Section-III
The results obtained on oviposition, host plants, egg laying, hatching of eggs, instar characters and duration, pupation and pupal period, food consumption and utilization indices of each instar in the laboratory are all described here under for each of the four Papilionidae butterfly species studied.

3.1. Studies on detailed Biology of *Graphium agamemnon* (L.)

Results

Adults (Fig. 3.1.1a)

The adults of *Graphium agamemnon*, with a wing span of 85-100 mm, are very showy due to the brownish black upper side of wing surface with a number of bright green spots and stripes. The larval host plant, *Polyalthia longifolia* var. *pendula*, is grown commonly as ornamental species. All other *Annonaceae* member can also serve as a larval host. *Graphium agamemnon* is a fast and strong flier that hovers while nectering, thus it requires floral nectar resources in sufficient density to get the required energy.

Oviposition

Oviposition was observed on *Annona lawii, Polyalthia longifolia, Cinnamomum macrocarpum, Michelia champaka* and *Artabotrys hexapetal* in the present study areas. *Polyalthia longifolia* and *Michelia champaka* were found to be most commonly used plants for oviposition. While the female was searching for a suitable host, it exhibited the ‘plasiotypic’ behavior (Sensu Wiklund, 1997), testing the suitability of the potential host leaves by ‘touch and go’ and laid single egg by abdominal carving. Both surfaces of tender leaves are used for ovoposition.
Life history stages

Eggs (Fig. 3.1.1b)

A breeding female laid 8-12 eggs in sequence, but on different leaves of the host plant. The eggs are spherical and white with a smooth surface each measuring 1.9-2.2 mm diameter. They hatch after 3-4 days. The freshly emerged larvae first eat the empty shell and then begin to consume the foliage of the host plant.

Larva

The larva undergoes four moults and has five instars, which are described below:

I instar (Fig. 3.1.1c)

This stage lasts for 2-3 days. On day 1st it was 1.5-2 mm long, and on day 2nd it was 3-3.3 mm long. Its head was smooth, and measures 1.0-1.5 mm in diameter; its thoracic region has hairy structures. Its body was snuff colored and the abdomen is white and anal regions showed snuff colored spines.

II instar (Fig. 3.1.1d)

This stage lasts for 3 days. It grows upto 4.5-5.5 mm in length its head was 1.5-2 mm in diameter and its thorax wider than other body parts.

III instar (Fig. 3.1.1e)

This stage lasted for 3-4 days. It grows to 18-20 mm in length and 2-3 mm in width, its head was 1.6 mm in diameter and body color changes from snuff to pale brown. Its thorax was pale yellow with snuff colored spines.
IV instar (Fig. 3.1.1f)

This stage lasted for 3-4 days. It grows to 32-42 mm in length and 3.5-43 in diameter. Its body segmentation was clear with pale color spots. Spines remain snuff colored. Anterior part was larger than the posterior part of the body.

V instar (Fig. 3.1.1g)

This stage lasted for 4-5 days. When fully grown it was green and measured 42-45 mm in length and 6.0-7 mm in width. Its head was 3-4 mm wide. Body segmentation clear with spine size decreasing. There was no change observed in the other characters.

Pupa (Fig. 3.1.1h)

The larvae thus passed through five instars over a period of 15-19 days entered the prepupal stage, this stage took 2 days for transformation to the pupa. It measured 38-40 mm in length and attached to the substratum with its entire body.

The pupal stage lasted for 13-14 days. The color was green and measured 28-30 mm long and 8-9 mm wide. The thorax was snuff colored. Posterior end of the pupa remain pointed.

As detailed above, the egg matured over a period of 3-4 days, total larval period spanned over 14-19 days, the prepupal and pupal stage occupied 13-15 days with the ultimate emergence of adult. Thus, the total period required for the adult to develop into adult spanned over 29-35 days.

Food consumption and growth

The quantity of food consumed by each of the five instars and the weight gained by the respective instar are given the Table- 3.1.1. Both the quantity of
food consumed and the weight gained by the larvae increased across the successive instars. Adopting the regression equation $Y=a\pm bx$, the regression on the weight gained by larva to the weight of the food ingested per day showed a linear relationship between these two variables (Fig. 3.1.2). This correlation indicated the existence of a direct correlation between the two variables, with the $r$ value ($r=0.87$) and regression equation $Y=0.16X-52.77$. Of the total food consumed, the proportion the food consumed by the successive respective instars were 0.68, 3.03, 7.24, 22.11 and 69.25%. Thus, the last two instars consumed maximum amount of food. The proportion of the food gained by each instars in the total weight were 0.23, 2.45, 9.60, 28.35 and 78.11% thus the last two instars consumed more food and gained a greater weight than earlier instars. There was a general trend of decrease in the value of growth rate (GR) and consumption index (CI) as the instar progressed, but there was no uniform decrease. The value of GR varied between 0.14 to 0.95 mg/day and those of CI between 1.8 to 10.28 mg/day. In both cases the highest values were associated first instars and lowest with the final instars respectively.

