Life Table Parameters of *Lycoriella auripila* (Diptera: Sciaridae) on Button and Oyster Mushrooms

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**ABSTRACT**

Life table parameters of *Lycoriella auripila* (Winnertz) (Diptera: Sciaridae) were studied at various constant temperatures, 65±5% relative humidity and a photoperiod of 12L:12D h on different varieties of button (737 and A15) and oyster (Florida and Ostreatus) mushrooms. Adult longevity was decreased with an increase of temperature on A15, Ostreatus and Florida varieties. The longest oviposition period was obtained at 10˚C on A15 and at 20˚C on Florida. All females died immediately after oviposition at 27˚C on 737, at 10 and 25˚C on A15, at 20˚C on Ostreatus and at 20 and 25˚C on Florida. The linear regression revealed a significant relation between the mean generation time of *L. auripila* and temperature on all mushroom varieties. Daily reproductive rates declined gradually after reaching their peaks at all temperatures and on all varieties, except for 20˚C on Ostreatus. All demographic parameters seem to be food-dependent. The highest values of rm were recorded at 25˚C for all experimental varieties. This increase in rm was due to shorter developmental time and higher fecundity. The net reproductive rate (R₀) was the highest at 12.5˚C on A15 and at 25˚C on 737, Ostreatus, and Florida varieties. Increasing temperature resulted in decreasing generation times of *L. auripila* on A15, Ostreatus, and Florida. The A15 and Ostreatus varieties and temperatures below 25˚C are highly recommended for mushroom cultivation to minimize pest damage.

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1. Introduction

Since the 70's, the world mushroom industry has been developing rapidly and mushroom production has increased significantly. From 1970 to 2011, mushroom production increased from 789604 to 7698773 tons with an average annual growth rate of 5.7% (FAO, 2011). The main mushroom production areas of the world are in Asia, Europe and North America, of which the Asian mushroom production is 5302486 tons; accounting for 68.9% of the world production. Among more than 67 mushroom producing countries, China, Italy, United States, the Netherland and Poland are the most important respectively, with an annual output of more than 6663845 tons and 86.5% of the world's mushroom production (FAO, 2011). *L. auripila* (Winnertz) (Diptera: Sciaridae) and *L. ingenua* (Dufour) are major pests of the button mushrooms, *Agaricus bisporus* (Lange) Imbach and the oyster mushrooms, *Pleurotus* spp. (Hussey and Gurney, 1968; Binns, 1980; Richardson and Grewal, 1991; Scheepmaker et al., 1997; Fletcher and Gaze, 2008; Shamshad et al., 2009). Adult flies invade mushroom buildings containing freshly pasteurized or spawned compost and lay eggs in the compost, so mushroom compost is an ideal substrate for larvae of *L. auripila* but the accumulation of their feces makes it unsuitable for

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mushroom growth (White et al., 2000; Grewal, 2007). Emerging larvae feed on compost, destroying structure and water retention capacity. Mycelial colonization of the compost is inhibited, reducing mushroom yields. Meanwhile, some larvae directly feed on fruiting bodies of mushroom. Adult flies play a role as vectors for nematodes, mites and some parasitic fungi (White, 1981; Clift et al., 2004; Grewal, 2007).

Temperature and host have profound effects on insect life history processes such as development, reproduction, survival, mortality and sex ratio (Nava-Camberos et al., 2001; Honek et al., 2003; Keena, 2006; Sánchez-Ramos et al., 2007; Reznik et al., 2009; Chidawanyika, 2010; Xie et al., 2011; Kim et al., 2013). Knowledge about thermal requirements of insects could be important in predicting the potential geographical range of a species and in developing phenological models to predict population dynamics and the timing of various stages for planning control or survey programs (Keena, 2006).

Despite of importance of temperature and host varieties on performance of insect pests, their influence on demography of L. auripila have not been studied. Therefore, the current study was conducted to investigate and compare the effects of temperature and mushroom varieties on L. auripila.

