., D.W. Ragsdale, E.B Radeliffe, N.C. Gudmestad and G.A. Secor. 1997. Seasonal abundance of aphid vectors of potato virus Y in the Red River Valley of Minnesota and North Dakota. J. Econ. Entomol. 90: 824-831.

Dixon, A.F.G. 2000. Insect predator-prey dynamics: Ladybird beetles and biological control. Cambridge University Press.

Drinkwater, T.W. 2003. Bioassays to compare the systemic activity of three neonicotinoids for control of *Heteronychus arator* Fabricius (Coleoptera: Scarabaeidae) in maize. Crop Protec. 22(7): 989-993.

Duffey, S.S. and M.J. Stout. 1996. Antinutritive and toxic components of plant defense against insects. Arch Insect Biochem. Physiol. 32: 3–37.

Dufour, R. 2003. Research and IPM, phenology model database, green peach aphid. Statewide IPM program, agriculture and natural resources, university of California. Phenology/ma-green_peach_aphid.html

Edward P. 2008. The official website of the Government of Prince Edward Island, Canada. Agriculture green peach aphid.htm. Home / Agriculture / Horticulture / Potatoes / Pests / Atlantic Candada Potato Guide Pests /

Eigenbrode, S.D. and J.T. Trumble. 1994. Plant resistance to insects in integrated pest management in vegetables. J. Agric. Entomol. 11: 201-224.

Elliott, N.C., R.W. Kieckhefer, J.H. Lee and B.W. French. 1998. Influence of within-field and landscape factors on aphid predator populations in wheat. Landsc. Ecol. 14: 239–252.

Elzen, G.W., P.J. O'Brien and J.E. Powell. 1989. Toxic and behavioral effects of selected insecticides on *Heliothis* parasitoid *Microplitis croceipes*. J. Biocont. 34(1): 87-94.

Elzen, G.W. 2001. Lethal and sublethal effects of insecticide residues on *Orius insidiosus* (Hemiptera: Anthocoridae) and *Geocoris punctipes* (Hemiptera: Lygaeidae). J. Econ. Entomol. 94: 55–59.

Felsot, A. 2001. Admiring risk reduction. does imidacloprid have what it takes? Agrochem. & Environ. News. 186: 1-7.

Ferry, N., M.G. Edwards, J. Gatehouse, T. Capell, P. Christou and A.M.R. Gatehouse. 2006. Transgenic plants for insect pest control. A forward looking scientific perspective. Transgenic Res. 15: 13–19.

ffrench-Constant, R.H., R. Harrington and A.L. Devonshire. 1998. Effect of repeated applications of insecticides to potatoes on numbers of Myzus persicae (Sulzer) (Hemiptera: Aphididae) and on frequencies of insecticide-resistant variants. Crop Protec. 7:55-61.

Fleming, R.A. and G.M. Tatchell. 1995. Shifts in the flight periods of British aphids: a response to climate warning? Insects in a changing environment. pp: 505–508.

Florida. 1996. Crop profile for potatoes in Florida. General production information. Insect Management Guide. UF/IFAS guide SP-51.

Florida. 1999. Crop profile for potatoes in Florida. Crop profiles.htm. NSF Center for IPM.

Follas, G. and S. Bland. 1994. Control of aphids in tomatoes and brassicas with pymetrozine. Proc. 47th N.Z. Plant Protec. Conf. pp: 125–127.

Fragoyiannis, D.A., R.G. McKinlay and D.M. JPF. 2000. "Effects of different nitrogen sources and aphid herbivory on foliar glycoalkaloid production in two potato cultivars." The BCPC Conference: Pests and Dis.: pp. 3.????????

Fragoyiannis, D.A., R.G. McKinlay and D.M. JPF. 2001. Interactions of aphid herbivory and nitrogen availability on the total foliar glycoalkaloid content of potato plants. J. Chem. Ecol. 27(9): 1749-1762.

Fréchette, B., D. Coderre and E. Lucas. 2006. *Chrysoperla rufilabris* (Neuroptera: Chrysopidae) females do not avoid ovipositing in the presence of conspecific eggs. J. Biol. Cont. 37(3): 354-358.

Galvan, T.L., R.L. Koch and W.D. Hutchison. 2005. Effects of spinosad and indoxacarb on survival, development, and reproduction of the multicolored Asian lady beetle (Coleoptera: Coccinellidae). J. Biol. Cont. 34(1): 108-114.

Gatehouse, J.A. 2002. Plant resistance towards insect herbivores: a dynamic interaction. New Phytol. 156: 145–169

Gautam, R.D. and Tesfaye A. 2002. Potential of the green lacewing *Chrysoperla carnea* (Stephens) in crop pest management. New Agriculturist 13(1/2): 147–158.

Girling, R. D. and M. Hassall. 2008. Behavioural responses of the seven-spot ladybird *Coccinella septempunctata* to plant headspace chemicals collected from four crop Brassicas and *Arabidopsis thaliana*, infested with *Myzus persicae*. Agric. and Forest Entomol. 10(4): 297-306.

Glogoza, H. 2005. Field crop insect management recommendations. Department of Entomology, North Dakota State University.

Godfrey, L. D. and D.R. Haviland. 2003. UC IPM Pest Management Guidelines: Potato. UC ANR Publication 3463.

Goundoudaki, S. Tsitsipis, A. John and J.T. Margaritopoulos. 2003. Performance of the tobacco aphid *Myzus persicae* (Hemiptera: Aphididae) on Oriental and Virginia tobacco varieties. Agric. and Forest Entomol. 5 (4): 285–291.

Halbert, S. E., G. Zhang, and Z. Pu. 1986. Comparison of sampling methods for alate aphids and observations on epidemiology of soybean mosaic virus in Nanjing, China. Ann. Appl. Biol. 109: 473-483.

Hamm, P. B. 2001. Progress Report 2000 – 2001 Agriculture Research Foundation Oregon Potato Commission on Project 'Monitoring Aphid Populations in Umatilla, Morrow, Baker, and Union Counties'. http://oregonstate.edu/potatoes/reports/2001/page004.pdf.

Hannan, A.K.M., M. Ahmad, and M.A. Taleb. 1999. Influence of different foods on the biology of Micraspis discolor (Fabricius) (Coleoptera: Coccinelidae). Bangladesh. J. Entomol. 8(1-2): 69-80.

Hapter, C. 2007. Insect Management. Integrated pest management of green peach aphid. Cornell University, USA. pp: 11-15. http://www.nysaes.cornell.edu/hp/2007vegetableguide/2007veg03.pdf.

Harrington, R. 2008. Aphids are sentinels of climate change. Science Centric | 7 August 2008 13:26 GMT. Science Centric-Science, health and technology, breaking news. pp: 2011-2015.

Harrington, R., E. Bartlet, D.K. Riley, R.H. ffrench-Constant, and S.J. Clark, 1989. Resurgence of insecticide-resistant *Myzus persicae* on potatoes treated repeatedly with cypermethrin and mineral oil. J. Crop Protec. 8(5): 340-348.

Harrington, R., J.S. Bale and G.M. Tatchell. 1995. Aphids in a changing climate. Insects in a changing environment. pp: 125–155.

Heil, M. 2008. Indirect defence via tritrophic interactions. New Phytol. 178: 41–61.

Heuvel, J.V.D., S.A. Hogenhout, M. Verbeek and F. Wilk. 1998. Azadirachta indica metabolites interfere with the host-endosymbiont relationship and inhibit the transmission of potato leaf roll virus by *M. persicae*. Entomol. Exp. Appl.. 86(3): 253

Hindayana, D., R. Meyhöfer, D. Scholz, and H. Poehling. 2001. Intraguild predation among the hoverfly *Episyrphus balteatus* de Geer (Diptera: Syrphidae) and other aphidophagous predators. J. Biol. Cont. 20(3): 236-246.

Hodek, I. and A. Honek. 1996. Ecology of Coccinellidae. Kluwer Acad. Publishers, Boston.

Horn, D.J. 1989. Secondary parasitism and population dynamics of aphid parasitoids (Hymenoptera: Aphidiidae). J.-KANS.-ENTOMOL.-SOC. 62 (2): 203-210

Howitt, A. 1993. Green Peach Aphid *Myzus persicae* (Sulzer). Common tree fruit pests, NCR 63. Michigan State University. Fruit IPM Fact Sheet.com

Huang, J., S. Rozelle, C. Pray, and Q. Wang, 2002. Plant biotechnology in China. Sci. 295: 674-677.

Huang, J., R. Hu, S. Rozelle, and C. Pray. 2005. Insect- resistant GM rice in farmer's fields: assessing productivity and health effects in China Sci. 308: 688–690.

IRAG Resistance Alert. 2007. Insecticide-resistant peach-potato aphids on potatoes. RAG's » Aphid Resistance Alert. www.pesticides.gov.uk/rags.asp?id=2163.

Irwin, M. E. 1980. Sampling aphids in soybean fields. In M. Kogan and D. Herzog (eds.). Sampling methods in soybean entomology. Springer, New York. pp. 239-259.

Ito, K., K. Furukawa and T. Okubo. 2005. Conservation biological control of aphids in potato fields with reduced use of insecticides in Hokkaido, Japan. Jap. J. Appl. Entomol. and Zool. 49(1): 11-22.

James, C. 2005. Preview: Global status of commercialized biotech/GM crops: ISAAA brief No. 34. ISAAA (http://www.africabio.com/pdf/Briefs%2034.pdf).

James, D.G. and J. Coyle. 2001. Which pesticides are safe to beneficial insects and mites? Agric. Environ. News 178: 12–14.