**Indices of food utilization efficiency**

Table 3.1.1 also includes the data on Approximate digestibility (AD), Efficiency of conversion of digested food (ECD), Efficiency of conversion of ingested food (ECI). The values of AD decreased as the larval stage advanced; the values ranged between a high of 99% in the I instar to a low of 85% in the V instar. The values of ECD and ECI increased as the larval stage progressed. The values of ECD ranged between 8.12- 19.8% and those of ECI from 3.5-20.3%, in both the cases the lowest values were observed at the I instar, whereas the highest values were associated with V instar.
Table 3.1.1. Food consumption, growth and utilization efficiencies of *Graphium agamemnon* on *Polyalthia longifolia* leaves

<table>
<thead>
<tr>
<th>Instar No.</th>
<th>Wt. of the food ingested (mg)</th>
<th>Wt. of the faeces (mg)</th>
<th>Wt. gain by the larva (mg)</th>
<th>GR</th>
<th>CI</th>
<th>AD %</th>
<th>ECD %</th>
<th>ECI %</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>25.2±0.85</td>
<td>0.15±0.06</td>
<td>2.56±0.40</td>
<td>0.95</td>
<td>1.80</td>
<td>99</td>
<td>8.12</td>
<td>3.5</td>
</tr>
<tr>
<td>II</td>
<td>102.5±1.85</td>
<td>3.05±0.36</td>
<td>14.60±0.65</td>
<td>0.55</td>
<td>3.12</td>
<td>96</td>
<td>18.65</td>
<td>18.8</td>
</tr>
<tr>
<td>III</td>
<td>1512.8±5.5</td>
<td>108.50±2.85</td>
<td>215.6±3.10</td>
<td>0.45</td>
<td>3.83</td>
<td>95</td>
<td>15.5</td>
<td>14.2</td>
</tr>
<tr>
<td>IV</td>
<td>2550.5±15.23</td>
<td>185.5±1.56</td>
<td>275.2±4.65</td>
<td>0.18</td>
<td>1.71</td>
<td>90</td>
<td>13.6</td>
<td>13.6</td>
</tr>
<tr>
<td>V</td>
<td>2800.4±12.56</td>
<td>510.6±5.12</td>
<td>575.8±4.10</td>
<td>0.14</td>
<td>1.28</td>
<td>85</td>
<td>19.8</td>
<td>20.3</td>
</tr>
</tbody>
</table>

Fig. 3.1.2. Regression line showing larval growth Vs food consumption rate in *Graphium agamemnon*
Life history stages of *Graphium agamemnon* (L.)

- Adult
- Eggs
- I\(^\text{st}\) Instar
- II\(^\text{nd}\) Instar
- III\(^\text{rd}\) Instar
- IV\(^\text{th}\) Instar
- V\(^\text{th}\) Instar
- Pupa

"Ecology of butterflies of the family Papilionidae in mid Western Ghats of Shimoga district, Karnataka"
3.2. Studies on detailed Biology of Papilio demoleus (Linnaeus)

Results

Adults (Fig. 3.2.1a)

Both male and female butterflies are black and tailless, with a wingspan of 60-70 mm. Upper forewing has a broad irregular yellow discal band divided into large irregular spots and patches. Marginal and terminal rows of yellow spots are present on fore and hind wings. Head is pale black with white markings, and antennae are snuff colored. As the age advanced, the yellow markings on the wings become deep orange.

Life History Stages

Oviposition

Ovipositing occurs mainly during 08.00-12.00 O’clock of the day. Breeding females lay their eggs singly on the either surface of tender leaves, sometimes on tender twigs of its host plants viz., Citrus aurantifolia, Citrus grandis, Citrus limon, Citrus sinensis, Murraya koenigii, Glycosmis arborea, Aegle marmelos, Chloroxylon swietenia, Xanthoxylum rhetsa and Acronychia pedunculata from our study areas. But most commonly it preferred Citrus aurantifolia, Citrus grandis, Citrus limon, Citrus sinensis and Murraya koeniggi for oviposition in the present study areas.

Eggs (Fig. 3.2.1b)

The same leaf is used to deposit 8-10 eggs at a time or it may be used again and again over a period of 2-3 days. The eggs are cream colored, spherical, smooth, and 1.80-2.10 mm in diameter. They hatch after 3-4 days.
Larva

The larva undergoes four moults and has five instars, which are described below:

**I instar** (Fig 3.2.2c)

This instar lasts for duration of 2-3 days. The larva grows to 4.5-5.2 mm in length and its head is round with two tiny lateral brown spines. Its body is light brown to pale black with white blotch on the dorsal surface between thorax and abdomen showing resemblance to birds excreta. The abdomen is terminated with a berry narrow anal region.

**II instar** (Fig 3.2.2d)

This instar lasts for 3-4 days. It grows up to 10.5-11.5 mm in length, its head is 1.00-1.6 mm in diameter. Its body is rough black with less spiny surface and with a white blotch obliquely along the lateral sides of the abdomen, thorax and anal region. A horn like structure was present on dorsal side.

**III instar** (Fig 3.2.2e)

The duration of this instar lasts for 3-4 days. It grows to 20-22 mm in length and 4.0-5.1 mm in width. Its head is 3-5 mm in diameter. Other characters remained unchanged as of II instar except the size.

**IV instar** (Fig 3.2.2f)

This instar lasts 3-4.5 days. It grows to 28-31.5 mm in length and 5.5-7.5 mm in diameter. Its head is 2.5-3.20 long and 2.3-3.0 mm wide, the ventral profile of the body is pale green with oblique black bands on the abdominal and anal regions. The legs are brown and body segmentation is clear, spines are
prominent on the lateral side of the head and anal regions. Two reddish osmeteria openings were seen on the first thoracic segment.

**V instar** *(Fig 3.2.2g)*

This instar lasts for duration of 3.5-4.5 days. It grows to 44.00-45.5 mm in length 9.5-11.5 mm in width. Its head is dark brown, 3-4.5 mm long and 4.6-5.5 mm wide. The thorax and dorsal profile of the body show two horizontal brownish bands, and the color changes to green and the black spots begin to fade. Two eyes like spots were present on second thoracic segment and horn like structures were present on the lateral side of body segments. Other characters remain the same as in IV instar.

**Pupa** *(Fig. 3.2.2h)*

The larvae thus passed through five instars over a period of 15-19 days enter the Prepupal stage, this stage took 1.5-2 days for transformation to the pupa. It measured 36-38 mm in length. It attaches to the substratum with its entire body hung with the help of silk girdle.