2. Materials and Methods

2.1. Insects culture

Adult flies of L. auripila were originally collected from commercial mushroom farms in Kermanshah (western part of Iran), using aspirator during November 2009. They were placed in plastic dishes containing compost and mycelium of A. bisporus mushroom. All dishes were maintained into a mushroom cultivation saloon at 25±1°C, with relative humidity of 65±5% and a photoperiod of 12L:12D h. Flies were reared in laboratory at least for two generations in order to adapt to laboratory conditions.

2.2. Mycelium culturing on PDA

The sterile spawn of experimental varieties of A. bisporus (A15 and 737) and Pleurotus spp. (Ostreatus and Florida) was cultured on Potato Dextrose Agar (PDA) media in Petri dishes. Experimental dishes were transferred to growth chamber at 25±1°C. The surface of media was fully covered with mycelia of mushroom after 10-15 days.

2.3. Life table parameters

The life table parameters of L. auripila were studied at 10, 12.5, 15, 22.5, 25 and 27°C on a varieties of button mushrooms and at 15, 20 and 25°C on oyster mushroom varieties. Reproduction at 8 and 30 °C were not included since our primary observation confirmed no survival at these temperatures (Shirvani et al., 2013). In order to determine life-table parameters, 15–20 female adults were selected from the stock culture and were transferred to the mushroom filled Petri dishes, for oviposition. After 24h, adults were removed and the numbers of laid eggs were counted. All eggs (between 100-120 eggs at each temperature) were checked daily and after hatching, first instar larvae were transferred to new Petri dishes and separately checked until the emergence of adult flies. Their development was observed daily until maturity. Newly emerged adult females were transferred into new Petri dishes and one male was added to each of the dishes. The number of eggs laid by each female was recorded every 24h until the last female died. The life table parameters for females held at different temperatures were estimated using methods described by Carey (2001). The life table parameters included the intrinsic rate of natural increase (r_m), net reproductive rate (R_0), finite rate of increase (λ) and mean generation time (T).

2.4. Statistical analysis

For statistical analysis, each mean value is given with its standard error of measurement (SEM). As the temperature is a continuous independent variable, a linear regression method was used to fit the relationship between the dependent variable Y (reproduction period and adult longevity) and the independent variable X (temperature). A t-test was run for comparison of biological parameters between two varieties of either button or oyster mushroom at a given temperature. A significance level of α=0.05 was used for all tests. Also, survival rates of L. auripila on each variety at different temperatures were compared using Kruskal-Wallis test. The statistical analysis was carried out using SPSS 16.0 software (SPSS, 2007). Differences in r_m, R_0, T and λ values were statistically tested by estimating variances through the Jackknife procedure (Meyer et al., 1986; Maia et al., 2000). This procedure is often used to estimate variance and bias of parameters and is carried out through repeated recalculation of the required parameters for n-1 females, by eliminating data of one female in turn (Maia et al., 2000). It is used to quantify uncertainty in
estimation of parameters, as an alternative analytical method, in such cases very complicated mathematical derivation is required in analytical procedures (Maia et al., 2000). Here, the Jackknife procedure is described only for \( r_m \). Similar procedures were used for the other parameters (\( R_n \), \( T \) and \( \lambda \)). The Jackknife method was performed in several steps as follows:

(a) Estimation of \( r_m \), \( R_n \), \( T \) and \( \lambda \) using obtained data for all the \( n \) females. The estimates obtained in this step are denoted as \( r_{m(all)}, R_{n(all)}, T_{all} \) and \( \lambda_{all} \) (Maia et al., 2000).

(b) The step (a) was \( n \) times repeated and in each time the data of one female was excluded in calculation. With this method, in each step \( i \), data of \( n-1 \) females were considered to estimate parameters and the estimates were named \( r_{m(i)}, R_{n(i)}, T_{i} \) and \( \lambda_{i} \) (Maia et al., 2000).