Jansson, R.K. and Z. Smilowitz 1986. Influence of nitrogen on population parameters of potato insects: abundance, population growth, and within-plant distribution of the green peach aphid, *Myzus persicae* (Homoptera: Aphididae). Environ. Entomol. 15:49-55.

Jenkins, J.J. 1994. Use of imidacloprid for aphid control on apples in oregon. Potential for ground and surface water contamination. Department of Agricultural Chemistry. Oregon State University, Corvallis.

Jensen, L. 2007. Check your potato field. News letters. http://extension.oregonstate.edu/malheur/Agriculture/Newsletters/P-O_June%2025.pdf.

Johnson, R. 2001. Press Release. North Dokota Department of Agriculture. http:www.Actara

Jones, W.A., M.A. Ciomperlik and D.A. Wolfenbarger. 1998. Lethal and sublethal effects of insecticides on two parasitoids attacking *Bemisia argentifolii* (Homoptera: Aleyrodidae). J. Biol. Cont. 11(1): 70-76.

Kabaluk, J.T., R.S. Vernon and D. Henderson. 2006. Population development of the green peach aphid and beneficial insects in potato fields in British Columbia. Can. Entomol. 138(5): 647-660.

Kalushkov, P and I. Hodek. 2005. The effects of six species of aphids on some life history parameters of the ladybird *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae). Europ. J. Entomol. 102(3): 449-452.

Kanrar, S., J. Venkateswari, P.B. Kirti and V.L. Chopra. 2002. Transgenic Indian mustard (*Brassica juncea*) with resistance to the mustard aphid (*Lipaphis erysimi* Kalt). Plant Cell Reports. 20: 976–981.

Karimullah., S. Ahmad., A.M. Paracha and M.T. Jan. 1995a. Infestation of apid *Myzus persicae* (Sulz) on potato in Peshwar, NWFP, Pakistan. Sarhad J. Agric. 11: 741-744.

Karimullah., and A.M. Paracha. 1995b Integrated control of potato aphi, *Myzus persicae* (Sulz) in Peshawar. Sarhad J. Agric. 11: 165-171.

Karley, A.J., J.W. Pitchford, A.E. Douglas, W.E. Parker and J.J. 2003. The causes and processes of the mid-summer population crash of the potato aphids Macrosiphum euphorbiae and *Myzus persicae* (Hemiptera: Aphididae). Bul. of Entomol. Res. 93(5): 425-438.

Kassem, S.A.A., M.A.M. Abo-Tayesh, R.I.E. Magouz. 2005. Survey and population fluctuations of parasitoids of the green peach aphid, *Myzus persicae* (Sülzer) attacking squash plantations and adverse effects of insecticide applications on it. Plant Protection Res. Institute. Sakha Agric. Sta. ARC. The third International Conference, IPM role in integrated crop management and impacts on environment and agricultural products. 26-29 November, Giza, Egypt. http://www.arabscientist.org/english/page/986/.

Kerns, D. L., J.C. Palumbo and D.N. Byrne. 1988. Relative susceptibility of red and green color forms of green peach aphid to insecticides. Publication AZ1101: "1998 Vegetable Report," College of Agriculture, The University of Arizona, Tucson, Arizona, 85721. http://ag.arizona.edu/pubs/crops/az1101/az1101_25.html

Kessler, A. and I.T. Baldwin. 2004. Herbivore-induced plant vaccination. Part I. The orchestration of plant defenses in nature and their fitness consequences in the wild tobacco *Nicotiana attenuate.* Plant J. 38: 639–649.

Kidd, H. and D. James. 1994. Agrochemicals Handbook. Third Edition. Royal Society of Chemistry. Cambridge, England.

Kindlmann, P. and Z. Ruzicka. 1992. Possible consequences of a specific interaction between predators and parasites of aphids. Ecol. Model. 61: 253–265.

Koch, R.L., E.C. Burkness, W.D. Hutchison and T.L. Rabaey. 2005. Efficacy of systemic insecticide seed treatments for protection of early-growth-stage snap beans from bean leaf beetle (Coleoptera: Chrysomelidae) foliar feeding. Crop Protec. 24(8): 734-742

Kogan, M. and E.F. Ortman, 1978. Antixenosis – a new term proposed to define Painter's 'Non – preference' modality of resistance. Bull. Entomol. Soc. Amer. 24: 175-176.

Kogan, M. 1998. Integrated pest management: historical perspectives and contemporary developments. Ann. Rev. of Entomol. 43: pp. 243–270.

Koss, A. M., G.C. Chang and W.E. Snyder. 2004. Predation of green peach aphids by generalist predators in the presence of alternative, Colorado potato beetle egg prey. J. Biol. Cont. 31(2): 237-244.

Koss, A.M., A.S. Jensen, A. Schreiber, K.S. Pike and W.E. Snyder. 2005. Comparison of predator and pest communities in Washington potato fields treated with broad-spectrum, selective, or organic insecticides. Environ. Entomol. 34(1): 87-95.

Kramarz P. and J.D. Stark. 2003. Population level effects of cadmium and the insecticide imidacloprid to the parasitoid, *Aphidius ervi* after exposure through its host, the pea aphid, *Acyrthosiphon pisum* (Harris). J. Biol. Cont. 34(2): 159-164.

Kuhar, T.P., L.J. Stivers-Young., M.P. Hoffmann and A.G. Taylor. 2002. Control of corn flea beetle and Stewart's wilt in sweet corn with imidacloprid and thiamethoxam seed treatments. Crop Protec. 21(1): 25-31.

Kuroli, G. and Z. Lantos. 2006. Long-term study of alata aphid flight activity and abundance of potato colonizing aphid species. Acta Phyto. et Ento. Hung. 41(3-4): 261-273.

Labonne, G., F. Lauriaut and J. Quiot. 1989. Comparison de trois types de pieges pour I'echantillonnage des populations de pucerons ailes. Agron. 9: 547-557.

Lagos, N.A., E. Fuentes-Contreras, F. Bozinovic and H.M. Niemeyer, 2001. Behavioural thermoregulation in *Acyrthosiphon pisum* (Homoptera: Aphididae): the effect of parasitism by *Aphidius ervi* (Hymenoptera: Braconidae). J. Thermal Biol. 26(2): 133-137.

Langhof, M., R. Meyhöfer, H. Poehling and A. Gathmann. 2005. Measuring the field dispersal of *Aphidius colemani* (Hymenoptera: Braconidae). J. Agric. Ecosys. and Environ. 107(2-3):137-143.

Lapointe, S. L. and W.M. Tingey. 1986. Glandular trichomes of *Solanum neocardenasii* confer resistance to green peach aphid (Homoptera: Aphididae). J. Econ. Entomol. 79 (5): 1264-1268.

Lauderdale, Ft. 2005. Feeding disruption in *Myzus persicae* by a new insecticide, flonicamid. The 2005 ESA Annual Meeting and Exhibition. December 15-18, 2005

Lawton, J.H. 1995. The response of insects to environmental change. Insects in a changing environment: pp. 3–26.

Le R.V., J. Saguez, C. Vincent and P. Giordanengo. 2004. Rapid method to screen resistance of potato plants against *Myzus persicae* (Homoptera: Aphididae) in the laboratory. J. Econ. Entomol. 97(6): 2079-2082

Lee, J., C. Yoo, S. So., J.J. Lee., C.M. Yoo and S.S. So. 1999. Defence mechanism of glandular trichome of *Solanum tuberosum* against *Myzus persicae* (Homoptera: Aphididae). I. Morphology of trichome and effects of its extract on development of the aphid. Kor. J. Entomol. 29(3): 189-193.

Legaspi, J.C., R.I. Carruthers and D.A. Nordlund. 1994. Life-History of *Chrysoperla rufilabris* (Neuroptera: Chrysopidae) provided sweetpotato whitefly *Bemisia tabaci* (Homoptera: Aleyrodidae) and other food . J. Biol. Cont. 4(2): 174-178.

Li, X., M.A. Schuler and M.R. Berenbaum. 2002. Jasmonate and salicylate induce expression of herbivore cytochrome P450 genes. Nature. 419: 712–715.

Liu, S., Y. Li, and Z. Tang, 2003. Host resistance to an insecticide favors selection of resistance in the parasitoid, *Cotesia plutellae* (Hymenoptera: Braconidae). J. Biol. Cont. 28(3): 137-143.

Linda, A.M. and R.L. Blackman. 2003. Insecticide resistance in the aphid *Myzus persicae*: chromosome location and epigenetic effects on esterase gene expression in clonal lineages. Biol. J. Linn. Soc. 79(1): 107–113.

Lowery, D.T. and M.K. Sears. 1986. Effect of exposure to the insecticide azinphosmethyl on reproduction of green peach aphid (Homoptera: Aphididae). J. Econ. Entomol. 79:1534-1538.

Lundgren, J.G. 2009. Relationships of natural enemies and non-prey foods. Springer International, Dordrecht, The Netherlands.

Lundgren, J.G., A.J. Gassmann, J.B., J.J. Duan and J. Ruberson. 2009. Ecological compatibility of GM crops and biological control. Crop Protec. 28(12): 1017-1030

Mahr, S. 2000. Know your friend. University of Wisconsin - Madison. Midwest Biological Control News Online. 3(1). www.entomology.wisc.edu

Mannan, V.D., G.C. Varma and K.S. Brar. 1997. Biology of *Chrysoperla carnea* (Stephens) on *Aphis gossypii* Glover and *Myzus persicae* (Sulzer). J. Insect Sci. 10(2): 143-145.

Margaritopoulos, J. T., C. Tsourapas, M. Tzortzi, O.M. Kanavaki and J. A. Tsitsipis. 2005. Host selection by winged colonisers within the *Myzus persicae* group: a contribution towards understanding host specialization. Ecol. Entomol. 30 (4): 406- 418.