Pupa varied in colour from green, straw to brown, with majority being green in colour. This stage lasts for about 15-17 days and measures 29-32 mm long and 7.5-9 mm wide. Its thorax is pale green in color. Posterior end of the pupa is pointed. Thus total life cycle from egg to adult emergence was observed to be 31-39.5 days with an average of 35.25 days.

**Food consumption and growth**

The quantity food consumed by each of the five instars and the weight gained by the respective instar are given the Table 3.2.1. Both the quantity of food
consumed and the weight gained by the larvae increased across the instars. Adopting the regression equation $Y=a+bx$, the regression on the weight gained by larva to the weight of the food ingested per day showed a linear relationship between these two variables (Fig. 3.2.2), this indicated direct correlation between the two variables, with the $r$ value, $r = 0.74$ and regression equation $Y=0.15X-36.54$. Of the total food consumed, the proportion the food consumed by the successive instars were 0.58, 2.03, 8.24, 23.20 and 67.85%. Thus, the last two instars consumed a greater amount of food. The proportion of the weight gained by each instars in the total weight were 0.18, 2.65, 9.80, 26.25 and 74.11% thus the last two instars consumed more food and gained a greater weight than other instars. There was general trend of decrease in the value of growth rate (GR) and consumption index (CI) as the instar progressed, but there was no uniform decrease. The value of GR varied between 0.20 to 0.98 mg/day and those of CI between 1.28 to 9.50 mg/day. In both cases the highest values were associated first instars and lowest with the final instars.

**Indices of food utilization efficiency**

Table 3.2.1 includes the data on Approximate digestibility (AD), Efficiency of conversion of digested food (ECD), Efficiency of conversion of ingested food (ECI). The values of AD decreased as the larval stage advanced; the values ranged between a high of 96% in the I instar to a low of 78% in the V instar. The values of ECD and ECI increased as the larval stage progressed. The values of ECD ranged between 10.82- 20.8 % and those of ECI from 10.5-17.3%. In both the cases the lowest values were observed at the I instar, whereas the highest values were associated with V instar.
Table 3.2.1. Food consumption, growth and utilization efficiencies of *Papilio demoleus* (Linnaeus) on *Citrus limon* leaves

<table>
<thead>
<tr>
<th>Instar No.</th>
<th>Wt. of the food ingested (mg)</th>
<th>Wt. of the faeces (mg)</th>
<th>Wt. gain by the larva (mg)</th>
<th>GR</th>
<th>CI</th>
<th>AD %</th>
<th>ECD %</th>
<th>ECI %</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>28.2±0.67</td>
<td>0.35±0.05</td>
<td>3.46±0.50</td>
<td>0.96</td>
<td>8.50</td>
<td>96</td>
<td>10.82</td>
<td>10.5</td>
</tr>
<tr>
<td>II</td>
<td>122.5±2.85</td>
<td>3.10±0.066</td>
<td>20.50±0.65</td>
<td>0.52</td>
<td>4.52</td>
<td>89</td>
<td>12.55</td>
<td>14.8</td>
</tr>
<tr>
<td>III</td>
<td>452.8±3.50</td>
<td>65.50±1.65</td>
<td>148.6±3.10</td>
<td>0.42</td>
<td>3.56</td>
<td>85</td>
<td>13.56</td>
<td>12.3</td>
</tr>
<tr>
<td>IV</td>
<td>1680.5±6.28</td>
<td>138.5±1.66</td>
<td>245.2±4.65</td>
<td>0.33</td>
<td>2.28</td>
<td>83</td>
<td>17.86</td>
<td>11.5</td>
</tr>
<tr>
<td>V</td>
<td>2790.4±9.66</td>
<td>389.6±5.22</td>
<td>455.8±5.20</td>
<td>0.19</td>
<td>1.45</td>
<td>78</td>
<td>20.50</td>
<td>17.2</td>
</tr>
</tbody>
</table>

Y = 0.15X - 36.54
r = 0.74

Fig. 3.2.2. Regression Line showing larval growth Vs food consumption rate in *Papilio demoleus* (Linnaeus).
Figure - 3.2.1 Life history stages of *Papilio demoleus*

a. Adult
b. Eggs
c. I" Instar
d. II" Instar
e. III" Instar
f. IV" Instar
g. V" Instar
h. Pupa

"Ecology of butterflies of the family Papilionidae in mid Western Ghats of Shimoga district, Karnataka"
3.3. Studies on detailed Biology of *Papilio polytes* (Linnaeus)

Results

**Adults** (Fig. 3.3.1a)

A large butterfly with a wingspan of 80 - 115 mm. The male is black and has small creamy white markings on the outer margins of both wings. On both sides of the hind wing, there is a central band of creamy white spots. This is an interesting polymorphic species. The male has only one colour form but the female has three, two of which are mimics. The typical female form, *Cyrus* resembles the male. It is larger than the male and paler in color. The form *Stichius* mimics the unpalatable Common Rose. The third form, *Romulus*, mimics the unpalatable Crimson Rose. The 2 mimics are quite variable and frequently display aberrations including gynadromorphs.

**Oviposition**

Breeding females layed their eggs singly on the either surface of tender leaves, sometimes on tender twigs of *Citrus limon* and *Murraya koeniggi*.

**Life History Stages**

**Eggs** (Fig. 3.3.1b)

The same leaf is used to deposit 8-10 eggs at a time or it may be used again and again over a period of 2-3 days. Ovipositing occurs mainly during 0800-1200 O’clock of the day. The eggs are cream colored, spherical, smooth and 0.80-1.10 mm in diameter. They hatch after 3-4 days.