(c) The pseudo-values (\( r_{m(i)} \)) were calculated for each parameter using the following equation (Maia et al., 2000):

\[
\hat{r}_{m(i)} = n \times r_{m(all)} - (n-1) \times r_{m(i)}
\]

d) Using \( n \) pseudo-values estimated for \( r_m \), Jackknife estimate of the mean (\( \hat{r}_{m(mean)} \)), variance (\( \text{VAR}_{r_{m(mean)}} \)) and standard error of measurement (\( \text{SEM}_{r_{m(mean)}} \)) were calculated respectively, by the following equations (Maia et al., 2000):

\[
\hat{r}_{m(mean)} = \frac{\sum^n_i r_{m(i)}}{n}
\]

\[
\text{VAR}_{r_{m(mean)}} = \frac{\sum^n_i (r_{m(i)}-r_{m(all)})^2}{n-1}
\]

\[
\text{SEM}_{r_{m(mean)}} = \sqrt{\frac{\text{VAR}_{r_{m(mean)}}}{n}}
\]

### 3. Results

#### 3.1. Reproductive period and longevity at constant temperatures

Females reared on tested varieties of button and oyster mushrooms at different constant temperatures were tested for length of different reproductive periods and female longevity (Table 1). No adult flies were observed at 10°C on 737, at 27°C on A15 and at 20°C on Florida variety and all of the insects died before maturity. On all varieties, females longevity varied significantly as temperature increased (Table 1). Adult longevity decreased with an increase of temperature on A15, Ostreatus and Florida varieties (Table 1). The maximum longevity for females of \( L. auripila \) was obtained at 12.5, 10, 15 and 20°C on 737, A15, Ostreatus and Florida, respectively. Among all tested varieties, the highest longevity was observed at 10°C on 737, at 27°C on A15 and at 20°C on Florida variety.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Temperatures (°C)</th>
<th>Pre-Oviposition</th>
<th>Oviposition</th>
<th>Post Oviposition</th>
<th>Female Longevity</th>
</tr>
</thead>
<tbody>
<tr>
<td>737</td>
<td>12.5</td>
<td>4.00±0.45</td>
<td>2.00±0.38</td>
<td>2.40±0.55</td>
<td>9.00±1.09</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.70±0.26</td>
<td>4.10±0.31</td>
<td>4.10±0.45</td>
<td>8.90±0.50</td>
</tr>
<tr>
<td></td>
<td>22.5</td>
<td>1.44±0.28</td>
<td>2.00±0.33</td>
<td>0.78±0.27</td>
<td>4.22±0.22</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.30±0.22</td>
<td>1.90±0.23</td>
<td>0.10±0.18</td>
<td>2.30±0.21</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>0.50±0.59</td>
<td>2.00±0.84</td>
<td>0</td>
<td>2.50±1.50</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4.50±0.59</td>
<td>6.00±1.46</td>
<td>0</td>
<td>10.50±3.50</td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>4.00±0.38</td>
<td>2.20±0.49</td>
<td>3.00±0.59</td>
<td>9.20±1.07</td>
</tr>
<tr>
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<td>15</td>
<td>1.60±0.42</td>
<td>3.00±0.56</td>
<td>4.60±0.69</td>
<td>9.20±0.73</td>
</tr>
<tr>
<td></td>
<td>22.5</td>
<td>0.67±0.62</td>
<td>3.33±0.71</td>
<td>0.33±0.44</td>
<td>4.33±0.67</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.50±0.59</td>
<td>2.50±1.03</td>
<td>0</td>
<td>3.00±1.00</td>
</tr>
<tr>
<td>A15</td>
<td>15</td>
<td>1.50±0.59</td>
<td>2.50±0.59</td>
<td>3.00±1.19</td>
<td>7.00±3.00</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.50±0.59</td>
<td>4.00±1.19</td>
<td>0</td>
<td>5.50±1.50</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1.11±0.38</td>
<td>1.44±0.28</td>
<td>0.44±0.28</td>
<td>3.00±0.33</td>
</tr>
<tr>
<td>Ostreatus</td>
<td>15</td>
<td>1.50±0.59</td>
<td>2.50±0.59</td>
<td>3.00±1.19</td>
<td>7.00±3.00</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.50±0.59</td>
<td>4.00±1.19</td>
<td>0</td>
<td>5.50±1.50</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1.11±0.38</td>
<td>1.44±0.28</td>
<td>0.44±0.28</td>
<td>3.00±0.33</td>
</tr>
<tr>
<td>Florida</td>
<td>20</td>
<td>1.33±0.88</td>
<td>4.33±1.18</td>
<td>0</td>
<td>5.67±1.76</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1.20±0.30</td>
<td>1.00±0.34</td>
<td>0</td>
<td>2.20±0.44</td>
</tr>
</tbody>
</table>
rature being significantly longer than the others. Also, the longest oviposition period was recorded at 10°C on A15 and at 20°C on Florida. The linear regression revealed that female longevity of *L. auripila* is significantly influenced by temperature on all mushroom varieties (Table 3). The pre-oviposition period on 737 was significantly shorter than A15 at 15°C (*t*-test; *α*=0.05), while the other reproductive periods did not show significant differences among the four varieties. The post-oviposition period varied at different temperatures on 737, A15 and Ostreatus varieties and the longest post-oviposition period on these three varieties were observed at 15°C. All females died immediately after oviposition at 27°C on 737, at 10 and 25°C on A15, at 20°C on Ostreatus and at 20 and 25°C on Florida.

