Materials and Methods
The present studies were carried out under controlled conditions in the Department of Plant Protection and at the experimental fields of Faculty of Agricultural Sciences, AMU, Aligarh, (India) during rabi (winter) season of 2000-01 and 2001-02.

Location

Aligarh is located in the western part of the state of Uttar Pradesh at a distance of about 126 km from Delhi, the capital of India. It spreads from 27°29' to 28°10' north latitude and 77°29' to 78°38' east longitude. The greatest width from west to east is about 116 km and the maximum length from north to south is about 72 km. Rest spreads over 5024 sq. km, but area changes slightly due to change of course of the rivers Ganges and Yamuna.

Climate and weather

The climate in Aligarh is of subtropical type having three well-defined seasons winter, summer and monsoon. Winter season starts from November and continues up to first fortnight of April, whereas, summer sets in May. Months of May and June are the hottest wherein maximum day temperature plummets to 48°C. The second half of December and January are usually the coldest period. Monsoons normally start in the first week of July and continue with appreciable amount up to the first week of September. Annual rainfall of Aligarh district averages 315 mm of which 75-80% is received from second half of July to first week of September.

Soils

The soil of the experimental fields is illitic fine sandy loam. The physico-chemical properties of the soil include sand-61%, silt-25%, clay-14% and organic matter 0.41%. The soil water ratio is 1:2.5 and pH 7.3 to 8.1.

Cultivation

Fine seedbed was ensured for good germination. First ploughing was done with soil turning plough followed by two cross ploughing with harrow. Planking the field after ploughing broke clods. Farmyard manure and the recommended levels of fertiliser (60 kg N+ 40 kg P₂O₅ and 40 kg K₂O) were applied. Seed rate of 5 kg/ha
was taken. Row to row distance of 35 cm and plant-to-plant 15 cm was maintained by thinning.

3.1 HOST/PLANT RESISTANCE

Thirty-three promising varieties/germplasms were sown in a randomised block design during rabi season of 2000-2001 and 2001-2002. Each variety/germplasm, replicated thrice was sown in one row of 4 m in length with spacing of 15 cm and 45 cm plant-to-plant and row-to-row, respectively. Three different sowing dates, October 9 (early sowing), November 5 (timely sowing) and November 24 (late sowing) were selected for raising the crop. Observations on aphid infestation per inflorescence shoot were recorded at weekly intervals (starting from initial incidence to disappearance) on 20 randomly selected plants from each row as per the suggestions of Bakhetia and Sandhu (1973). The plants were categorised into 6 grades (0-5) depending upon aphid population and its symptoms. For working out the mean aphid infestation index, the number of plants in each grade was multiplied by the respective grade and then the number of plants divides the figure. The grades were distributed as under.

<table>
<thead>
<tr>
<th>Grade no.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
<td>Plant is completely free from aphid.</td>
</tr>
<tr>
<td>1.</td>
<td>Plants having 1-15 aphids per inflorescence shoot. There is no symptom of aphid damage.</td>
</tr>
<tr>
<td>2.</td>
<td>Plants having 16-100 aphids per inflorescence. Shoots and plants start curling due to aphid attack.</td>
</tr>
<tr>
<td>3.</td>
<td>Plants having more than 100 aphids per shoot. Aphids infest most of the branches. Leaves start drying. Pods are curled.</td>
</tr>
<tr>
<td>4.</td>
<td>Each and every branch of the plant is fully covered with aphids and some of the branches start drying.</td>
</tr>
<tr>
<td>5.</td>
<td>Plant is completely dry immaturesly due to aphid infestation.</td>
</tr>
</tbody>
</table>

All the thirty-three varieties/germplasms were procured from the National Research Centre on Mustard, Bharatpur, Rajasthan (India), they included,

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3.2 SUCCESSION OF IMPORTANT INSECT PESTS OF MUSTARD

The investigation on succession of important insect-pests was carried out during rabi (winter) season of 2000-01 and 2001-02 on B. campestris cv. Varuna, sown on three different dates (October 9, November 5 and 24). Insects were collected in the morning hours from 25 randomly selected plants replicated thrice from 20x20m plot area according to various techniques recommended by Southwood (1978). Observations were recorded at weekly interval on pest population starting from one week after sowing till maturity of the crop. The insects, closely related with the crop, were collected and ignoring those, which accidentally visited.