**Larva**

The larva undergoes four moults and has five instars, which are described below
I instar (Fig. 3.3.1c)

Duration of this instar is 2-3 days. The larva grows upto 5.5-6.2 mm in length, its head is round with two tiny lateral brown spines. Its body is pale brown with tufts of setae in the thoracic and anal regions. The abdomen is terminated with a berry narrow anal region.

II instar (Fig. 3.3.1d)

This stage lasts 3-4 days. Larvae grows upto 11.5-12.5 mm in length its head is 1.41-1.7 mm in diameter. Its body is rough snuff coloured and with a white markings on the dorsal profile of the abdomen and anal regions. The lateral sides of the head and anal region show two spines each.

III instar (Fig. 3.3.1e)

This stage lasts 3-4 days. It grows to 21-22 mm in length and 4.5-5.4 mm in width. Its head diameter is about 2-5 mm. All other characters remain similar to II instar.

IV instar (Fig. 3.3.1f)

This stage lasts 3-4 days. It grows to 29-30.5 mm in length and 6.5-7.5 mm in diameter. Its head is 2.2-3.10 long and 2.5-3.2 mm wide. The ventral profile of the body is brown while the dorsal profile green with two brown bands on the thorax and two lateral brown bands on the abdominal region and one horizontal brown band on anal region. The legs are brown and body segmentation is clear with 13 segments.
Section-III

V instar (Fig. 3.3.1g)

This stage lasts 3-4 days. It grows to 43.00-44.5 mm in length 9-11 mm in width and head is dark brown, 3-4 mm long and 4.5-5.7 mm wide the thorax and dorsal profile of the body show two horizontal bands. Other characters remain the same as in IV instar.

Pupa (Fig. 3.3.1h)

The larvae thus passed through five instars over a period of 15-19 days enter the Prepupal stage, this stage takes 1.5-2 days for transformation to the pupa it measures 37-39 mm in length. It attaches to the substratum with its entire body hung with the help of silk girdle.

Pupa varied in colour from straw to brown, with majority being straw in colour. This stage lasts for about 16-18 days and measures 30-32 mm long and 7.5-9 mm wide. Its thorax is pale straw in color. Posterior end of the pupa is pointed. Thus total life cycle from egg to adult emergence was observed to be 35-40 days with an average of 37.5 days.

Food consumption and growth

The quantity of food consumed by each of all the five instars and the weight gained by the respective instar are given in the Table 3.3.1. Both the quantity of food consumed and the weight gained by the larvae increased across the instars. Adopting the regression equation \( Y = a + bx \), the regression on the weight gained by larva to the weight of the food ingested per day showed a linear relationship between these two variables (Fig. 3.3.2). This correlation indicated direct correlation between the two variables, with the \( r \) value (\( r = 0.72 \)) and
regression equation $Y=0.14X-37.76$. Of the total food consumed, the proportion the food consumed by the successive instars were 0.55, 2.33, 5.21, 19.31 and 65.35%. Thus, the last two instars consumed a greater amount of food. The proportion of the food gained by each instars in the total weight were 0.11, 2.20, 8.62, 22.30 and 78.12% respectively, thus the last two instars consumed more food and gained a greater weight than other instars. There was general trend of decrease in the value of growth rate (GR) and consumption index (CI) as the instar progressed, but there was no uniform decrease. The value of GR varied between 0.19 to 0.99 mg/day and those of CI between 1.38 to 9.80 mg/day. In both cases the highest values were associated with first instars and lowest with the final instars.

**Indices of food utilization efficiency**

Table 3.3.1 also includes the data on Approximate digestibility (AD), Efficiency of conversion of digested food (ECD) and Efficiency of conversion of ingested food (ECI). The values of AD decreased as the larval stage advanced; the values ranged between a high of 99% in the I instar to a little low of 85% in the V instar. The values of ECD and ECI increased as the larval stage progressed. The values of ECD ranged between 10.15- 20.80 % and those of ECI from 10.5-16.2%. In both the cases the lowest values were met at the I instar, whereas the highest values revealed at V instar.
Table 3.3.1. Food consumption, growth and utilization efficiencies of *Papilio polytes* (Linnaeus) on *Citrus limon* leaves

<table>
<thead>
<tr>
<th>Instar No.</th>
<th>Wt. of the food ingested (mg)</th>
<th>Wt. of the faeces (mg)</th>
<th>Wt. gain by the larva (mg)</th>
<th>GR</th>
<th>CI</th>
<th>AD %</th>
<th>ECD %</th>
<th>ECI %</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>30.2±0.65</td>
<td>0.18±0.03</td>
<td>3.16±0.50</td>
<td>0.99</td>
<td>9.80</td>
<td>99</td>
<td>10.15</td>
<td>10.5</td>
</tr>
<tr>
<td>II</td>
<td>1035.5±1.85</td>
<td>3.80±.056</td>
<td>20.50±0.65</td>
<td>0.61</td>
<td>3.80</td>
<td>97</td>
<td>11.60</td>
<td>12.8</td>
</tr>
<tr>
<td>III</td>
<td>612.8±2.50</td>
<td>58.50±1.85</td>
<td>142.6±2.10</td>
<td>0.46</td>
<td>3.50</td>
<td>94</td>
<td>13.50</td>
<td>13.2</td>
</tr>
<tr>
<td>IV</td>
<td>1780.5±5.23</td>
<td>135.5±1.56</td>
<td>265.2±3.65</td>
<td>0.26</td>
<td>1.90</td>
<td>94</td>
<td>16.65</td>
<td>14.6</td>
</tr>
<tr>
<td>V</td>
<td>2650.4±8.56</td>
<td>450.6±4.12</td>
<td>455.8±4.10</td>
<td>0.19</td>
<td>1.38</td>
<td>85</td>
<td>20.80</td>
<td>16.2</td>
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</tbody>
</table>

Fig. 3.3.2. Regression line showing larval growth Vs food consumption rate in *Papilio polytes* (Linnaeus)
Figure - 3.3.1 Life history stages of *Papilio polytes*