3.2. Survival and fecundity

Age-specific survival and fecundity of *L. auripila* at different temperatures and on various varieties are shown in Fig. 1-3. On 737, little mortality occurred until 9 days at 12.5 and 15°C and until approximately 4 days at 22.5, 25 and 27°C. The sharp decline in survival curve occurred after 9-11 days on both lower temperatures (12.5 and 15°C), and after 3-4 days on higher temperatures (22.5 and 27°C). Complete mortalities for fungus gnats reared at 10, 12.5, 15, 22.5 and 25°C were observed after 72, 63, 82, 30 and 23 days on A15, respectively. These values were 76, 42 and 31 days on Ostreatus at 15, 20 and 25°C, respectively. On Florida, full mortalities occurred after 68 and 31 days at 20 and 25°C, respectively. According to *Kruskal-Wallis* test, the survival rate at different temperatures on 737 (*χ^2*=266.331; *df*=6; *P*-value=0.000), A15 (*χ^2*=356.852; *df*=6; *P*-value=0.000), Ostreatus (*χ^2*=110.944; *df*=6; *P*-value=0.000) and Florida (*χ^2*=120.220; *df*=6; *P*-value=0.000) was significantly different. Daily reproductive rates were declined gradually after reaching their peaks at all tested temperatures on all varieties, except for 20°C on Ostreatus variety. On 737 the *m*_x curve increased and peaked on 7, 2, 2, 1 and 3 days after adult emergence at 12.5, 15, 22.5, 25 and 27°C, respectively. On A15 at 10, 15, 22.5 and 25°C the curve was characterized by a rapid initial increase to the maximum followed by a decrease with age. The reproduction peaks on Ostreatus appeared on the first days after adult emerg-

![Fig. 1. Age-specific survival (*lx*) and Age-specific fecundity (*mx*) curves for *L. auripila* at different temperatures on 737 varieties.](image-url)
Fig. 2. Age-specific survival ($l_x$) and Age-specific fecundity ($m_x$) curves for *L. auripila* at different temperatures on A15 variety.