Marvier, M., C. McCreedy, J. Regetz and P. Kareiva. 2007. A meta-analysis of effects of Bt cotton and maize on nontarget invertebrates. Sci. p: 316.

Mau R.F.L. and J.L.M. Kessing. 1991. Green peach aphid *Myzus persicae* (Sulzer). Department of Entomology, Honolulu, Hawaii. Crop Knowledge Master.com

McKenzie. 2007. UK: Syngenta launch new potato insecticide. Farminguk.Com.

Meissle, M., E. Vojtech, and G.M. Poppy. 2005. Effects of Bt maize-fed pray on the generalist predator *Poecilus cupreus* (Coleoptera: Carabidea). Transgenic Res. 14: 123–132.

Meister, R.T. (ed.). 1995. Farm Chemicals Handbook '95. Meister Publishing Company. Willoughby, OH.

Messing, R. H. and J.M. Rabasse. 1995. Oviposition behaviour of the polyphagous aphid parasitoid *Aphidius colemani* Viereck (Hymenoptera: Aphidiidae). J. Agric. Ecosys. and Environ. 52(1): 13-17.

Min, K., C.S. Park and Y.I. Hahm. 1997. Occurrence pattern of insect pests on several varieties of potato. Kor. J. of Appl. Entomol. 36(2): 145-149.

MINFAL, 2008. Agricultural Statistics of Pakistan. Food and Agriculture Division. Ministry of Food and Agriculture and cooperative, Economic Wing, Govt. of Pakistan, Islamabad: 82-83.

Miranda, M.M.M., M. Picanco, A.L. Matioli and A. Pallini-Filho. 1998. Distribution in the plant and biological control of Aphids (Homoptera, Aphididae) in tomato. Rev. Bras. de Entomol. 42(1-2): 13-16.

Misra, S.S. and H.O. Agrawal. 1998a. Uptake and translocation of granular systemic insecticides in potato plants under irrigated and rainfed conditions for managing *Myzus persicae* (Sulzer). J. Entomol. Res. 22(3): 231-236.

Misra, S.S. and H.O. Agrawal. 1998b. Population dynamics of *Myzus persicae* (Sulzer) on potato crop under cropping systems prevalent in three different potato growing belts in India. J. Entomol. Res. 22(2): 157-162.

Mitchell, J., C. Summers, and J. Stapleton. 2001. Evaluation of reflective and cover crop mulches for insect, disease and weed control in fresh market tomato production systems. Pest management grants Final Report prepared for the California Department of Pesticide Regulation. http://www.cdpr.ca.gov/docs/pestmgt/grants/99-00/finlrpts/99-0222.pdf.

Mogahed, M.I. 2003. Influence of intercropping on population dynamics of major insect-pests of potato (*Solanum tuberosum*) in North Sinai Governorate, Egypt. Ind. J. Agric. Sci. 73(10): 546-549.

Mohamed A. H., P. J. Lester and T.O. Holtzer. 2000. Abundance and effects of predators and parasitoids on the Russian Wheat Aphid (Homoptera: Aphididae) under organic farming conditions in Colorado. Bioagricultural Sciences and Pest Management, Colorado State University, Fort Collins, CO 80523Ð1177.

Mohamed, B. M., H.F. van Emden. 1989. Host plant modification of insecticide susceptibility in *Myzus persicae*. Insect Sci. and Appl. 10: 699-703.

Moraes, J.C.D., E.F. Vilela and. J.C. De Moraes. 1995. Antixenosis to the aphid *Myzus persicae* (Sulzer), in clones of the wild potato *Solanum berthaultii* bearing glandular trichomes. Anais da Soc. Entomol. do Bras. 24(3): 613-618.

Moschetti, R. 2003. Biological control using beneficial insects. Biol. Cont. Bul. IPM of Alaska. www.ipmofalska.com. rocco@ipmofalaska.com

Moura, R., P. Garcia, S. Cabral and A.O. Soares, 2006. Does pirimicarb affect the voracity of the euriphagous predator, *Coccinella undecimpunctata* L. (Coleoptera: Coccinellidae)? J. Biol. Cont. 38(3): 363-368.

Mowry, T.M. 2001. Green peach aphid (Homoptera: Aphididae) action thresholds for controlling the spread of potato leafroll virus in Idaho. J. Econ. Entomol. 94: 1332–1339

Mowry, T.M. and D. John. 2002. Effects of sub-lethal imidacloprid levels on potato leaf roll virus transmission by *Myzus persicae*. Entomol. Exp. et Appl. 103 (3): 249 - 255

Mowry, T.M. 2005. Insecticidal reduction of Potato leafroll virus transmission by *Myzus persicae*. Ann. Appl. Biol. 146 (1): 81-88

Nagia, D.K., F. Mallik, S. Kumar, M. Saleem, D. Prasad and M.L. Saini. 1994. "Field evaluation of insecticides and fungicides against aphid, *Aphis gossypii* (Glover), *Myzus persicae* (Sulzer) and early blight *Alternaria solani* (Ellis and Martin) Jones and grout of potato. Plant Protec. Bul. Faridabad. 46(1): 28-30.

Namba, R. and E.S. Sylvester. 1981. Transmission of cauliflower mosaic virus by the green peach, turnip, cabbage, and pea aphids. J. Econ. Entomol. 74:546-551.

Narvaez, Z. and A. Notz. 1993. Development, lifespan and reproduction of the green sesame aphid *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) on potato plants (*Solanum tuberosum* L.) and sesame (*Sesamum indicum* L.). Bol. de Entomol. Venez. 8(1): 53-61.

Narvaez, Z. and A. Notz. 1994. Abundance of green peach aphid *Myzus persicae* (Sulzer) (Homoptera: Aphididae), in a potato crop, *Solanum tuberosum* L., in Saman Mocho, Edo. Carabobo, Venezuela. Bol. de Entomol. Venez. 9(1): 33-47.

Natwick, E. T., W.E. Chaney and N.C. Toscano. 2002. UC IPM Pest Management Guidelines: Lttuce. UC ANR Publication 3450

Nauen, R. and A. Elbert. 2003. European monitoring of resistance to insecticides in *Myzus persicae* and *Aphis gossypii* (Hemiptera: Aphididae) with special reference to imidacloprid. Bul. of Entomol. Res. 93: 47-54. Cambridge on line journal.

Nauen, R. and I. Denholm. 2005. Resistance of insect pests to neonicotinoid insecticides: current status and future perspective. Arch. Insect Biochem. Physiol. 58: 200–215.

Niaz, T. and A. Muhammad. 2007. Population pattern of Myzus persicae on potato crop at Faisalabad. J. Agric. Res. 45 (4):305-310.

Oakes, N.G. 1981. The resistance of spring wheat to cereal aphids. Ph.D. thesis, University of Reading, UK.

Obrist, L.B., A. Dutton, J. Romeis and F. Bigler. 2006. Biological activity of Cry1Ab toxin expressed by Bt maize following ingestion by herbivorous arthropods and exposure of the predator *Chrysoperla carnea*. J. Biol. Cont. 51: 31–48.

Ohashi, K., Y. Sakuratani, N. Osawa, S. Yano and A. Takafuji. 2005. Thermal Microhabitat Use by the Ladybird Beetle, *Coccinella septempunctata* (Coleoptera: Coccinellidae), and Its Life Cycle Consequences. Environ. Entomol. 34 (2): 432-439

Ohta, I., and M. Ohtaishi. 2002. Life history parameters of *Myzus persicae* (Sulzer) (Homoptera: Aphididae) reared on Qing-geng-cai at four constant temperatures. Jap. J. Appl. Entomol. and Zool. 46(4):259-261.

Palumbo, J.C. and D.L. Kerns. 1994. Effects of imidacloprid as a soil treatment on colonization of green peach aphid and marketability of lettuce. Southwestern Entomol. 19: 339-346.

Pappas, M.L., G.D. Broufas and D.S. Koveos. 2008. Effect of relative humidity on development, survival and reproduction of the predatory lacewing *Dichochrysa prasina* (Neuroptera: Chrysopidae). J. Biol. Cont. 46(2): 234-241.

PARC. 2009. Profile of Potato in Pakistan. Pakissan.com. http://www.pakissan.com/english/allabout/horticulture/vegetables/potato.shtml

Park, Y. and J.J. Obrycki. 2004. Spatio-temporal distribution of corn leaf Aphids (Homoptera: Aphididae) and lady beetles (Coleoptera: Coccinellidae) in Iowa cornfields. J. Biol. Cont. 31(2):210-217

Parker, W.E., R.H. Collier, P.R Ellis, A. Mead, D. Chandler, J.A. Blood Smyth and G.M. Tatchell. 2002. Matching control options to a pest complex: the integrated pest management of aphids in sequentially-planted crops of outdoor lettuce. Crop Protec. 21(3): 235-248.

Petitt, F.L. and Z. Smilowitz. 1982. Green peach aphid feeding damage to potato in various plant growth stages. J. Econ. Entomol. 75:431-435.

Petra A.M.H., L. Felix, J.R. Wäckers. 2007. Effects of honeydew sugar composition on the longevity of *Aphidius ervi.* Entom. Exp. et Applic. 122 (3), 223–232.

Peumans, E., van Damme and D. Boulter. 1995. Expression of snowdrop lectin in transgenic tobacco plants results in added protection against aphids. Transgenic Res. 4: 18–25.

Picard-Nizou, A.L., M.H. Pham-Delegue, V. Kerguelen, P. Douault, R. Marillaeu, L. Olsen, R. Grison, A. Toppan and C. Masson. 1995. Foraging behaviour of honey bees (*Apis mellifera* L.) on transgenic oilseed rape (*Brassica napus* L. var. *oleifera*). Transgenic Res. 4: 270–276.