- **Adult**
- **Eggs**
- **I⁻ Instar**
- **II⁻ Instar**
- **III⁻ Instar**
- **IV⁻ Instar**
- **V⁻ Instar**
- **Pupa**
3.4. **Studies on detailed Biology of *Graphium doson* (Linnaeus)**

**Results**

**Adult** (Fig. 3.4.1a)

*Graphium doson* is a black Papilionid butterfly with a pale blue semi-transparent central band that is formed by large spots. Wingspan: 70-85 mm. Male and female tailless, a pale green semi transparent discal band on both the wings from near apex of Fore Wing (FW) nearly to dorsum of Hind Wing (HW). This band passes through HW and is broken up into spots on FW, narrowing and becoming irregular towards apex. The short black, red centered costal bar near the base Under Hind wing (UNH) is not joined to the basal dark band. Extreme end cell is brown. Abdomen is black above and white below (Fig. 3.4.1a).

**Life history stages**

**Oviposition**

Oviposition was observed on *Annona lawii, Polyalthia longifolia, Cinnamomum macrocarpum, Michelia champaka* and *Artabotrys hexapetal* from the study areas. *Polyalthia longifolia* and *Michelia champaka* was found to be most commonly preferred plants for oviposition.

**Egg** (Fig. 3.4.1b)

The eggs are laid singly on the tender leaves of *Michelia champaka*. They are pale yellow in colour, round with smooth surface. Diameter 0.88-1.9 mm, the hatching period lasted for 3 to 4 ½ days (Fig.1b). Many Papilionids lay their eggs
single (Stamp, 1980) and the same trend was observed in *Graphium doson*. Larvae pass through five instars, whose specific characters and morphometry are mentioned below.

**I instar** (Fig. 3.4.1c)

This stage lasts for 2-3 days grows upto 3-4.4 mm in length and attains the width of 1.50 to 1.78 mm. Its body is snuff coloured with white hairy structure on head, thorax and abdomen region (Fig. 3.4.1c).

**II instar** (Fig. 3.4.1d)

The duration of this instar lasted for 3-3 ½ days and the larvae attained a length of 6.5 to 8.4 mm and width of 2.00 to 2.50 mm respectively. The colour of the body remained snuff. Thorax was wider than the abdomen (Fig. 3.4.1d).

**III instar** (Fig. 3.4.1e)

The third instar larvae changed its body colour from snuff to brown with pale yellow and snuff colored spines. The duration of the instar was for 3-4 days with length of 15-19.5 mm and width of 2.60-2.90 mm (Fig. 3.4.1e).

**IV instar** (Fig. 3.4.1f)

This stage lasts for 3-4 ½ days with the larvae attaining the length of 32-44 mm and a width: 3.50-4.70 mm. The Body colour resembled the III instar larvae with segmentation, spots and snuffs colored spines (Fig. 3.4.1f).
V instar (Fig. 3.4.1g)

This instar lasted for $4\frac{1}{2} - 5\frac{1}{2}$ days with the larval length of 45-50 mm and width of 5.0-6.0 mm. Body colour changes to green and its segmentation is clear (Fig. 3.4.1g). IV and V instar larvae had an osmeterial gland in the first thoracic segment and this organ serves as a defensive in function by secreting pungent odour if the larva is disturbed. These descriptions are similar with the findings of Leslie and Berenbaum (1990) who reported that secretions contain Iso-buteric acid and small quantities of methyl and ethyl esters.

Pupa (Fig. 3.4.1h)

Duration of pupal stage lasted for 15 to 17 days with green colour and several brown margins on the body, anterior end is V shaped and posterior end attached to substratum. The length and width of pupa was 30-34 mm and 8.0-9.5 mm respectively. Thus the total period from egg to adult emergence lasted for a span of 31-36 days (Fig. 3.4.1h).

Food consumption and growth

The quantity food consumed by each of the five instars and the weight gained by the respective instar are given the Table 3.4.1. Both the quantity of food consumed and the weight gained by the larvae increased across the instars. Adopting the regression equation $Y=a+bX$, the regression on the weight gained by larva to the weight of the food ingested per day showed a linear relationship between these two variables (Fig. 3.4.2), This correlation indicated direct...
correlation between the two variables, with the r value (r =0.92) and regression equation Y=0.18X-57.77. Of the total food consumed, the proportion the food consumed by the successive instars were 0.65, 2.03, 6.21, 20.31 and 66.35%. Thus, the last two instars consumed a greater amount of food. The proportion of the food gained by each instars in the total weight were 0.13, 2.00, 7.61, 26.30 and 68.12% thus the last two instars consumed more food and gained a greater weight than other instars. There was general trend of decrease in the value of growth rate (GR) and consumption index (CI) as the instar progressed, but there was no uniform decrease. The value of GR varied between 0.20 to 0.98 mg/day and those of CI between 1.28 to 9.50 mg/day. In both cases the highest values were associated first instars and lowest with the final instars.