Fig. 3. Age-specific survival ($l_x$) and Age-specific fecundity ($m_x$) curves for *L. auripila* at different temperatures on Florida and Ostreatus varieties.
ence at 12.5, 15, 22.5, 25 and 27°C, respectively. On A15 at 10, 15, 22.5 and 25°C the curve was characterized by a rapid initial increase to the maximum followed by a decrease with age. The reproduction peaks on Ostreatus appeared on the first days after adult emergence at 15 and 25°C (5 and 2 days, respectively); however, when reared on Florida, the number of eggs/female/day increased on final days of female life (Fig. 3).

### 3.3. Life table parameters

The effect of temperature and mushroom varieties on population growth parameters is given in Table 2.

#### Table 2. Population growth parameters (mean±SE) of *L. auripila* on 737, A15, Ostreatus and Florida varieties.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Temperatures (°C)</th>
<th>Intrinsic rate of natural increase (r&lt;sub&gt;m&lt;/sub&gt;)</th>
<th>Net reproductive rate (Ro)</th>
<th>Mean generation time (T)</th>
<th>Finite rate of increase (λ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>737</td>
<td>12.5</td>
<td>0.012±0.005</td>
<td>1.76±0.43</td>
<td>50.75±0.65</td>
<td>1.01±0.01</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.046±0.002</td>
<td>8.06±0.57</td>
<td>45.07±0.27</td>
<td>1.05±0.00</td>
</tr>
<tr>
<td>A15</td>
<td>22.5</td>
<td>0.027±0.008</td>
<td>1.64±0.31</td>
<td>22.05±0.24</td>
<td>1.02±0.01</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.134±0.011</td>
<td>14.59±2.98</td>
<td>20.10±0.09</td>
<td>1.14±0.01</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>-0.033±0.004</td>
<td>0.41±0.05</td>
<td>25.06±1.05</td>
<td>0.97±0.00</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>-0.011±0.000</td>
<td>0.48±0.01</td>
<td>63.97±0.62</td>
<td>0.99±0.00</td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>0.003±0.000</td>
<td>1.79±0.45</td>
<td>52.15±1.17</td>
<td>1.01±0.01</td>
</tr>
<tr>
<td>Ostreatus</td>
<td>22.5</td>
<td>0.008±0.005</td>
<td>1.49±0.35</td>
<td>53.31±0.13</td>
<td>1.01±0.00</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.000±0.000</td>
<td>0.97±0.27</td>
<td>28.10±0.50</td>
<td>1.00±0.01</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.052±0.075</td>
<td>1.16±1.48</td>
<td>21.77±0.06</td>
<td>1.01±0.11</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>-0.018±0.007</td>
<td>0.27±0.11</td>
<td>66.89±0.98</td>
<td>0.98±0.01</td>
</tr>
<tr>
<td>Florida</td>
<td>20</td>
<td>-0.021±0.023</td>
<td>0.33±0.22</td>
<td>36.99±1.23</td>
<td>0.98±0.02</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.081±0.022</td>
<td>4.52±1.69</td>
<td>19.62±0.22</td>
<td>1.08±0.02</td>
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<tr>
<td></td>
<td>20</td>
<td>0.011±0.015</td>
<td>1.27±0.60</td>
<td>36.15±1.83</td>
<td>1.01±0.02</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.083±0.015</td>
<td>6.05±2.00</td>
<td>22.21±0.67</td>
<td>1.09±0.02</td>
</tr>
</tbody>
</table>