Pike, K.S., G.L. Reed, G.T. Graf and D. Allison. 1993. Compatibility of imidacloprid with fungicides as a seed-treatment control of Russian Wheat Aphid (Homoptera: Aphididae) and effect on germination, growth, and yield of wheat barley. J. Econ. Entomol. 86(2): 586-593.

Pike, K. S., P. Stary, T. Miller, G. Graf, D. Allison, L. Boydston and R. Miller. 2000. Aphid parasitoids (Hymenoptera: Braconidae: Aphidiinae) of Northwest USA. Proc. Entomol. Soc. Wash. 102: 688-740.

Pineda, A., I. Morales and M.A. Marcos-Garcia. 2007. Oviposition avoidance of parasitized aphid colonies by the syrphid predator *Episyrphus balteatus* mediated by different cues. J. Biol. Cont. 42(3): 274-280

Pinto, R.M., V.H.P. Bueno and L.V.C. Santa-Cecilia. 2000. Population fluctuation of aphids (Hemiptera: Aphididae) associated with potato crop *Solanum tuberosum* L. at Winter planting in Alfenas, South of the State of Minas Gerais, Brazil. Ann. Soc. Entomol. Bras. 29(4): 649-657.

Polgár, L., M. Mackauer, and W. Völkl. 1991. Diapause induction in two species of aphid parasitoids: the influence of aphid morph. J. Insect Physiol. 37: 699–702.

Powell, D.M. 1980. Control of the green peach aphid on potatoes with soil systemic insecticides: preplant broadcast and planting time furrow applications, 1973-77. J. Econ. Entomol. 73:839-843.

Powell, W., F. Pennacchio, G. M. Poppy and E. Tremblay. 1995. Strategies Involved in the Location of Hosts by the Parasitoid *Aphidius ervi* Haliday (Hymenoptera: Braconidae: Aphidiinae).

Qaim, M. and D. Zilberman. 2003. Yield effects of genetically modified crops in developing countries. Science 299: 900–902.

Raman, K.V. and D.J. Midmore. 1983. Efficacy of insecticides against major insect pests of potatoes in hot climates of Peru. Crop Protec. 2(4): 483-489.

Ramel G. 2008. Earth-Life Web Productions. http://www.earthlife.net/insects/aphids.html

Rasmann. S. and A.A Agrawal. 2009. Plant defense against herbivory: progress in identifying synergism, redundancy, and antagonism between resistance traits. Current Opinion in Plant Biol. 12(4):473-478

Radcliffe, T. 1998. Insecticidal control of green peach aphid. Aphid Alert. Published cooperatively by departments of Entomology and Plant Pathology**,** College of Agri., Food and Envir. Sci.**,** University of Minnesota**,** the University of Minnesota Extension Service**,** and the State Seed Potato Programs of the states of Minnesota and North Dakota. 4: 1-7.

Riddick, E.W. and N.J. Mills. 2004. Potential of adult carabids (Coleoptera: Carabidea) as predators of fifth instar codling moth (Lepidoptera: Tortricidae) in apple orchards in California. Environ. Entomol. 23: 1338–1345.

Robert, Y. 2003. French national institute for agricultural research. HYPPZ on line. Ravageurs. HYPPZ Home Page. pp. 2205-2010.

Rogers, M.A., V.A. Krischik and L.A. Martin. 2007. Effect of soil application of imidacloprid on survival of adult green lacewing, *Chrysoperla carnea* (Neuroptera: Chrysopidae), used for biological control in greenhouse. J. Biol. Cont. 42(2): 172-177.

Romeis, J., M. Meissle, and F. Bigler, 2006. Transgenic crops expression *Bacillus thuringiensis* toxins and biological control. Nat. Biotechnol. 24: 63–71.

Ronald et al., 1991. *Myzus persicae* (Sulzer). Mau, Extension Entomologist, Department of Entomology , Honolulu, Hawai.

Roy, H.E., J.K. Pell, S.J. Clark and P.G. Alderson. 1998. Implications of predator foraging on aphid pathogen dynamics. J. Inverteb. Pathol. 71(3): 236-247.

Roy, H.E., P.G. Alderson and J.K. Pell. 2003. Effect of spatial heterogeneity on the role of *Coccinella septempunctata* as an intra-guild predator of the aphid pathogen *Pandora neoaphidis*. J. Inverteb. Pathol. 82(2): 85-95.

Sadeghi, H. and F. Gilbert. 2000. Oviposition preferences of aphidophagous hoverflies. Ecol. Entomol. 69: 91–100.

Saljoqi, A.U.R., and H.F. van Emden. 2003a. Differential susceptibilities of peach-potato aphid, *Myzus persicae (*Sulzer) (Homoptera: Aphididae) and its parasitoid *Aphidius matricariae* Haliday (Hymenoptera; Aphidiidae) to foliar insecticides on partially resistant and susceptible potato cultivars. Paki. J. Biol. Sci. 6(4): 386-393

Saljoqi, A.U.R., and H.F. van Emden. 2003b. Selective toxicity of different insecticicdes to the the peach-potato aphid *Myzus persicae (*Sulzer) (Homoptera: Aphididae) and its parasitoid *Aphidius matricariae* Haliday (Hymenoptera; Aphidiidae) in two differential resistant potato cultivars. Online J. Biol. Sci. 3(2): 215-227.

Saljoqi, A.U.R., and H.F. van Emden. 2003c. Effects of two potential pest management components, intercropping and yellow sticky plastic sheet traps in two differential resistant potato cultivars for the mangagement *Myzus persicae (*Sulzer) Assian J. Plant Sci. 2(12): 925-931.

Saljoqi, A.U.R., van Emden and HE Yu-rong. 2003. Field assessments of antibiotic resistance to *Myzus persicae* (Sulzer) in different potato cultivars. J. South China Agric. Univ. (Natu. Sci. Ed. 24(4): 31-37.

Saljoqi, A.U.R., K. Khan and S.U. Rahman. 2009. Integrated management of potato-peach aphid, *Myzus persicae* (Sulzer). Sarhad J. Agric. 25(4): 573-580.

Saljoqi, A.U.R. 2009. Population dynamics of *Myzus persicae* (Sulzer) and it associated natural enemies in spring potato crop, Peshawar-Pakistan. Sarhad J. Agric. 25(3): 451-456.

Sankula, S., G. Marmon and E. Blumenthal 2005. Biotechnology-derived crops planted in 2004 – impacts on US agriculture. National center for food and agricultural policy. www.ncfap.org.

Sauvion, N., H. Charles, G. Febvay and Y. Rahbé. 2004. Effects of jackbean lectin (ConA) on the feeding behaviour and kinetics of intoxification of the pea aphid, *Acyrthosiphon pisum*. Entomol. Exp. Appl. 110 (2004), pp. 31–44.

Sauge, M.H. and R. Monet. 1998. Analysis of the mechanisms of resistance to the green peach aphid in several Prunus genotypes. Proceedings of the fourth international peach symposium, Bordeaux, France, 22-26 June 1997. 2(465): 731-739.

Scholz, K. and R. Fritz. 1998. Photolysis of imidacloprid (NTN 33893) on leaf surfaces of tomato plants. Abstracts, 9th International Congress of Pesticide Chemistry, London, UK.

Schuler, T.H., R.P.J. Potting, I. Denholm, S.J. Clark, A.J. Clark, C.N. Stewart, and G.M. Poppy, 2003. Tritrophic choice experiments with Bt plants, the diamondback moth (*Plutella xylostella*) and the parasitoid (*Cotesia plutellae*). Transgenic Res. 12: 351–361.

Schutz, S. and H.E. Hummel. 1997. Impact of elevated atmospheric ozone on the interaction of potato plants (*Solanum tuberosum* Lin., cv. Granola) and aphids (*Myzus persicae* Sulzer). Proc. of the German Soc. for general and applied entomol., Bayreuth, Germany, 18-22 March. 11(1-6): 297-301.

Schwörer, U. and W. Völkl. 2001. Foraging Behavior of *Aphidius ervi* (Haliday) (Hymenoptera: Braconidae: Aphidiinae) at Different Spatial Scales: Resource Utilization and Suboptimal Weather Conditions. J. Biol. Cont. 21(2): 111-119.

Seif, A. A. 1988. Comparison of green and yellow water traps for sampling citrus aphids at the Kenya coast. E. Afr. Agric. For. J. 53: 159-161.

Sharma, K.K and R. Ortiz. 2000. Program for the application of genetic transformation for crop improvement in the semi-arid tropics. In vitro Cell. Dev. Biol. Plant. 36: 83–92.

Sharma, H.C., K.K Sharma, N. Seetharama and R. Ortiz. 2001. Genetic transformation of crop plants: risks and opportunities for the rural poor. Curr. Sci. 80: 1495–1508.

Shean, B. and W.S. Ranshaw. 1991. Differential Susceptibilities of Green Peach Aphid (Homoptera: Aphididae) and Two Endoparasitoids (Hymenoptera: Encyrtidae and Braconidae) to Pesticides. J. Econ. Entomol. 84(3): 844-850.

Sheets, L.P. 2001. Imidacloprid: A Neonicotinoid insecticide. Handbook of Pesticide Toxicology (Second Edition). pp: 1123-1130.

Shi, Y., W.B. Wang, K.S. Powell, E. Van Damme, V.A. Hilder, A.M.R. Gatehouse, D. Boulter and J.A. Gatehouse. 1994. Use of the rice sucrose synthase-1 promoter to direct phloem-specific expression of B-glucuronidase and snowdrop lectin genes in transgenic tobacco plants. J. Exp. Bot. 45: 623–631.

