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Determination of the Silkworm (*Bombyx mori* L.) Heat Requirements in Rearing Room of Village House for Optimal Environmental Conditions

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A B S T R A C T

Aim of this study was to determine heat requirement for silkworm larval period of 27 days to ensure optimal environmental conditions in the rearing room in April and May. Firstly, when silkworm rearing started on April 20, it was determined that rearing room should be heated during the larval period. During this period, heat requirements of silkworm 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} instar stages were 2036.38, 1851.25, 1666.13, 647.94 and 1796.79 W/h, respectively. Secondly, when the rearing started on April 27, heat requirements of 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} instar stages were 2036.38, 1018.19, 833.36, 647.94 and 1796.79 W/h, respectively. Thirdly, when it started on May 1, heat requirements of 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} instar stages were 1203.31, 1018.19, 833.06, 647.94 and 1796.79 W/h, respectively. When rearing started on May 1, the heat requirement of the 1^{st} instar stage was 40.9% less than that of April 20 and April 27. As silkworm released urine, the heat requirement of the 5^{th} instar stage was higher than that of other periods. As a result, keeping in view the heat requirements and the development the of mulberry leaves, the rearing starting on May 1 was found to be the most suitable period compared to other two rearing periods.

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SG conceived, designed and executed the project. AB helped in data analysis and writing of the article.

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INTRODUCTION

Silkworm (*Bombyx mori* L.) is a domesticated insect, which feeds exclusively on mulberry leaves to produce cocoon (Nagaraju and Goldsmith, 2002). Rearing silkworm is traditional and an important sub-branch of agriculture, which has 1500-years old history in Anatolia and is usually done on a small scale and does not require much investment (Taşkaya, 2011).

In Mediterranean countries summer temperatures are quite high and unsuitable for silkworm rearing Therefore, in Turkey, silkworms are reared twice a year, one of which is spring rearing (April, May and June) and the other is autumn rearing (August and September). However, spring rearing is more common because of more advantageous in terms of fresh mulberry leaves and economy.

Temperature is key environmental factor that influences the physiology of insects. The silkworm is sensitive to environmental fluctuations and unable to survive naturally due to continuous domestication. Interaction of environmental conditions and developmental stages govern the physiology of silkworm, which affects the growth, development, productivity and quality of silk (Hussain *et al*., 2011a). While rise in temperature increases various functions and vice versa decreases some activities. For instance, increased temperature accelerates larval growth and shortens the larval period and at low temperature the growth is slow and larval period is prolonged. The optimum temperature for normal growth of silkworms is between 20°C and 28°C and the desirable temperature for maximum productivity ranges from 23°C to 28°C. Temperature above 30°C directly affects the health of the worm. If the temperature is below 20°C all the physiological activities are retarded (Devi and Karuna, 2012; Rahmathulla, 2012; Singh, 2012).

Humidity plays a vital role in silkworm rearing and its role is both direct and indirect. The combined effect of both temperature and humidity largely determines the satisfactory growth of the silkworms and production of good-quality cocoons. It directly influences the physiological functions of the silkworm. The young-age silkworms can withstand high humidity conditions than later-age worms and under such conditions, the growth of worm is vigorous (Rahmathulla, 2012; Devi and Karuna, 2012).

Since silkworms cannot adjust their body temperature according to surrounding temperature, the rearing room needs to be heated during the first days of feeding using the stove or electric heaters (Gülseren and Sipahioğlu, 1992). Temperature should be kept constant in all instar stages as much as possible and should be avoided from sudden changes due to its negative effect on properties of silkworm (Kıraş, 2010).

Very little information is available on heat

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requirement for silkworm, and the cocoon yield can be optimized by ensuring the optimal environmental conditions for silkworm. The aim of this study was therefore, to calculate the amount of the heat needed by the silkworm during the three different rearing periods, and to determine optimum economical rearing period.

MATERIALS AND METHODS

In Kahramanmaraş province, village houses are usually built as reinforced concrete structures, one or two storeys with 2-3 rooms, bath room, kitchen, hall and bed room. In some village houses, its first floor is used as foodstuff storage area and their walls are made of briquettes with or without plastered.

In order to plan a naturally ventilated silkworm rearing room with a 20.000 larval capacity and to provide optimum environmental conditions, various project criteria, given below, were used to calculate heat requirement of silkworm.