The immature stages of lepidopterous pests feeding on the plant foliage were reared on the plants, they were placed in nylon mesh cages measuring 40x15 cm. Opening of the cages was tied with rubber band to avoid escape of larvae, enough foliage was placed inside each cage. At transformation into pupa, they were collected and brought to the laboratory for adult emergence. The caterpillars/larvae collected from the field were also individually reared at room temperature in the laboratory, in glass jars (10x20 cm) having approximately 2 cm sand at the bottom. To maintain humidity, the soil was kept moist; this provided an optimum condition for pupation. The various insects and their developmental stages collected during the different stages of the crop growth viz., seedling, vegetative, flowering and pod formation was preserved in liquid preservative and collection boxes. Their identification was ascertained on the basis of identification keys and also by sending them to taxonomists at different organisations/institutions.

3.3 BIO-EFFICACY OF INSECTICIDES

A replicated field was laid out in a randomised block design during rabi (winter) season of 2000-01 and 2001-02. The cultivar Varuna was sown on November 5 in 2000 and 2001. The size of plots was maintained at 4 x 3 m, with row-to-row and plant-to-plant spacing of 35 and 15 cm, respectively. The recommended cultural and agronomic practices, as mentioned earlier, were followed.
The crop, thus raised, was sprayed with recommended doses (Appendix 1) of seven insecticides so as to evaluate their relative efficacy. Hand operated knapsack sprayer was used for spraying the crop. The first spray was applied before commencement of flowering and the next two at an interval of 15 days each; a control was run simultaneously to compare the relative efficacy. There were a total of eight treatments, replicated thrice. The population count of mustard aphid was recorded in the early hours of the morning from 25 tagged plants from each plot. The data was recorded on 1, 7, and 14 days after each spray. The control plot was sprayed with water. At the time of spray, polythene sheets were used as barrier to avoid drifting of insecticide from one plot to another. On the basis of population count of aphids from 10 cm terminal shoot per plant, the efficacy of the insecticides was evaluated. Seed yield was recorded after harvesting of the crop and the cost: benefit ratio over control was calculated.

Relative safety of these insecticides was also determined against *C. septempunctata* and *I. scutellaris*. Observations were taken at weekly intervals after each spray. From each treatment 25 plants were randomly selected and tagged for subsequent recording of the population of these predators.

### 3.4 LIFE-TABLE STUDIES

The adults of *C. septempunctata* were collected from the mustard field to maintain culture. They were released in individual petri-dishes (15 cm diameter) for obtaining eggs. The bottom of each petri-dish was lined with card board paper. Fresh aphid infested cut twigs were provided to beetles as food daily. Further, counted number of same age old eggs (approximately 1000) obtained from these adults were placed separately in petri-dishes and allowed to hatch at different temperatures (18, 24, 28, 18/24, 18/28, 24/28±1°C coupled with 70±5% relative humidity) in BOD incubator and under natural conditions (for field study). Egg hatch percentage was recorded from each aliquot and subsequently adjusted, so that life-table commenced with 100 eggs in a cohort.

Fluctuating temperature was maintained by transferring the petri-dishes/plastic vials from one constant temperature to another at an interval of 12 hours and L:D of 12 hours was also maintained.
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One hundred same aged juvenile larvae were collected with the help of soft camel brush from the hatched eggs. These were individually reared on L. erysimi in petri-dishes. Initially, first and second instar Lipaphis nymphs were provided as food to the early instar larvae of coccinellids, thereafter with an advancement of age of the larvae, third and fourth instar nymphs were supplied. The longevity and mortality of each larval instar, pre-pupa, pupa and adult during the course of investigation was recorded daily. This method was employed for construction of life-table of C. septempunctata for two successive generations. Similar procedure was adopted for maintaining culture and constructing life-table of I. scutellaris, with the difference that adult flies were released in egg laying jars (25x15 cm) along with mustard inflorescence. While constructing life-tables, observations were also taken on predation potential of both predators.

Under field conditions, 100 newly hatched larvae obtained from culture were picked up in batches of 10 each with the help of camel brush and distributed on respective plants. Initially 10 grubs/maggots were released on aphid-infested twigs. Such twigs harbouring coccinellids and syrphids were covered with nylon cages (60 mesh) measuring 40x25 cm. When coccinellid grubs attained the age of 8 days and the syrphid maggots 5 days, they were allowed to lead their lives individually in cages. The opening of each cage was tied, with the help of rubber band or strong thread permitting no chances for insect escape. Before entering into pupal stage, some extra amount of leaves was supplied in the cage so as to provide optimum conditions for pupation. Larval and pupal mortality, if any, was recorded daily till the emergence of adults. The cause of the mortality was also ascertained. The adults so obtained were allowed to feed on aphids in case of coccinellids and on flower pollen for syrphid flies continuously till their death so as to record data on the life span. This procedure was followed for construction of life-table for two successive generations of the predators.