Simmons, A.T. and G.M. Gurr. 2006. The effect on the biological control agent *Mallada signata* of trichomes of F_1 *Lycopersicon esculentum* × *L. cheesmanii* f. *minor* and *L. esculentum* × *L. pennellii* hybrids. Biol. Cont. 38(2): 174-178

Singh, J., H.S. Sukhija, P. Singh and G.S. Dhaliwal. 1994. Effect of insecticides on *Telenomus dignoides* Nixon, an egg parasite of yellow stem borer, *Scirpophaga incertulas* (Walker) of rice. Pest Manag. and Econ. Zool. 27: 147-149.

Singh, S.R., K.F.A. Walters, G.R. Port and P. Northing. 2004. Consumption rates and predatory activity of adult and fourth instar larvae of the seven spot ladybird, *Coccinella septempunctata* (L.), following contact with dimethoate residue and contaminated prey in laboratory arenas. J. Biol. Cont. 30(2): 127-133.

Sjekhawat, G.S. 1990. Potato aphids and their management. Central Potato Research Institute, Shimla-171 001, HP, India.

Smith, B.C. 1971. Effects of various factors on the local distribution and density of coccinellid adults on corn (Coleoptera: Coccinellidae). Can. Entomol. 103: 1115–1120.

Snyder, W.E. and G.M. Clevenger. 2004. Negative dietary effects of Colorado potato beetle eggs for the larvae of native and introduced ladybird beetles. Biol. Cont. 31(3): 353-361.

Snyder, W.E., S.N. Ballard, S. Yang, G.M. Clevenger, T.D. Miller, J.J Ahn, T.D. Hatten and A.A. Berryman. 2004. Complementary biocontrol of aphids by the ladybird beetle *Harmonia axyridis* and the parasitoid *Aphelinus asychis* on greenhouse roses. J. Biol. Cont. 30(2): 229-235.

Snyder, G.B., D.L. Finke and W.E. Snyder. 2008. Predator biodiversity strengthens aphid suppression across single- and multiple-species prey communities. J. Biol. Cont. 44(1): 52-60.

Solangi, B. K., M.K Lohar, G.H. Abro and M.A. Talpur. 2007a. Searching ability and feeding potential of larvae, 7-Spotted beetle *Coccinella septempuntata* Linn under laboratory and field conditions. Sarhad J. Agric. 23(3): 705-711

Solangi, B. K., A.G. Lanjar and M.K. Lohar. 2007b. Comparative toxicity of some insecticides on 4th instar grub of Coccinella septempunctata L. under laboratory conditions. Sarhad J. Agric. 23(4): 1095-1100.

Stapel, J.O., A.M. Cortesero and W.J. Lewis, 2000. Disruptive sublethal effects of insecticides on biological control: altered foraging ability and life span of a parasitoid after feeding on extrafloral nectar of cotton treated with systemic insecticides. J. Biol. Cont. 17(3): 243-249.

Stoetzel, M.B., G.L. Miller, P.J. O'Brien and J.B. Graves. 1996. Aphids (Homoptera: Aphididae) colonizing cotton in the United States. Florida Entomol. 79:193-205.

Suarez, M., C. Murguido and M.L. Gonzalez M. L. 1991. Influence of some climatic factors and of plant phenology on the appearance of the green aphid *Myzus persicae* on potato (*Solanum tuberosum*). Proteccion de Plantas. 1(3-4):69-79.

Sutherland J. and G. Poppy. 2004. Can transgenic crop technology benefit biocontrol. Ecology and Evolutionary Biology Southampton, UK. Jps4@soton.ac.uk.

Syngenta, 2008a. Actara Potato Aphids. Actara Product Use. NDSU Extension Service. Pp. 1-3. http://www.syngenta-crop.co.uk/pdfs/products/Actara_uk_directions

Syngenta, 2008b. http://www.syngenta-crop protection poduct.htm

Syngenta, 2008c. www.UK Syngenta launch new potato insecticide.htm

Thaler, S. 1999. Jasmonate-inducible plant defences cause increased parasitism of herbivores. Nature 399: 686–688.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M. Ferreira de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Philips, and S.E. Williams. 2004. Extinction risk from climate change. Nature, 427: 145–148.

Tingey, W.M. and J.E. Laubengayer. 1981. Defense against the green peach aphid and potato leafhopper by glandular trichome of *Solanum berthaultii*. J. Econ. Entomol. 74:721-725.

Toba, H. H. 1964. Life-History Studies of *Myzus persicae* in Hawaii. J. Econ. Entomol. 57(2): 290-291.

Tobias, L. and D. L. Olson. 2006. Screening for resistance to green peach aphid, *Myzus persicae* Sulzer (Hemiptera: Aphididae) in *Solanum etuberosum* derived germplasm.

The ESA annual meeting, students competition for the President's Prize, section Fa. Host Plant Resista. 0472.

Tsaganou, F. C., C.J. Hodgson, C.G. Athanassiou, N.G. Kavallieratos and Tomanovi. 2004. Effect of *Aphis gossypii* Glover, *Brevicoryne brassicae* (L.), and *Megoura viciae* Buckton (Hemiptera: Aphidoidea) on the development of the predator *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae). J. Biol. Sci. 31(2): 138-144

UC Publication. 2008. Relative Toxicities of insecticides and miticides used in potatoes to natural enemies and honey bees. UC IPM Pest Management Guidelines: Potato. UC ANR Publication 3463.

Unruh, T.R. and L.S. Willett. 2008. Survey for resistance to four inecticides in *Myzus persicae* Clones from peach and weeds in South-central Washington. J. Econ. Entomol. 101: 1919-1929.

van Emden, H.F. 1987. Cultural methods : The plant. In : A.J. Burn, T.H. Coaker and P.C. Jepson [Eds.] Integ. Pest Manag. pp. 27-68. Academic Press, London.

van Emden, H.F. 1989. Pest Control (second edition). Edward Arnold, London, pp 117.

van Emden, H.F. 1990. The interaction of host plant resistance to insects with other control measures. Brighton Crop Protection Conference: Pests and Diseases. 939-947.

van Toor, R.F., S.P. Foster, J.A. Anstead, S. Mitchinson, B. Fenton, and L. Kasprowicz, 2008. Insecticide resistance and genetic composition of *Myzus persicae* (Hemiptera: Aphididae) on field potatoes in New Zealand. J. Crop Protec. 27(2): 236-247.

Vargas, R.R., A.J. Troncoso, D.H. Tapia, R. Olivares-Donoso and H.M. Niemeyer. 2005. Behavioural differences during host selection between alate virginoparae of generalist and tobacco-specialist *Myzus persicae*. Entomol. Exp. Appl. 116 (1): 43–53.

Varghese, B. and S.N. Beevi. 2004. Safety of insecticides to the green lacewing, *Chrysoperla carnea* (Stephens). Insect Environ. 10(1): 45–47.

Verkerk, R.H.J., S.R. Leather and D.J. Wright. 1998. The potential for manipulating crop–pest-natural enemy interactions for improved insect pest management, Bulletin of Entomol. Res. 88: 493–501.

Vojtech, E., M. Meissle, and G.M. Poppy. 2005. Effect of Bt maize on the herbivore *Spodoptera littoralis* (Lepidoptera: Noctuidae) and the parasitoid *Cotesia marginiventris* (Hymenoptera: Braconidae). Transgenic Resistance. 14: 133-144.

Wäckers, F.L. 2005. Suitability of (extra-) floral nectar, pollen, and honeydew as insect food sources. Plant-provided Food for Carnivorous Insects (ed. by FL Wäckers, PCJ van Rijn & J Bruin), pp. 17–74. Cambridge University Press.

Walker, M.K., M.A.W. Stufkens, and A.R. Wallace, 2007. Indirect non-target effects of insecticides on Tasmanian brown lacewing (*Micromus tasmaniae*) from feeding on lettuce aphid (*Nasonovia ribisnigri*). J. Biol. Cont. 43(1): 31-40.

Wiethoff, R., H.M. Meyhofer and H.M. Poehling. 2002. Use of combinations of natural enemies for biological control of *Myzus persicae* (Sulzer) (Hom.: Aphididae) on sweet pepper in greenhouses. Gesunde Pflanzen. 54 (3-4): 126- 137.

Wiebe, A.P. and J.J. Obrycki. 2002. Prey Suitability of *Galerucella pusilla* Eggs for Two Generalist Predators, *Coleomegilla maculata* and *Chrysoperla carnea*. J. Biol. Cont. 23(2): 143-148.

Wiles J.A. and P.C. Jepson. 1994. Sub-lethal effects of deltamethrin residues on the within-crop behaviour and distribution of Coccinella septempunctata. J. Entomol. Exp. Appl. 72(1): 33-45

Wink, M. 2008. Plant secondary metabolism: diversity, function and its evolution. Nat Prod. Commun. 3: 1205–1216.

Wolfenbarger L.L., S.E. Naranjo, J.G. Lundgren, R.J. Bitzer and L.S. Watrud. 2008. Bt crop effects on functional guilds of non-target arthropods: a meta-analysis, PLoS One. 3: 2118 10.1016/j.cropro.2009.06.001.

Wurst, S. and T.H. Jones. 2003. Indirect effects of earthworms (Aporrectodea caliginosa) on an above-ground tritrophic interaction. Pedobiologia. 47(1): 91-97.

Wyman, J. 2005. Pest management in future. A strategic plan for the Wisconsin, Minnesota, Michigan, and North Dakota potato industry. Fargo, North Dakota. Dept. of Entomol. Madison, WI, USA.