**Indices of food utilization efficiency**

Table 3.4.1 also includes the data on Approximate digestibility (AD), Efficiency of conversion of digested food (ECD), Efficiency of conversion of ingested food (ECI). The values of AD decreased as the larval stage advanced; the values ranged between a high of 99% in the first instar to a low of 88% in the V instar. The values of ECD and ECI increased as the larval stage progressed. The values of ECD ranged between 11.12- 21.8 % and those of ECI from 11.5-18.3% in both the cases the lowest values were observed in the I instar, whereas the highest values were associated with V instar.
Table 3.4.1. Food consumption, growth and utilization efficiencies of *Graphium doson* on *Michelia champaka* leaves

<table>
<thead>
<tr>
<th>Instar No.</th>
<th>Wt. of the food ingested (mg)</th>
<th>Wt. of the faeces (mg)</th>
<th>Wt. gain by the larva (mg)</th>
<th>GR</th>
<th>CI</th>
<th>AD %</th>
<th>ECD %</th>
<th>ECI %</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>29.2±0.65</td>
<td>0.25±0.03</td>
<td>3.56±0.50</td>
<td>0.98</td>
<td>9.50</td>
<td>99</td>
<td>11.12</td>
<td>11.5</td>
</tr>
<tr>
<td>II</td>
<td>132.5±1.85</td>
<td>4.10±.056</td>
<td>21.60±0.65</td>
<td>0.51</td>
<td>4.12</td>
<td>96</td>
<td>13.65</td>
<td>16.8</td>
</tr>
<tr>
<td>III</td>
<td>512.8±2.50</td>
<td>68.50±1.85</td>
<td>152.6±2.10</td>
<td>0.45</td>
<td>3.53</td>
<td>95</td>
<td>14.5</td>
<td>13.2</td>
</tr>
<tr>
<td>IV</td>
<td>1750.5±5.23</td>
<td>145.5±1.56</td>
<td>265.2±3.65</td>
<td>0.36</td>
<td>2.10</td>
<td>93</td>
<td>18.6</td>
<td>12.6</td>
</tr>
<tr>
<td>V</td>
<td>2980.4±8.56</td>
<td>410.6±4.12</td>
<td>475.8±4.10</td>
<td>0.20</td>
<td>1.28</td>
<td>88</td>
<td>21.8</td>
<td>18.3</td>
</tr>
</tbody>
</table>

Fig. 3.4.2. Regression line showing larval growth Vs food consumption rate in *Graphium doson*
Figure - 3.4.1 Life history stages of *Graphium doson*

- **Adult**
- **Eggs**
- **1st Instar**
- **2nd Instar**
- **3rd Instar**
- **4th Instar**
- **5th Instar**
- **Pupa**

“Ecology of butterflies of the family Papilionidae in mid Western Ghats of Shimoga district, Karnataka”
Discussion

For each of the four Papilionidae butterfly species studied, data was recorded in respect of oviposition, larval host plants, egg-laying patterns, incubation period, the number of moults and hence the number of instars, and their duration, pupal period, and larval performance on the basis of growth rate (GR), consumption index (CI), approximate digestibility (AD), efficiency of conversion of digested food (ECD) and efficiency of conversion of ingested food (ECI). Based on the duration of egg hatching, larval life, pupal period and adult life expectancy, the number of broods expected annually was also estimated. These different aspects of the study have been discussed below in the light of the related information available from temperate and tropical regions of the world.

Successful ovipositing involves three steps. They are: (1) the adult female searching for the host plant and her responses to the cues or stimuli from the available potential host plant(s); (2) contact of the adult female with the host plant tissue; and (3) the adult female curving its abdomen ventrally and ovipositing (Renwick and Chew, 1994). The breeding females searching for host plants for depositing eggs may locate the potential host plants while flying and alight on them or may not be able to recognize the host plants before alighting on them and therefore alight at random to test their suitability for ovipositing. The former behavior is named as ‘apotypic’, and the latter as ‘plasiotypic’ (Sensu and Wiklund, 1977). Apotypic behaviour enables the butterfly to utilize the less abundant plants with reasonable regularity. On the other hand, plasiotypic behaviour restricts freedom of choice and hence abundant species are only amenable for utilization with reasonable regularity. The study found plasiotypic behaviour with all the egg-laying females of the four butterfly species, and the
host plants used for oviposition by each of the butterfly species is relatively abundant in the study area.

Female butterflies touched down and 'tasted' the leaf or the other substratum with her front legs, perhaps to perceive the volatile biochemical properties of the substratum (Isle, 1955; Fox, 1966; Renwick and Chew, 1994). Once the correctness of the substratum 'tasted', the female engaged in egg-laying alighted on the substratum and deposit egg by curving its abdomen ventrally. This kind of touch and go device used for 'tasting' the suitability of host plant was also reported by Vaidya (1970); Sensu and Wiklund (1977); Saxena and Goyal (1978); Opler and Krizek (1984); Venkataramana (1998); Krishna Reddy (2000) and Atluri et al. (2004). This behaviour is identical to all the four Papilionidae described in our study.

Some authors attempted to find the heritable basis for host plant selection by ovipositing females - reviewed in Thompson and Pellmyr (1991). These authors suggest that host selection is controlled by a single gene or by more than one gene. In *Papilio oregonius* and *P. zelicaon*, oviposition preference is under the control of one or more loci on the X-chromosomes (Thompson, 1988).

Thus it appears that host selection by the ovipositing females is not that simple to understand and interpret. A complex set of factors appears to influence host plant choice by the breeding females for laying their eggs. Host plant chemistry, plant size and appearance, leaf or substratum characters like shape and colour, and ecological factors like phenology and host plant quality and also the microclimate are all among such factors implicated in host plant selection for oviposition (Chew and Robbins, 1984; Singer, 1984; Thompson and Pellmyr,
1991; Renwick and Chew, 1994). The abundance of host plants and environmental factors determine the ecological adaptation of the respective butterfly species as suggested by Janz et al. (1994).

Host plant specialization is considered to be advantageous since it enables more efficient exploitation of the host resource (Singer, 1984). Host specificity of the butterfly not only influences the food supply of larvae but also stimulates the adults to lay eggs (Moore and Menash, 2001). The larval food plants recorded for each of the four butterflies under our study area is in agreement with the earlier reports (Talbot, 1947; Wynter-Blyth, 1957; Sevastopulo, 1973; Gunathilagaraj et al., 1998; Kunte, 2000).