For complete study of every aspect of life parameters, three different types of life-tables were constructed.

a) Age specific life-table (Deevy, 1947)

b) Stage specific life-table (Harcourt, 1969 and Southwood, 1978)

c) Age specific survival and fertility-table for female (Birch, 1948 and Southwood, 1978).

The procedures adopted for calculating various life parameters were as specified by above workers as well as by Choudhary and Bhattacharya, 1986.
3.4.1 Age Specific Life-Table

Observations on number of alive and dead out of hundred larvae were recorded daily. The following assumptions were used in the construction of age specific life-table.

\( x \) = Age of the insect in days.

\( I_x \) = Number surviving at the beginning of each interval \( x \) out of 100.

\( d_x \) = Number dying during the age interval \( x \) out of 100.

\( e_x \) = Expectation of life or mean life remaining for individuals of age \( x \).

Life expectation was calculated using the equation; \( e_x = \frac{T_x}{I_x} \)

To obtain \( e_x \) two other parameters \( L_x \) and \( T_x \) were also computed as below.

\( L_x \) = The number of individuals alive between age \( x \) and \( x+1 \) and calculated by the equation.

\( L_x = \frac{I_x + (x+1)}{2} \).

\( T_x \) = the total number of individual of \( x \) age units beyond the age \( x \), and obtained by the equation,

\( T_x = I_x + (I_x + 1) + (I_x + 2) + \ldots + I_w \).

Where,

\( I_w \) = The last age interval.

3.4.2 Stage Specific Life-Table

Data on stage specific survival for eggs, larvae, pupae and adults were recorded from the age specific survival and mortality life-table. The data obtained from such table was used for computing various life parameters as given below:

3.4.2.1 Apparent Mortality

This is measured mortality and gives the information on number dying as percentage of number entering that stage and was calculated by using the formula:

Apparent Mortality = \( \frac{d_x}{L_x} \times 100 \)

3.4.2.2 Stage specific survival fraction \((S_x)\)

Data obtained on apparent mortality was used for the calculation of the stage specific survival fraction \((S_x)\) of each stage by using the equation:

\( S_x \) of particular stage = \( \frac{I_x \text{ of subsequent stage}}{I_x \text{ of particular stage}} \).
3.4.2.3 Generation Survival Fraction (SG)

This parameter was calculated by the following equation

\[ S_G = S_E \cdot S_{L1} \cdot S_{L2} \cdot S_{L3} \cdot S_{PP} \cdot S_P \]  

(for *C. septempunctata*)

\[ S_G = S_E \cdot S_{L1} \cdot S_{L2} \cdot S_{L3} \cdot S_{PP} \cdot S_P \]  

(for *I. scutellaris*)

Where, 
- \( S_E \) = \( S_x \) of egg stage.
- \( S_{L1} \) = \( S_x \) of first instar larval stage.
- \( S_{L2} \) = \( S_x \) of second instar larval stage.
- \( S_{L3} \) = \( S_x \) of third instar larval stage.
- \( S_{L4} \) = \( S_x \) of fourth instar larval stage.
- \( S_{PP} \) = \( S_x \) of pre-pupal stage.
- \( S_P \) = \( S_x \) of pupal stage.

3.4.2.4 Mortality Survivor Ratio (MSR)

It is the increase in population that would have occurred if the mortality in the stage, in question had not occurred and was calculated as follows:

\[ \text{MSR of particular stage} = \frac{\text{Mortality in particular stage}}{I_x \text{ of subsequent stage}} \]

3.4.2.5 Indispensable Mortality (IM)

This type of mortality would not be there in case the factor(s) causing it are not allowed to operate. However, the subsequent mortality factors operate. The equation is,

\[ \text{IM} = \text{Number of adults emerged} \times \text{M.S.R. of particular stage} \]

3.4.2.6 k-values

It is the key factor, which is primarily responsible for increase or decrease in number from one generation to another and was computed as the difference between the successive values for "Log \( I_x \)". The total generation mortality was calculated by adding the k-values of different development stages of the insect, which is designated/indicated as "K" [Varley and Gradwell, 1970; Southwood, 1978).

\[ K = k_0 + k_1 + k_2 + \ldots + k_n \]

Where, \( k_0, k_1, k_2, \ldots, k_n \) are the k-values at egg, first instar, second instar, third instar, fourth instar, pre-pupal and pupal stages.
3.4.3 Age Specific Survival and Fertility-Table

To record fecundity, ten pairs of coccinellid beetles of different age groups were released individually in petri-dishes with aphid infested mustard twigs at respective temperatures. Similarly, ten pairs of syrphid flies were released individually in egg laying glass jars measuring 25x15 cm, with their tops covered with muslin cloth. A cotton swab with 10% honey solution and a few flowering shoots of mustard were kept inside each jar to provide food for flies (Makhmoor and Verma, 1987 and Radhakrishnan and Muraleedharan, 1993). For field studies the petri-dishes/jars were placed under shades of trees so as to record data on fecundity. The observations for the age specific survival of the female and the number of unhatched and hatched eggs were recorded.