Wyman, J.A. and S.A. Chapman. 2003. Vegetable crops entomology field research. College of agriculture and life sciences, project report. Department of Entomology, University of Wisconsin-Madison. http://www.entomology.wisc.edu/vegento/2003AnnualReport.pdf.

Youn, Y.N., M.J. Seo, J.G. Shin, C. Jang and Y.M. Yu. 2003. Toxicity of greenhouse pesticides to multicolored Asian lady beetles, *Harmonia axyridis* (Coleoptera: Coccinellidae). J. Biol. Cont. 28(2): 164-170.

Zou, Y., M. Qinglei, H. Lijuan, Y. Yihe and H. Shixiang. 1993. Relationship between contents in "Qinyou 2' rape and population dynamics of *Myzus persicae*. Chin. J. Appl. Ecol. 4(3): 283-288.

APPENDICES

Appendix A

Table A1: Analysis of variance for the impact of seasons, location, varieties and plant growth stages (days after seeds germination) on the population of green peach aphid (GPA), *Myzus persicae* (Sulzer) per nine compound leaves in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Seasons (S)	1	25029.12	25029.12	40322.80	0.00
Locations (L)	2	40.72	20.36	32.80	0.00
S x L	2	116.13	58.06	93.54	0.00
Replication (S x L)	12	4.69	0.39	0.63	
Varieties (V)	8	1292.11	161.51	260.21	0.00
S x V	8	742.28	92.79	149.48	0.00
L x V	16	14.47	0.90	1.46	0.13
S x L x V	16	17.72	1.11	1.78	0.04
Error	96	59.59	0.62		
Plant Growth Stages (Pgs)	4	11459.71	2864.93	7121.69	0.00
S x Pgs	4	9947.93	2486.98	6182.19	0.00
L x Pgs	8	38.83	4.85	12.07	0.00
S x L x Pgs	8	81.59	10.20	25.35	0.00
V x Pgs	32	307.29	9.60	23.87	0.00
S x V x Pgs	32	306.76	9.59	23.83	0.00
L x V x Pgs	64	33.93	0.53	1.32	0.06
S x L x V x Pgs	64	35.11	0.55	1.36	0.04
Error	432	173.79	0.40		
Total	**809**	**49701.76**			
Coefficient of Variation:	8.08%				

Table A2: Analysis of variance for the impact of seasons, locations and plant growth stages (days after seeds germination) on the population of Coccinellids “ladybird beetles; LBB” per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Seasons (S)	1	91.61	91.61	76.05	0.00
Locations (L)	2	8.00	4.00	3.32	0.04
S x L	2	37.73	18.87	15.66	0.00
Replication (S x L)	12	23.40	1.95	1.62	0.12
Plant Growth Stages (Pgs)	4	230.01	57.50	47.74	0.00
S x Pgs	4	186.88	46.72	38.79	0.00
L x Pgs	8	29.11	3.64	3.02	0.01
S x L x Pgs	8	15.36	1.92	1.59	0.15
Error	48	57.82	1.21		
Total	**89**	**679.91**			
Coefficient of Variation:	27.50%				

Table A3: Analysis of variance for the impact of seasons, locations and plant growth stages (days after seeds germination) on the populations of Syrphidae 'syrphidfly' per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Seasons (S)	1	29.47	29.47	27.12	0.00
Locations (L)	2	87.14	43.57	40.09	0.00
S x L	2	2.01	1.00	0.92	
Replication (S x L)	12	10.82	0.90	0.83	
Plant Growth Stages (Pgs)	4	508.86	127.21	117.06	0.00
S x Pgs	4	126.13	31.53	29.01	0.00
L x Pgs	8	19.57	2.45	2.25	0.04
S x L x Pgs	8	20.86	2.61	2.40	0.03
Error	48	52.16	1.09		
Total	**89**	**857.01**			
Coefficient of Variation:	21.24%				

Table A4: Analysis of variance for the impact of seasons, locations and plant growth stages (days after seeds germination) on the population of *Chrysoperla spp* "green lacewing; GLW" per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Seasons (S)	1	41.21	41.21	33.06	0.00
Locations (L)	2	12.53	6.26	5.02	0.01
S x L	2	0.69	0.34	0.27	
Replication (S x L)	12	5.71	0.48	0.38	
Plant Growth Stages (Pgs)	4	472.10	118.02	94.68	0.00
S x Pgs	4	18.68	4.67	3.75	0.01
L x Pgs	8	19.59	2.45	1.96	0.07
S x L x Pgs	8	5.93	0.74	0.60	
Error	48	59.83	1.25		
Total	**89**	**636.26**			
Coefficient of Variation:	26.16%				

Table A5: Analysis of variance for the impact of seasons, locations and plant growth stages (days after seeds germination) on the population of parasitized green peach aphid (GPA), *M. persicae* (Sulzer), mummies per nine compound leaves in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Seasons (S)	1	9933.00	9933.00	1610.58	0.00
Locations (L)	2	383.32	191.66	31.08	0.00
S x L	2	76.34	38.17	6.19	0.00
Replication (S x L)	12	204.97	17.08	2.77	0.01
Plant Growth Stages (Pgs)	4	8062.48	2015.62	326.82	0.00
S x Pgs	4	5690.48	1422.62	230.67	0.00
L x Pgs	8	107.52	13.44	2.18	0.05
S x L x Pgs	8	61.38	7.67	1.24	0.29
Error	48	296.03	6.17		
Total	**89**	**24815.53**			
Coefficient of Variation:	12.39%				

Appendix B

Table B1: Analysis of variance for the percent survival rate of green peach aphid (GPA), *M. persicae* (Sulzer), on various potato varieties

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	3.10	1.55	1.10	0.36
Varieties	8	2967.49	370.94	261.95	0.00
Error	16	22.66	1.42		
Total	**26**	**2993.25**			
Coefficient of Variation:	1.50%				

Table B2: Analysis of variance for development time (in 10 days) of green peach aphid (GPA), *M. persicae* (Sulzer), on various potato varieties

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	0.197	0.099	0.34	
Varieties	8	55.71	6.96	23.75	0.00
Error	16	4.69	0.29		
Total	**26**	**60.60**			
Coefficient of Variation:	7.53%				

Table B3: Analysis of variance for fecundity over 10 days of green peach aphid (GPA), *M. persicae* (Sulzer) on various potato varieties

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	1.27	0.63	0.92	
Varieties	8	545.57	68.20	99.38	0.00
Error	16	10.98	0.69		
Total	**26**	**557.81**			
Coefficient of Variation:	2.30%				

Table B4: Analysis of variance for r_m of green peach aphid (GPA), *M. persicae* (Sulzer), on various potato varieties

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	0.00	0.00	1.03	0.38
Varieties	8	0.107	0.013	86.59	0.00
Error	16	0.002	0.000		
Total	**26**	**0.110**			
Coefficient of Variation:	3.73%				

Appendix C

Table C1: Analysis of variance for the effect of potato varieties, foliar insecticides, insecticide doses and post treatment day intervals on the populations of green peach aphid (GPA), *M. persicae* (Sulzer), per nine compound leaves in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	10.81	5.41	5.74	0.00
Varieties (V)	1	1847.15	1847.15	1960.09	0.00
Fr. Insecticide Doses (D)	2	8483.57	4241.78	4501.13	0.00
V x D	2	728.08	364.04	386.30	0.00
Fr. Insecticides (I)	1	57.45	57.45	60.97	0.00
V x I	1	21.62	21.62	22.94	0.00
D x I	2	15.38	7.69	8.16	0.00
V x D x I	2	0.23	0.12	0.12	
Time/Days Interval (T)	4	437.53	109.38	116.07	0.00
V x T	4	146.80	36.70	38.95	0.00
D x T	8	1036.19	129.52	137.44	0.00
V x D x T	8	126.33	15.79	16.76	0.00
I x T	4	5.68	1.42	1.51	0.20
V x I x T	4	11.04	2.76	2.93	0.02
D x I x T	8	6.25	0.78	0.83	
V x D x I x T	8	11.11	1.39	1.47	0.17
Error	118	111.20	0.94		
Total	**179**	**13056.43**			
Coefficient of Variation:	9.08%				

Table C2: Analysis of variance for the effect of potato varieties, foliar 'Fr' insecticides, insecticide doses and post treatment day intervals on the population of Coccinellids "ladybird beetles; LBB" per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.76	0.38	1.30	0.29
Varieties (V)	1	2.45	2.45	8.35	0.01
Fr. Insecticide Doses (D)	2	199.51	99.75	339.49	0.00
V x D	2	0.16	0.08	0.28	
Fr. Insecticides (I)	1	6.25	6.25	21.27	0.00
V x I	1	0.05	0.05	0.19	
D x I	2	6.21	3.10	10.56	0.00
V x D x I	2	0.04	0.02	0.07	
Error	22	6.46	0.29		
Total	**35**	**221.91**			
Coefficient of Variation:	16.13%				

Table C3: Analysis of variance for the effect of potato varieties, foliar insecticides, insecticide doses and post treatment day intervals on the populations of Syrphidae 'syrphidfly' per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.04	0.02	0.17	
Varieties (V)	1	30.25	30.25	239.01	0.00
Fr. Insecticide Doses (D)	2	148.23	74.11	585.58	0.00
V x D	2	4.46	2.23	17.62	0.00
Fr. Insecticides (I)	1	3.61	3.61	28.52	0.00
V x I	1	0.13	0.13	1.06	0.31
D x I	2	0.89	0.44	3.50	0.05
V x D x I	2	0.63	0.31	2.48	0.11
Error	22	2.78	0.13		
Total	**35**	**191.03**			
Coefficient of Variation:	11.62%				