Based on the spectrum of plant species utilized by the larvae for feeding, the butterfly species are generally categorized into three groups as (1) monophagous, (2) oligophagous and (3) polyphagous. The first category of butterflies feed on only a few plant species in one genus, the second category on several plants in different genera of a family or a few closely related families, and the third category on many plants in a number of unrelated families (Opler and Krizek, 1984). Analysis of the host plants of the four butterfly species under study in the context of the above concept indicating that, all the four Papilionidae Graphium agamemnon, Papilio demoleus, Papilio polystes polystes and Graphium doson could be treated as oligophagous or polyphagous.

Sevastopulo (1973) compiled a list of the food plants for 345 butterfly species of 10 families occurring in the zoological area embracing the present political India, Pakistan, Bangladesh, Burma and Sri Lanka. Of this total butterfly species, 43.75% are monophagous, 39.75% oligophagous, and the remaining
16.50% polyphagous. Based on the information of larval food plants of 302 butterfly species in 10 families given as Appendix by Wynter-Blyth (1957), it is found that 64% of are monophagous, 20% oligophagous and the other 16% polyphagous. Thus it appears that in any geographical area, most species have adapted to monophagy or oligophagy. But the present observations made for all the four species studied from this area, all of them are found to be polyphagous but they prefer to have oligophagy. This observation support the analysis of Futuyma (1976) who mentioned that plants contain a variety of chemicals, particularly the alkaloids, and these chemicals are implicated as a cause for the evolution of larval feeding strategy with restriction in host choice.

Scriber (1986) expressed that the extent of feeding niche that could be realized is restricted by several factors including ecological and behavioural factors and the low density of physiologically suitable food plants, and therefore local food plant(s) specialization or ‘ecological monophagy’ is likely to be the rule in Lepidoptera rather than exception. Accepting this concept of ecological monophagy, it can be said that the four butterfly species may become local specialists depending on the spatial distribution of their food plants, this also agrees with the earlier workers of Fox and Marrow (1981) who concluded that food plant specialization is a local phenomenon.

Kitching (1981) recognized three categories of butterflies: (1) those that lay large clusters of greater than 10 eggs, (2) those that lay clusters of 2-10 eggs, and (3) those that lay eggs singly. Most authors considered only two categories: (1) the cluster or batch layers, and (2) those laying eggs singly. Analyses of the egg-laying habits among the butterflies of different geographical regions revealed the dominance of the single-egg laying habit than the cluster or batch laying habit
(Chew and Robbins, 1984; Thompson and Pellmyr, 1991). In India also there is the predominance of single-egg laying habit (Kunte, 2000). Atluri et al. (2004) working on some Papilionidae butterflies of south India opined majority of the butterflies lay eggs singly. Stamp (1980), described 66 of the 67 Papilionid butterfly species lay their eggs singly. The only Papilionid that is a batch layer is the malabar banded swallowtail *Papilio buddha* which lays eggs in groups of 6 or more (Kunte, 2000). The four Papilionid butterfly species of the present study exhibit single-egg laying habit. Thus, it can be concluded that this geographical area i.e. Mid-Western Ghats region also has the predominance of single egg layers over cluster or batch layers.

It is generally known that growth to the adult in insects is discontinuous. The larvae pass through several instars during which they feed and grow, separated by non-feeding moulting periods. The number of moultings, and hence the number of instars during the larval period may vary from species to species. But many species in general exhibit 4-6 instars (Wigglesworth, 1965). Each of the four butterfly species under study exhibited five distinct instars. No variation was found from this number at any time during the course of the study. There was no variation also between individuals of a species. Therefore, this number of five instars recorded may be constant for each of the butterfly species under the present study.

The results on duration required for the development from egg through larval and pupae stage to the emergence of adult and developmental success of larva and pupae in the laboratory all suggested more than one brood occurring with all the four Papilionidae butterfly species of our study area.
The developmental time from the laying of egg to the emergence of adults is much shorter in all the butterfly species of our study. Palanichamy et al. (1982) working with the lepidopteran Eupterote mollfera observed faster development at higher temperatures resulting in decreased instar duration from 12 days at 22°C to 5 days at 37°C. According to Nayar et al. (1976), the larvae of Eurema blanda become full grown in 22-26 days in December (winter month) and 11-14 days in March (summer month); the adult emerges in 11-14 days in December and 6-7 days in March. Also low and high temperature effects influenced the duration of the life cycle of Papilio demoleus. Its life cycle normally occupies 18-40 days, but depending on temperature extends to 145 days. The study area being located in the Western Ghats zone, there is no much temperature extremes, hence there is only little variation in the duration in winter and summer months. But the wet period including rainy and winter months registered higher breeding activity than the summer months with all the four butterfly species under study. These observations are in line with Wynter-Blyth (1957) who stated that over most part of India, the favourable period for breeding of butterflies is the rainy season, followed by post-monsoon and south-west monsoon periods, and in South India these best months depend on local rainfall.

In temperate regions of the world very distinct climate seasons exist and thus butterfly flight is severely limited by severe winter conditions (Gooden, 1974), and therefore the butterflies have a restricted and predictable breeding seasons. Accordingly, majority of butterfly species of temperate regions are univoltine and have a single brood annually. On the other hand, climate is less seasonal in the tropics and a fairly high temperature prevails throughout the year, and as such most of the flora and fauna remain luxuriant throughout the year,
many butterflies have 5-6 broods each per year (Ewusie, 1980; Venkataramana, 1998; Krishna Reddy, 2000). Accordingly, butterflies in the tropical regions breed throughout the year or over a major part of the year, and thus have more than one brood annually. Similar observations were made from our study where all the four species are multivoltine with 5-6 broods each per year with better breeding ability during October to February.