In the villages of Kahramanmaraş province, Mediterranean climate prevails. Three periods of spring rearing of silkworm were considered; first rearing period started on April 20, the second on April 27 and the third on May 1 (Anonymous, 2013a,b).

İnal (2000) determined that the 1st instar period including feeding and moulting lasted 4 days, 2nd period 3 days, 3rd period 4 days, 4th period 6 days, 5th period 9-10 days, thus, making total silkworm rearing period of 26-27 days. The weight of 2,000 newly hatched silkworms is about 1g (20,000 silkworm eggs approximately 10 g). Silkworm producers were given silkworm eggs in the boxes by the Kozabirlik Union, each box containing ten grams or 20,000 silkworm eggs. About 18,000 instars emerged from one box, and about 2,000 died when rearing bed was cleared of old mulberry leaves and fecal matter of silkworms. About 16,000 5th instar larvae were used for calculation of heat requirement. To rear a box of silkworm, an area of 30 m² was needed (Başkaya, 2013) and required mulberry leaves of 1-2 kg, 5-6 kg, 20-25 kg, 80-90 kg and 475-500 kg for 1st, 2nd, 3rd, 4th and 5th instar stages, respectively. The 500 kg mulberry leaves harvested from 50-55, 5 year-old mulberry trees (Başkaya, 2013; İnal, 2000; Gülseren and Sipahioğlu, 1992).

Silkworm was grown in a room which was 6x4x2.7 m with two ante halls (1 m width). There were three leaves rearing stands with four tiers (1x2.5 m). Each room had three windows (1x1.2 m) area of which was 15% of the floor area of the room and door size was 1.1 x 2.0 m. The thickness of the plaster with lime inside and outside of the structure was 2 and 3 cm, respectively (Ekmekyapar, 1997). Physical properties of structural elements of rearing room are shown in Table I. The coefficient of heat conductance of structural elements such as ceiling and door was taken from Şahin and Ünal (2005).

Table I.- Physical properties of structural elements of the planned silkworm rearing room.

Structural elements	Materials of structural elements	Heat conductance coefficient (U) ($W/m^{2o}C$)	Area of structural elements (m^2)
Ceiling	10 cm reinforced concrete	3.07	24
Door	Wood	3.49	2.2
Window	Wooden frame, 3 cm glass	2.56	3.6
Wall	40x20x20 cm briquette / inside 2cm and outside 3 cm plaster with lime	1.96	48.2

The equations, given below, were used to provide heat and humidity balance in the planned silkworm rearing room.

The following equations were used to calculate heat requirement for the three rearing periods with 1st, 2nd, 3rd, 4th and 5th instar stages. Equation 1 was used to estimate heat balance (Lindley and Whitaker, 1996; Öztürk, 2003).

$$Qm = Q \quad (1)$$

This equation was written in the form of equation 2.

$$Qm \geq\leq q_y + q_h \quad (2)$$

where Qm is sensible heat requirement by the larvae in watt (W), Q is total heat loss in W, q_y is heat loss from structural elements (ceiling, wall, window, door, floor) in W, and q_h is heat loss through ventilation in W.

Equation 2 may not provide heat balance all the time. There is a heat deficit if Qm is less than $q_y + q_h$. In that case, heat losses are inevitable and heating is needed to raise optimal temperature level in silkworm room. Heat losses (q_y) from structural elements was calculated by using the equation 3.

$$q_y = \sum U.\ A.\ \Delta t \quad (3)$$

where $\sum U$ is the coefficient of conductance of structural elements ($Wm^{-2}\ {}^oC^{-1}$), A is the surface area of structural elements in m^2, Δt (ti-td) is the difference between inside (ti) and outside (td) temperature of room (ºC).

The coefficient of total heat conductance of structural elements (U) was calculated by using following equation 4.

$$U = \frac{1}{\frac{1}{fi} + \sum_{i=1}^{n} \frac{di}{ki} + \frac{1}{fd}} \quad \text{............................ (4)}$$

where fi and fd are the surface coefficient of inside and outside heat conductance of structural elements in $Wm^{-2o}C^{-1}$, d and k are width of structural elements in m and thermal conductivity in $Wm^{-1o}C^{-1}$, respectively.

The amount of heat lost through ventilation from the growth room can be found utilizing equation 5.

qh = 0.341.Q.Δt .... (5)

Where qh is the heat lost through ventilation from the growth room in W, 0.341 is coefficient (which raises the temperature of per cubic meter of air by 1°C (Wh/m^3 °C)), Q is minimum air flow (m^3/h).