Table C4: Analysis of variance for the effect of potato varieties, foliar insecticides, insecticide doses and post treatment day intervals on the populations of *Chrysoperla spp* "green lacewing; GLW" per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	1.28	0.64	2.66	0.09
Varieties (V)	1	12.25	12.25	50.81	0.00
Fr. Insecticide Doses (D)	2	196.47	98.23	407.42	0.00
V x D	2	0.09	0.04	0.18	
Fr. Insecticides (I)	1	3.36	3.36	13.94	0.00
V x I	1	0.59	0.59	2.44	0.13
D x I	2	2.54	1.27	5.26	0.01
V x D x I	2	0.08	0.04	0.17	
Error	22	5.30	0.24		
Total	**35**	**221.96**			
Coefficient of Variation:	14.42%				

Table C5: Analysis of variance for the effect of potato varieties, foliar insecticides, insecticide doses and post treatment day intervals on the population of parasitized green peach aphid (GPA), *M. persicae* (Sulzer), mummies per nine compound leaves in potato

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	12.92	6.46	4.83	0.02
Varieties (V)	1	275.96	275.96	206.51	0.00
Fr. Insecticide Doses (D)	2	4254.06	2127.03	1591.73	0.00
V x D	2	119.12	59.56	44.57	0.00
Fr. Insecticides (I)	1	33.88	33.88	25.35	0.00
V x I	1	2.55	2.55	1.90	0.18
D x I	2	19.22	9.61	7.19	0.00
V x D x I	2	2.44	1.22	0.91	
Error	22	29.40	1.34		
Total	**35**	**4749.54**			
Coefficient of Variation:	6.79%				

Table C6: Analysis of variance for the effect of potato varieties, foliar insecticides and doses on the percent parasitism of green peach aphid (GPA), *M. persicae* (Sulzer), by its parasitoids '*Aphidius spp*' (PPA*A*) in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.02	0.01	0.06	
Varieties (V)	1	13.65	13.65	104.45	0.00
Fr. Insecticide Doses (D)	2	398.23	199.12	1523.75	0.00
V x D	2	7.36	3.68	28.16	0.00
Fr. Insecticides (I)	1	5.19	5.19	39.73	0.00
V x I	1	0.68	0.68	5.24	0.03
D x I	2	2.32	1.16	8.86	0.00
V x D x I	2	0.08	0.04	0.30	
Error	22	2.88	0.13		
Total	**35**	**430.40**			
Coefficient of Variation:	8.89%				

Table C7: Analysis of variance for the effect of potato varieties, foliar insecticides and doses on the percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *M. persicae* (Sulzer), mummies (PER*A*) in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	1.56	0.78	0.37	
Varieties (V)	1	411.73	411.73	197.15	0.00
Fr. Insecticide Doses (D)	2	38725.15	19362.57	9271.58	0.00
V x D	2	69.86	34.93	16.73	0.00
Fr. Insecticides (I)	1	818.36	818.36	391.86	0.00
V x I	1	5.02	5.02	2.40	0.14
D x I	2	652.79	326.39	156.29	0.00
V x D x I	2	29.49	14.74	7.06	0.00
Error	22	45.94	2.09		
Total	**35**	**40759.89**			
Coefficient of Variation:	2.70%				

Table C8: Analysis of variance for the effect of potato varieties, foliar insecticides and doses on the fecundity rates of mature female of *Aphidius spp* (FR*A*) in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	8.46	4.23	0.98	
Varieties (V)	1	1427.49	1427.49	332.52	0.00
Fr. Insecticide Doses (D)	2	54275.56	27137.78	6321.39	0.00
V x D	2	193.10	96.55	22.49	0.00
Fr. Insecticides (I)	1	1215.32	1215.32	283.09	0.00
V x I	1	14.87	14.87	3.46	0.08
D x I	2	873.89	436.95	101.78	0.00
V x D x I	2	30.83	15.42	3.59	0.04
Error	22	94.45	4.29		
Total	**35**	**58133.97**			
Coefficient of Variation:	2.03%				

Table C9: Analysis of variance for the effect of potato varieties, foliar insecticides and doses on the yield of potato tubers in tons/hectare

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.01	0.01	0.04	
Varieties (V)	1	22.14	22.14	143.03	0.00
Fr. Insecticide Doses (D)	2	69.44	34.72	224.32	0.00
V x D	2	0.70	0.35	2.26	0.13
Fr. Insecticides (I)	1	7.10	7.10	45.86	0.00
V x I	1	0.41	0.41	2.65	0.12
D x I	2	1.91	0.96	6.17	0.01
V x D x I	2	0.11	0.06	0.37	
Error	22	3.41	0.16		
Total	**35**	**105.23**			
Coefficient of Variation:	3.17%				

Appendix D

Table D1: Analysis of variance for the effect of potato varieties, soil routed insecticides, insecticide doses and post treatment day intervals on the populations of green peach aphid (GPA), *M. persicae* (Sulzer), per nine compound leaves in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	7.03	3.52	3.15	0.05
Varieties (V)	1	1117.04	1117.04	998.97	0.00
Sl. Insecticide Doses (D)	2	4802.20	2401.10	2147.30	0.00
V x D	2	574.05	287.02	256.68	0.00
Sl. Insecticides (I)	1	16.09	16.09	14.39	0.00
V x I	1	0.14	0.14	0.12	
D x I	2	5.61	2.80	2.51	0.09
V x D x I	2	2.34	1.17	1.05	0.35
Time/days Interval (T)	4	3460.06	865.02	773.58	0.00
V x T	**4**	187.78	46.95	41.98	0.00
D x T	8	19.54	2.44	2.18	0.03
V x D x T	8	8.55	1.07	0.96	
I x T	4	1.32	0.33	0.30	
V x I x T	4	2.47	0.62	0.55	
D x I x T	8	14.55	1.82	1.63	0.12
V x D x I x T	8	10.11	1.26	1.13	0.35
Error	118	131.95	1.12		
Total	**179**	**10360.82**			
Coefficient of Variation:	10.85%				

Table D2: Analysis of variance for the effect of potato varieties, soil routed insecticides, insecticide doses and post treatment day intervals on the population of Coccinellids "ladybird beetles; LBB" per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.81	0.40	1.98	0.16
Varieties (V)	1	8.80	8.80	43.05	0.00
Sl. Insecticide Doses (D)	2	171.88	85.94	420.36	0.00
V x D	2	0.84	0.42	2.06	0.15
Sl. Insecticides (I)	1	10.03	10.03	49.05	0.00
V x I	1	0.25	0.25	1.22	0.28
D x I	2	5.06	2.53	12.36	0.00
V x D x I	2	1.58	0.79	3.86	0.04
Error	22	4.50	0.20		
Total	**35**	**203.75**			
Coefficient of Variation:	10.37%				

Table D3: Analysis of variance for the effect of potato varieties, soil routed insecticides, insecticide doses and post treatment day intervals on the populations of Syrphidae 'syrphidfly' per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.60	0.30	1.43	0.26
Varieties (V)	1	68.34	68.34	325.11	0.00
Sl. Insecticide Doses (D)	2	112.83	56.41	268.38	0.00
V x D	2	2.08	1.04	4.95	0.02
Sl. Insecticides (I)	1	6.76	6.76	32.16	0.00
V x I	1	2.35	2.35	11.19	0.00
D x I	2	4.58	2.29	10.89	0.00
V x D x I	2	2.80	1.40	6.67	0.01
Error	22	4.62	0.21		
Total	**35**	**204.97**			
Coefficient of Variation:	10.53%				

Table D4: Analysis of variance for the effect of potato varieties, soil routed insecticides, insecticide doses and post treatment day intervals on the populations of *Chrysoperla spp* "green lacewing; GLW" per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.51	0.25	2.05	0.15
Varieties (V)	1	52.80	52.80	427.09	0.00
Sl. Insecticide Doses (D)	2	117.09	58.54	473.51	0.00
V x D	2	4.20	2.10	16.99	0.00
Sl. Insecticides (I)	1	4.55	4.55	36.81	0.00
V x I	1	1.96	1.96	15.85	0.00
D x I	2	5.28	2.64	21.36	0.00
V x D x I	2	1.85	0.92	7.47	0.00
Error	22	2.72	0.12		
Total	**35**	**190.96**			
Coefficient of Variation:	7.53%				

Table D5: Analysis of variance for the effect of potato varieties, soil routed insecticides, insecticide doses and post treatment day intervals on the population of parasitized green peach aphid (GPA), *M. persicae* (Sulzer), mummies per nine compound leaves in potato

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	22.42	11.21	2.98	0.07
Varieties (V)	1	988.29	988.29	262.85	0.00
Sl. Insecticide Doses (D)	2	2437.71	1218.86	324.18	0.00
V x D	2	62.52	31.26	8.31	0.00
Sl. Insecticides (I)	1	184.46	184.46	49.06	0.00
V x I	1	0.40	0.40	0.11	
D x I	2	183.64	91.82	24.42	0.00
V x D x I	2	5.35	2.68	0.71	
Error	22	82.72	3.76		
Total	**35**	**3967.50**			
Coefficient of Variation:	6.81%				

Table D6: Analysis of variance for the effect of potato varieties, soil routed insecticides and doses on the percent parasitism of green peach aphid (GPA), *M. persicae* (Sulzer), by its parasitoids '*Aphidius spp*' (PPA*A*) in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.43	0.22	1.83	0.18
Varieties (V)	1	5.99	5.99	51.21	0.00
Sl. Insecticide Doses (D)	2	462.36	231.18	1975.21	0.00
V x D	2	4.60	2.30	19.63	0.00
Sl. Insecticides (I)	1	2.28	2.28	19.43	0.00
V x I	1	0.06	0.06	0.52	
D x I	2	1.06	0.53	4.53	0.02
V x D x I	2	0.07	0.03	0.29	
Error	22	2.58	0.12		
Total	**35**	**479.42**			
Coefficient of Variation:	5.10%				