The fertility table was constructed with the following assumptions:

a) The survivorship rates were assumed to be the same for both the sexes, as it was not possible to identify the sexes prior to the adult stage.
b) The sex could not be identified at the egg stage. Therefore a sex ratio of 1:1 was considered in each batch of eggs.

The table was constructed on the suggestions made by Birch 1948 and Southwood (1978). It consisted of following columns:

\[ x = \text{Pivotal age of the class in days.} \]
\[ I_x = \text{Number of females alive at the beginning of the age interval } x \text{ (as fraction of initial population of one).} \]
\[ m_x = \text{Average number of female eggs laid per female in each age interval assuming 50:50 sex ratio and computed as:} \]
\[ m_x = \frac{N_x}{2}; \]
where, \( N_x = \text{Total natality per female offspring in each age.} \)

Besides \( m_x \) total number of female offspring in each age interval i.e., female eggs laid in an age interval \( x \), \( I_xm_x \) was also computed by multiplying the column \( I_x \) with \( m_x \). This is also termed as 'Reproductive expectation'.

A number of the parameters were computed from the age specific survival and fertility life-table of female these include:
3.4.3.1 Net Reproductive or Replacement Rate ($R_o$)

This is also referred to as the "carrying capacity" of the average insect under defined environmental conditions. The information on the multiplication rate of a population in one generation is obtained from it. It is denoted as,

$$R_o = I_x m_x$$

3.4.3.2 Mean length of Generation (T)

It is defined as the mean period between the birth of the parent and the birth of their offspring. This period is a weighted approximate value since the progeny is produced over a period of time and not at a definite time. Calculation followed the method suggested by Dubin & Lotka (1925)

$$T_x = I_x.m_x / I_x.m_x.$$

3.4.3.4 Intrinsic Rate of Increase (r)

It is also denoted by 'r' or 'r_m' or 'r_{max}' and called as 'biotic potential'. It is defined as the instantaneous rate of increase of a population in a unit time under a set of ecological conditions (Birch, 1948). A rough estimate of the intrinsic rate of increase (r) can be calculated by using the following equation:

$$r = \frac{\log R_o}{T}$$

Where, $R_o$ represents net reproductive rate, which is calculated by multiplying $I_x$ and $m_x$, i.e., $R_o = I_x.m_x$.

'T' represents mean length of the generation. For an accurate estimate of 'r' Birch (1948) introduced some approximation to the method to minimize the experimental errors in the formula suggested by Lotka (1925). This is as under:

$$\Sigma e^{-rx} I_x m_x.d_x = 1 \quad \text{Lotka (1925)}$$

$$e^{-rx} I_x.m_x = 1 \quad \text{Birch (1948)}$$

3.4.3.5 Finite Rate of Increase ($\lambda$)

It provides the information about the frequency of the population multiplication in a unit of time (Birch, 1948). It is denoted as

$$\lambda = e^r.$$ Taking log on both sides we get; $\log \lambda = \log e^r$

where, $\lambda = \text{Antilog } e^r$

This was used for computing the rate of increase of population per year.
3.4.3.6 Potential Fecundity (Pf)

It expresses the total number of eggs laid by an average female in her life span. It is obtained or calculated by adding up the age specific fecundity column,

\[ Pf = \sum m_a. \]

3.4.3.7 Doubling Time (DT)

It is defined as the time required for the population to double and is calculated as follows:

\[ DT = \frac{\ln 2}{r}. \]

3.4.3.8 Annual Rate of Increase (ARI)

This can be calculated from the intrinsic rate of increase (r) or finite rate of increase (\( \lambda \)) or doubling time (DT) or the net reproductive rate (\( R_o \)) assuming that the rate of increase was constant throughout the year.

\[ ARI = 365 = e^{365r} = 2^{365/DT} = R_o^{365/T}. \]

3.5 COLLECTION OF NATURAL ENEMIES OF C. SEPTEMPUNCTATA AND I. SCUTELLARIS

Observations were also made to find out the extent of field parasitisation of C. septempunctata and I. scutellaris by the hyper-parasitoids. The larvae of the predators were collected at weekly interval from the field and brought to the laboratory for further individual rearing in plastic vials, measuring 4x3.0 cm, till the emergence of hyper-parasites, if any. For aeration of larva, central part of the lid of each vial was provided with wire mesh.