In controlling humidity, ventilation is based on the moisture balance in rearing room. By using equation 6, minimum air flow Q (m^3/h) was calculated to maintain air moisture content in growth room in order to keep the desired design criteria level required by silkworms (Timmons and Gates, 1987; Albright, 1990; Anonymous, 1994).

$$Q = \frac{\sum wa}{qi - qd} \quad \text{... (6)}$$

Where $\sum wa$ is the amount of moisture released by larvae into the growth room (g/h), qi and qd are inside and outside absolute moisture (g/m^3).

After the silkworm growth room had been planned, the probability of temperature and relative humidity to estimate heat and humidity balance in the silkworm room was calculated by Weibull Method (Tülücü, 1988). To apply this method, long term (1980-2011) monthly temperature and relative humidity data given in the Figure 1 were used. As a result of this calculation, the temperature and relative humidity of April and May was determined with the contingency of 80 percent.

To calculate heat requirements of the rearing room during 1st, 2nd, 3rd, 4th and 5th instar, optimum relative humidity and temperature values were taken as 85%, 85%, 80%, 70% and 70%, and 28°C, 27°C, 26°C, 25°C and 24°C, respectively (Rahmathulla, 2012). Since silkworm is a poikilothermic insect, it does not release heat and moisture in its surroundings except for 5th instar stage (Wu and Hou, 1993; Kıraş, 2010; Anonymous, 2013a). Therefore, it was found that 40 ml of urine produced by 100 5th instars was the source of moisture produced in the 5th instar (İnal, 2000).

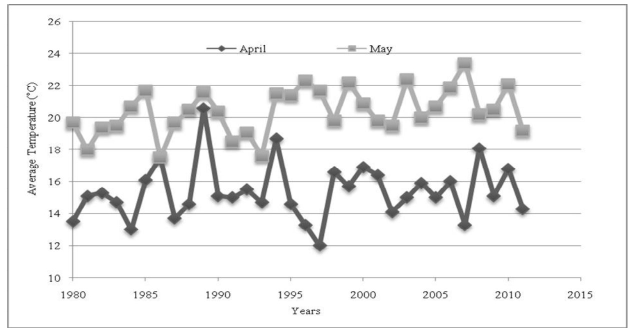

Fig. 1. Monthly average temperature for long term (Temperature values of April and May rearing months).

Using the data in Table II on instar period (feeding+ moulting), instar stages, moisture production, the temperature, and inside and outside temperature and absolute water content of room heat requirements of silkworm were calculated.

RESULTS AND DISCUSSION

The outside temperature and relative humidity of April and May were determined as 17°C and 21.5°C, and 63% and 59%, respectively, with an 80% contingency based on long-term climatic data analysis in Kahramanmaraş (Fig. 1).

Using thermal conductivity by Ekmekyapar (1997), heat conductance coefficient of walls was calculated as 1.96 $Wm^{-2o}C^{-1}$, and that of doors, windows and ceiling given directly by Şahin and Ünal (2005) were 3.49, 2.56 and 3.07 $Wm^{-2o}C^{-1}$, respectively (Table I). There were no insulation materials on walls, ceiling, door and windows of rearing room.

The required amount of heat by silkworms in rearing room is the difference between the heat loss from the structural elements and air ventilation, and the heat emitted by larvae. However, it is assumed that silkworms did not release heat and moisture into its surrounding except moisture in the 5th instar stage. Thus, the heat required by silkworm is equal to the heat lost through the structural elements and air ventilation. The 100 instars release about urine of 40 ml in the 5th instar stage (just before knitting cocoon) and for 16.000 larvae, this value is about 6.400 g (Specific weight of urine is taken as 1 g/cm^3). Relative humidity changes between 70-80% in rearing room for all instar stages (Hussain *et al.*, 2011b,c) and thus in this study relative humidity of 5th instar stage in rearing room was taken as 70%.

Table II.- Data used in providing optimal environment conditions of rearing room.