Table D7: Analysis of variance for the effect of potato varieties, soil routed insecticides and doses on the percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *M. persicae* (Sulzer), mummies (PER*A*) in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.31	0.15	0.14	
Varieties (V)	1	117.17	117.17	103.05	0.00
Sl. Insecticide Doses (D)	2	27135.63	13567.82	11933.30	0.00
V x D	2	5.89	2.94	2.59	0.10
Sl. Insecticides (I)	1	374.65	374.65	329.51	0.00
V x I	1	0.45	0.45	0.40	
D x I	2	203.36	101.68	89.43	0.00
V x D x I	2	3.00	1.50	1.32	0.29
Error	22	25.01	1.14		
Total	**35**	**27865.47**			
Coefficient of Variation:	1.87%				

Table D8: Analysis of variance for the effect of potato varieties, soil routed insecticides and doses on the fecundity rates of mature female of *Aphidius spp* (FRA) in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.59	0.30	0.00	
Varieties (V)	1	4135.26	4135.26	55.92	0.00
Sl. Insecticide Doses (D)	2	41707.95	20853.98	281.99	0.00
V x D	2	2700.52	1350.26	18.26	0.00
Sl. Insecticides (I)	1	228.31	228.31	3.09	0.09
V x I	1	18.49	18.49	0.25	
D x I	2	39.54	19.77	0.27	
V x D x I	2	10.47	5.24	0.07	
Error	22	1626.95	73.95		
Total	**35**	**50468.08**			
Coefficient of Variation:	5.92%				

Table D9: Analysis of variance for the effect of potato varieties, soil routed insecticides and doses on the yield of potato tubers in tons/hectare

SOV	DF	SS	MS	F-Value	Prob.
Replication	2	0.06	0.03	0.17	
Varieties (V)	1	12.59	12.59	72.61	0.00
Sl. Insecticide Doses (D)	2	33.60	16.80	96.87	0.00
V x D	2	0.04	0.02	0.13	
Sl. Insecticides (I)	1	1.67	1.67	9.62	0.01
V x I	1	0.51	0.51	2.95	0.10
D x I	2	1.69	0.84	4.87	0.02
V x D x I	2	0.22	0.11	0.64	
Error	22	3.82	0.17		
Total	**35**	54.20			
Coefficient of Variation:	3.54%				

Appendix E

Table E1: Analysis of variance table the effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the population of green peach aphid (GPA), *M. persicae* (Sulzer), per nine compound leaves in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	0.22	0.11	1.56	0.39
Varieties (V)	1	1081.43	1081.43	15600.41	0.00
Error	2	0.14	0.07		
Treatments (T)	5	2059.96	411.99	4284.96	0.00
V x T	5	228.41	45.68	475.11	0.00
Error	20	1.92	0.10		
Plant Growth Stages (Pgs)	4	1150.88	287.72	2888.02	0.00
V x Pgs	4	80.21	20.05	201.29	0.00

T x Pgs	20	2179.42	108.97	1093.81	0.00
V x T x Pgs	20	321.12	16.06	161.16	0.00
Error	96	9.56	0.10		
Total	**179**	**113.27**			
Coefficient of Variation:	4.17%				

Table E2: Analysis of variance table the effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the population of Coccinellids "ladybird beetles; LBB" per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	1.11	0.56	6.25	0.14
Varieties (V)	1	5.69	5.69	64.00	0.02
Error	2	0.18	0.09		
Treatments (T)	5	71.44	14.29	8.70	0.00
V x T	5	0.38	0.08	0.05	
Error	20	32.84	1.64		
Plant Growth Stages (Pgs)	4	1249.20	312.30	145.63	0.00
V x Pgs	4	1.09	0.27	0.13	
T x Pgs	20	100.00	5.00	2.33	0.00
V x T x Pgs	20	7.84	0.39	0.18	
Error	96	205.87	2.14		
Total	**179**	**1675.64**			
Coefficient of Variation:	37.02%				

Table E3: Analysis of variance table the effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the populations of Syrphidae 'syrphidfly' per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	4.01	2.01	5.92	0.14
Varieties (V)	1	52.27	52.27	154.25	0.01
Error	2	0.68	0.34		
Treatments (T)	5	27.29	5.46	11.40	0.00
V x T	5	0.63	0.13	0.26	
Error	20	9.58	0.48		
Plant Growth Stages (Pgs)	4	568.14	142.04	190.09	0.00
V x Pgs	4	15.48	3.87	5.18	0.00
T x Pgs	20	47.79	2.39	3.20	0.00
V x T x Pgs	20	12.46	0.62	0.83	
Error	96	71.73	0.75		
Total	**179**	**810.06**			
Coefficient of Variation:	25.63%				

Table E4: Analysis of variance table the effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the populations of *Chrysoperla spp* "green lacewing; GLW" per ten plants in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	0.14	0.07	0.14	
Varieties (V)	1	60.09	60.09	118.86	0.01
Error	2	1.01	0.51		
Treatments (T)	5	32.64	6.53	7.24	0.00
V x T	5	0.64	0.13	0.14	
Error	20	18.04	0.90		
Plant Growth Stages (Pgs)	4	711.37	177.84	144.52	0.00
V x Pgs	4	13.08	3.27	2.66	0.04
T x Pgs	20	47.30	2.37	1.92	0.02
V x T x Pgs	20	12.52	0.63	0.51	
Error	96	118.13	1.23		
Total	**179**	**1014.98**			
Coefficient of Variation:	29.89%				

Table E5: Analysis of variance table the effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the population of parasitized green peach aphid (GPA), *M. persicae* (Sulzer), mummies per nine compound leaves in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	10.90	5.45	5.08	0.16
Varieties (V)	1	2135.56	2135.56	1991.71	0.00
Error	2	2.14	1.07		
Treatments (T)	5	1515.93	303.19	80.04	0.00
V x T	5	85.31	17.06	4.50	0.01
Error	20	75.76	3.79		
Plant Growth Stages (Pgs)	4	19250.94	4812.74	1119.96	0.00
V x Pgs	4	556.72	139.18	32.39	0.00
T x Pgs	20	1508.46	75.42	17.55	0.00
V x T x Pgs	20	79.74	3.99	0.93	
Error	96	412.53	4.30		
Total	**179**	25634.00			
Coefficient of Variation:	11.11%				

Table E6: Analysis of variance table the effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the percent parasitism of green peach aphid (GPA), *M. persicae* (Sulzer), by its parasitoids '*Aphidius spp*' (PPA*A*) in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	0.70	0.35	1.97	0.34
Varieties (V)	1	169.95	169.95	954.97	0.00
Error	2	0.36	0.18		
Treatments (T)	5	204.28	40.86	501.93	0.00
V x T	5	4.01	0.80	9.85	0.00
Error	20	1.63	0.08		
Plant Growth Stages (Pgs)	4	770.87	192.72	1730.94	0.00
V x Pgs	4	15.91	3.98	35.72	0.00
T x Pgs	20	266.79	13.34	119.81	0.00
V x T x Pgs	20	16.64	0.83	7.47	0.00
Error	96	10.69	0.11		
Total	**179**	**1461.82**			
Coefficient of Variation:	6.98%				

Table E7: Analysis of variance table the effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the percent emergence rates of '*Aphidius spp*' from parasitized green peach aphid (GPA), *M. persicae* (Sulzer), mummies (PER*A*) in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	22.28	11.14	15.60	0.06
Varieties (V)	1	3135.93	3135.93	4391.30	0.00
Error	2	1.43	0.71		
Treatments (T)	5	30777.93	6155.59	9174.85	0.00
V x T	5	35.78	7.16	10.66	0.00
Error	20	13.42	0.67		
Plant Growth Stages (Pgs)	4	7578.52	1894.63	2302.61	0.00
V x Pgs	4	164.92	41.23	50.11	0.00
T x Pgs	20	16853.25	842.66	1024.12	0.00
V x T x Pgs	20	220.79	11.04	13.42	0.00
Error	96	78.99	0.82		
Total	**179**	**58883.22**			
Coefficient of Variation:	1.18%				

Table E8: Analysis of variance table the effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the fecundity rates of mature female of *Aphidius spp* (FRA) in potato crop

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	684.99	342.50	23.94	0.04
Varieties (V)	1	41158.15	41158.15	2876.57	0.00
Error	2	28.62	14.31		
Treatments (T)	5	71659.64	14331.93	312.19	0.00
V x T	5	1163.58	232.72	5.07	0.00
Error	20	918.16	45.91		
Plant Growth Stages (Pgs)	4	164347.70	41086.92	1300.86	0.00
V x Pgs	4	2773.68	693.42	21.95	0.00
T x Pgs	20	26131.11	6306.56	199.67	0.00
V x T x Pgs	20	1173.53	58.68	1.86	0.02
Error	96	3032.10	31.58		
Total	**179**	**413071.25**			
Coefficient of Variation:	3.74%				

Table E9: Analysis of variance table the effect of potato varieties, treatments and plant growth stages 'Pgs' (days after seeds germination) on the yield of potato tubers in tons/hectare

SOV	DF	SS	MS	F-Value	Prob.
Replications	2	1.02	0.51	60.75	0.02
Varieties (V)	1	29.76	29.76	3560.17	0.00
Error	2	0.02	0.01		
Treatments (T)	5	71.97	14.39	129.86	0.00
V x T	5	1.77	0.35	3.20	0.03
Error	20	2.22	0.11		
Total	**35**	**106.75**			
Coefficient of Variation:	2.55%				