*Confidence Interval 95%*
The highest values of \( r_m \) were 0.134, 0.052, 0.081 and 0.083 (females/female/day) on 737, A15, Ostreatus and Florida, respectively and were recorded at 25°C. The net reproductive rate (\( R_0 \)) showed the highest value at 12.5°C on A15 and at 25°C on 737, Ostreatus and Florida. The negative values of \( r_m \) were obtained at 27°C on 737, at 10°C on A15 and at 15 and 20°C on Ostereatus. The finite rates of increase (\( \lambda \)) on 737 were 1.14 and 0.97 (females/female/day) at 25 and 27°C, respectively. The mean generation time (\( T \)) on 737 strongly decreased with increasing temperature from 12.5 to 25°C and then increased from 25 to 27°C. The increased temperature resulted in shorter generation times of \( L. auripila \) on A15, Ostreatus and Florida. Based on the linear regression model, a significant relationship between mean generation time and temperature was detected on all mushroom varieties (Table 3). On the contrary, the linear regression between net reproductive rate and temperature on all varieties was not statistically significant (Table 3). The results revealed that population growth parameters were not significantly different at 12.5°C, between 737 and A15 varieties \((t\text{-test}; \ a=0.05)\). In contrast, all parameters were significantly influenced by button varieties at 15 and 22.5°C. Moreover, mean generation time at 25°C was significantly different between two varieties of button mushroom.

4. Discussion and Conclusions
This study documents the influence of temperature and mushroom varieties on reproductive period, fecundity, survival and life table parameters of \( L. auripila \). To the best of the researchers’ knowledge no study has covered the full range of temperatures that are suitable for the fecundity and the survival of \( L. auripila \).

Talebi et al. (2003) reported a 0.071 intrinsic rate of increase and a net rate of reproductive 9.30 for \( L. auripila \) at 20°C, which were considerably higher than those obtained on Florida and Ostreatus varieties in this study. By comparing the results of the present study with the data in the literature, many differences among the various population parameters for \( L. auripila \) collected in different geographical areas and from different host mushrooms were revealed. The obtained results showed that fecundity and oviposition periods were affected by diet and that both parameters were higher and longer when reared on button mushroom. At 25°C, the highest rates for fecundity occurred on 737 varieties. These findings clearly showed that 737 varieties are the most susceptible host for \( L. auripila \) at 25°C. On the other hand, at 12.5°C the greatest rates of reproduction and fecundity were observed on A15 variety. Therefore, we can conclude that temperature has a key role in the resistance of different varieties of button mushroom to sciarid flies so that at lower temperature, A15 was the most susceptible variety, and at higher temperature, 737 was the most vulnerable variety.

The intrinsic rate of natural increase (\( r_m \)) is the only statistic that adequately describes the physiological qualities of an insect relative to its capacity of increase (Andrewartha and Birch, 1954). Fecundity rate and net reproductive rate of \( L. auripila \) on A15 were greater at 12.5°C than at 15°C (Table 2), but the intrinsic rate of increase at 15°C was greater than that of 12.5°C. Thus, the difference between the \( r_m \) of \( L. auripila \) at 12.5°C and 15°C is mainly due to its pre-imaginal developmental time. Because of the minus sign in the intrinsic rate of increase equation (Carey, 2001), \( \Sigma l_x m_x e^{-r_m x} = 1 \), increasing the pre-imaginal developmental time leads to more \( x \) value, so \( e^{-r_m x} \) decreases. The negative values for \( r_m \) at 27°C on 737, at 10°C on A15 and at 15 and 20°C on Ostreatus showed that \( L. auripila \) was not able to increase its population in these conditions and will be extinct over time. The foregoing results clearly indicate that all life table parameters (\( r_m, R_0, \lambda \) and \( T \)) are affected by food type and temperature. The highest \( r_m \) and \( \lambda \) and the lowest \( T \) occurred at 25°C on all varieties, suggesting that 25°C is the optimal temperature for \( L. auripila \). The intrinsic rate of increase (\( r_m \)) was higher when reared on 737 compared with A15, indicating that it is a more sensitive host for this pest. All in all, the obtained \( r_m \) values at different temperatures and on four varieties proved that fecundity of \( L. auripila \) is very low on cultured mycelia on PDA medium.

The findings of this study could be useful to perform a more detailed IPM program for \( L. auripila \) in mushroom growing fields. Among button and oyster mushroom varieties, A15 and Ostereatus are more resistant to \( L. auripila \) and we recommend the mushroom grower to set the temperature of mushroom cultivation room below 25°C in order to minimize the risk of \( L. auripila \).
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