Instar periods (feed+moulting) (day)	Stages	Moisture production (ml/100larvae)	Temperature (°C)			Absolute water content (g/m³)		
			Inside (ti)	Outside (td)	Differ. (ti-td)	Inside (qi)	Outside (qd)	Differ. (qi-qd)
Criteria used in the first rearing period (April 20)								
4	1st	0	28	17.0	11.0	23.25	9.19	14.06
3	2nd	0	27	21.5	5.5	22.00	9.19	12.82
4	3rd	0	26	21.5	4.5	19.54	9.19	10.36
6	4th	0	25	21.5	3.5	16.08	11.19	4.89
9-10	5th	40	24	21.5	2.5	15.28	11.19	4.09
Criteria used in the second rearing period (April 27)								
4	1st	0	28	17.0	11.0	23.25	9.19	14.06
3	2nd	0	27	21.5	5.5	22.00	11.19	10.81
4	3rd	0	26	21.5	4.5	19.54	11.19	8.35
6	4th	0	25	21.5	3.5	16.08	11.19	4.89
9-10	5th	40	24	21.5	2.5	15.28	11.19	4.09
Criteria used in the third rearing period (May 1)								
4	1st	0	28	21.5	6.5	23.25	11.19	12.06
3	2nd	0	27	21.5	5.5	22.00	11.19	10.81
4	3rd	0	26	21.5	4.5	19.54	11.19	8.35
6	4th	0	25	21.5	3.5	16.08	11.19	4.89
9-10	5th	40	24	21.5	2.5	15.28	11.19	4.09

When the silkworms were reared in the first rearing period, it was heated growth room during the whole instar period of 27 days. During this rearing silkworm period, heat requirements of silkworm in 1st, 2nd, 3rd, 4th and 5th instar stages were determined as 2036.38, 1851.25, 1666.13, 647.94 and 1796.79 W/h, respectively. When they were reared in the second rearing period, heat requirements in the 1st, 2nd, 3rd, 4th and 5th instar stages were determined as 2036.38, 1018.19, 833.36, 647.94 and 1796.79 W/h, respectively. When they were reared in the third rearing period, heat requirements in 1st, 2nd, 3rd, 4th and 5th instar stages were determined as 1203.31, 1018.19, 833.06, 647.94 and 1796.79 W/h, respectively (Fig. 2).

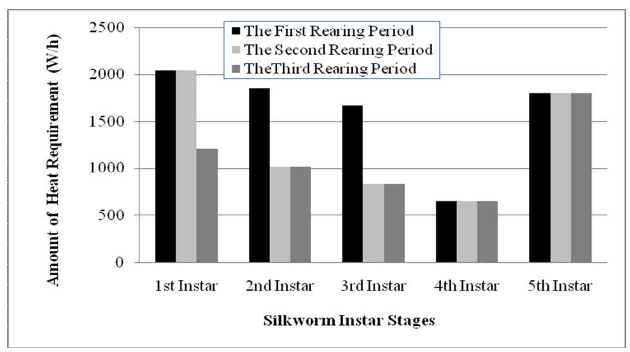

Fig. 2. Silkworm heat requirement for rearing periods.

As seen in the Figure 2, the heat requirement of silkworm for both in the instar stages and three rearing periods were decreased from 1st to 4th instar stage but again increased in 5th instar stages, and the heat requirement with 647.94 W/h in 4th instar stage was the lowest and with 2130.29 W/h in 5th instar stage was the highest. When heat requirements in the third rearing period was compared with that in the first rearing period and that in the second rearing period for all instar stage, the heat requirements in the third rearing period were lower than the others' or equal. For example, when the heat requirement of 2nd (1851.25 W/h) and 3th (1666.13 W/h) instar stages in the first rearing period was compared with that of 2nd (1018.19 W/h) and of 3th (833.06 W/h) instar stages in the second rearing period, that of 2nd and 3th instar stages in the second rearing period was lower with 45% and 50% than that of 2nd and 3th instar stages of the first rearing period, respectively. When heat requirement of the second rearing period was compared with that of the third rearing periods, only value of 1th instar stage was different from each other and the others were same. The reason for being different was that temperature and relative humidity values of the last four days of April were used in calculation. If rearing silkworm started on May 1 (the third rearing period), the heat requirement of 1st instar stage (1203.31 W/h) was lower with 40.9% than that of 1st instar stage (2036.38 W/h) in the first and second rearing period. The reason for the increase in heat requirement in the 5th instar stage in the third rearing period was that instars were releasing urine. If urine were not released by the instars into surrounding, heat requirement would be 462.81 W/h instead of 1796.79 W/h.

As a result, taking into consideration both being low heat requirement and development of mulberry leaves, the third rearing period (1 May) was found to be the most suitable for rearing silkworm in Kahramanmaraş.

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