The larvae of the four butterfly species under study were found to eat firstly the egg-shell containing ‘valuable nutrients available immediately after larvae hatched out from the egg. After eating the shell, the larvae continued to feed on young leaves and/or flower buds of the oviposition host plant. Therefore, the larvae were reared in the laboratory by providing fresh young leaves every day to feed. There was 100% survival and good growth on such food material was observed. There is an evidence to show that, the leaves possess ample supplies of the essential nutrients (Fraenkel, 1953), and the young leaves support better larval growth than older ones (Fleeny, 1976; Watanabe, 1979). Some species prefer young inflorescences (Breedlove and Ehrlich, 1968; Wiklund and Ahrberg, 1978; Courtney, 1981, 1982). Both young leaves and flowers are known to be rich in nitrogen content (Muthukrishnan, 1990), and satisfy the nutritional requirement of larvae. Higher nitrogen levels increase larval survival (Myers, 1985; Baylis and Pierce, 1991). However, Dethier (1954) expressed that relative abundance of nitrogen, carbohydrates and minerals, i.e., overall metabolic rate of the host plant, is of greater importance than such gross factors as nitrogen or carbohydrate or even C/N ratio.

The data obtained on the quantity of food consumed and growth achieved, and the values of consumption index (CI) and growth rate (GR) showed a definite
trend of increasing gradually and declining rates of CI and GR with all the four species of butterflies under study. There was a straight line relationship between food consumption and growth. A similar strategy of increased food consumption with the advancement of larval age has been reported in the lepidoptera in general (David and Gardiner, 1962; Waldbauer, 1968; Mathavan and Pandian, 1975; Scriber and Slansky, 1981; Palanichamy et al., 1982; Selvasundaram, 1992; Ghosh and Gonchaudhuri, 1996; Venkataramana, 1998; Krishna Reddy, 2000 and Atluri et al., 2004).

Consumption index (CI) of I instar was the highest in all the butterfly species under study (Table -3.1.1 to 3.4.1). The values increased rather steeply from the I instar but decreased rather slowly as the instars progressed. This decline in CI as the larvae aged may be related to the increase in body size of the larvae or to the increase in conversion efficiency of ingested food to body mass (ECI). When the values of ECI increase, the values of CI decrease or the vice versa (Slansky and Scriber, 1985). So the high consumption index of early instars is due to the low conversion efficiency. The values of conversion efficiency (ECI) showed an increasing trend as the values of CI decreased across the instars (Table 3.1.1 to 3.4.1). The values of CI obtained in the present study for early and late instars agree well with the values obtained for some Papilionidae butterfly by Atluri et al. (2004).

As the larval instar progressed the relative rates (Growth rate) generally declined (Table- 3.1.1 to 3.4.1). Probably GR is size dependant, and therefore its values declined as the instar progressed gaining weight and size. A similar declining trend in GR has been reported in other butterfly species (Atluri et al., 2004) and in the moth Pencallia ricini (Ghosh and Gonchaudhuri, 1996). Thus, an
increase in both food consumption and growth occurred during the final instar larvae of the four butterfly species under study. Such increase is considered essential to accumulate energy-rich fat to meet the metabolic requirements of non-feeding pupal and adult stages (Waldbauer, 1968; Delvi and Pandian, 1972; Pandian, 1973; Downer and Mathews, 1976; Slansky and Scriber, 1985).

Like CI and GR, the values of assimilation efficiency or approximate digestibility (AD) also declined from early to late instars. But AD profile has an inverse relationship with the amount of food intake by the successive instars. This is in conformity with Waldbauer (1968) and Atluri et al. (2004) who observed a similar relationship, and stated that AD would be at its highest in I instar. In the present study the same expectation has been realized with AD value being at its highest in the I instar in all the four butterfly species.

The AD values of the present study ranged between 85-96%. These values appear to be on the higher side of the range 19-81% given for 60 species of lepidopteran larvae by Pandian and Marian (1986), and the range 28.7-84.6% for Pericallia ricini (Ghosh and Gonchaudhuri, 1996). They are comparable to some tropical butterflies (89-99%) given by Venkataramana (1998) and those (31.0-91.5%) estimated by Krishna Reddy (2000) for Papilinoid butterflies. Food plant characteristics such as nitrogen and water content have a positive influence on AD (Pandian and Marian, 1986).

The declining trend in AD as the larvae grow older is related to the changes in the composition of food selected by the successive instars. Evans (1939) suggested that the I instar larvae eat small bits only, at later instars eat almost the whole leaf. That's way the larvae ingest a larger proportion of indigestible crude
fibre as they become aged which influences AD values to decrease along the successive instars (Kogan, 1986).

An inverse relationship is expected between assimilation efficiency (AD) and efficiency of conversion of digested food or net conversion efficiency (ECD). The ECD values ranged between (8.12 - 21.80) for the four butterfly species of the present study, and are low compared to AD values (Table 3.1.1-3.4.1), but are within the range of 2-87% estimated for lepidoptera feeding on forb foliage (Slansky and Scriber, 1985).

The ECI values in the present study varied between 3.50-20.30% (Table 3.1.1-3.4.1). The values showed a continuous increase from I to V instar. These values are within the range of 1-78% reported for forb foliage chewing Lepidoptera (Slansky and Scriber, 1985). The relationship between food consumption and assimilation efficiency is considered to be rather complex (Muthukrishnan, 1990). But it is generally believed that a faster consumption results in rapid passage of food through the gut and thus provides less time for digestive enzymes to deal with the substrate. Since assimilation efficiencies are large for all the four butterfly species under study. It is presumed that food might have been retained for sufficient period for the digestive enzymes to act on it, as the leaf contains higher fibre content.

Finally, it may be said that feeding habits and other environmental factors change from place to place, so it is frequently difficult to interpret the cause of the changes in performance values of the larvae. An interaction of internal and external factors may take place in complex ways during the larval development that need to be understood.