Indoor Rearing of the Japanese Oak Silkworm, *Antheraea yamamai*

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Japanese oak silkworm (*Antheraea yamamai* Guérin-Méneville) which is called Tensan, is a typical wild silkworm (Plate 1) native to Japan. It inhabits in mountains and plains of the whole country, feeding on leaves of oaks such as Kunugi (*Quercus acutissima* Carruth), Konara (*Quercus serrata* Thunb), Kashiwa (*Quercus dentata* Thunb), Shirakashi (*Quercus myrsinaefolia* Blume), etc. In some areas, it is reared. Particularly, it is famous that in Ariake district, Nagano Prefecture, located on the piedmont of North Alpus, a large scale rearing of Tensan has been continued since Ten-mei era (1781–1789). The fibre spinned from Tensan is called Tensan silk, which is characterized by graceful gloss, thick diameter, and large elongation rate. Textile made of this silk is strong, durable, difficult to become wrinkled, and has an extremely good touch: outstandingly excellent among wild silks. Therefore, it is compared to "diamond of fibre". As the Tensan silk mix-woven with usual silk improves textile quality as clothes, demand for it is rapidly increasing in recent years. Use of Tensan silk as the materials for Tensan textiles, furnitures and interior decorations is also increasing.

As a result, Tensan rearing has been gradually increasing from year to year. However, its efficiency of cocoon production is extremely low in general, because a large number of the larvae die in the course of rearing: only about 20–30% of the larvae produce cocoon actually. In 1979, about 240,000 larvae were used for rearing, but only about

Plate 1. Tensan larvae

70,000 larvae produced cocoons, from which only around 25 kg of silk was obtained.

The reason for such poor cocoon yields of Tensan obtained every year is considered to be attributable to the fact that Tensan is mostly reared outdoors, and hence exposed directly to harsh climatic conditions, and liable to be suffered from damages caused by birds, insect pests and diseases.

Therefore, the author tried to carry out indoor rearing under different feeding and climatic conditions with observations on ecological characteristics of the Tensan. It was found that when suitable conditions were given its growth was quite good, showing almost no dead larvae, and the cocoons produced were quite excellent in quality.

Based on the results of the experiments, ecological characteristics, suitable conditions of indoor rearing, and the indoor rearing system for Tensan will be presented in this paper.

Ecological characteristics of Tensan

The Tensan used in the experiments was a strain which had been reared outdoors from generation to generation for many years in Ariake district of Nagano Prefecture. The food plant is oak (Kunugi; *Quercus acutissima* Carruth). The larvae were reared by the following three methods: (a) outdoor rearing:

Plate 2. Box rearing of Tensan.

Plate 3. Tensan rearing on cut shoots dipped in water in bottles.

outdoor rearing on leaves of oak trees growing outdoors, (b) indoor box rearing: larvae were placed into boxes with flat bottom to which collected leaves were supplied (Plate 2), and (c) indoor cut shoots rearing: larvae were placed on cut shoots dipped in water in bottles (Plate 3).

1) Characteristics at larval stage

a) Egg hatching is not uniform. b) Since immediately after hatching, the larvae move actively. c) The larvae show a strong fear to shake, sound, touch, etc.: they stop eating and shrink their body. d) They prefer solitude to aggregation. e) When they are too much crowded, they sometimes harm each other. f) Due to an extremely strong grasping power of legs, they can hardly be removed from shoots etc. g) As water content of food leaves is lower than that of the larvae, their water requirement is high, and they take rainwater or dew (Plate 4). h) They eat exuvium, petioles or paper, etc. i) They travel long distance particularly at the time before cocooning. j) Growth process is not uniform, being influenced by environmental factors, especially air temperature or light. k) Food leaves show a decrease of water content in a short time after leaf emergence, and become to be hard. The hard leaves are not suitable for feeding, particularly for young larvae. 1) Many insect pests on trees eat food leaves. Corpse of diseased insects may possibly transmit diseases to Tensan.

2) Characteristics at pupal stage

a) Pupal period is long due to summer diapause, and b) it varys greatly by individuals. c) It is influenced markedly by environmental factors especially light and temperature. d) The pupae become soft soon before eclosion.

3) Characteristics at adult stage

a) Imago emergence, copulation (Plate 5), and oviposition occur only in night. b) Copulation begins after sun-set, and continues in that state until dawn. Copulating pair is separated by light, sound and human access. c) Oviposition usually begins in the night of the next day of copulation, and lasts for 2–3 days with interruptions in daytime. d) Egg laying is irregular, either by single egg or egg mass. e) Imagoes kept in basket lay eggs outside of the basket by pushing out their caudal portion between the meshes (Plate 6). f) Light intensity higher than 20 lux is inhibitive to oviposition. g) Low percentage of

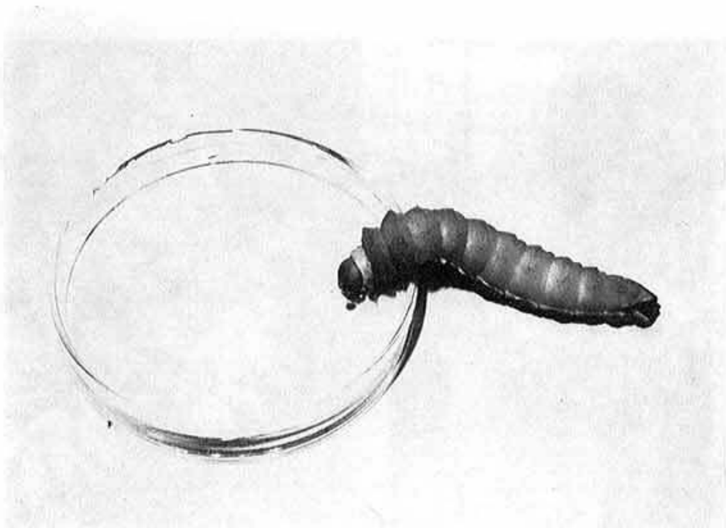

Plate 4. Tensan larva drinking water in a Petri dish.

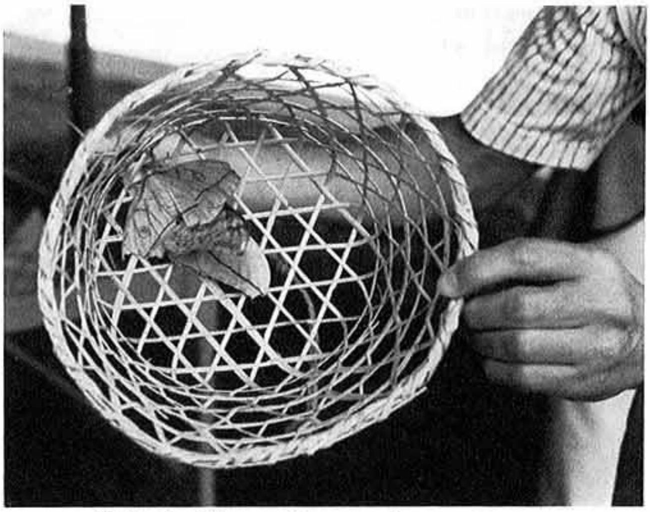

Plate 5. Tensan imagoes in copulation.

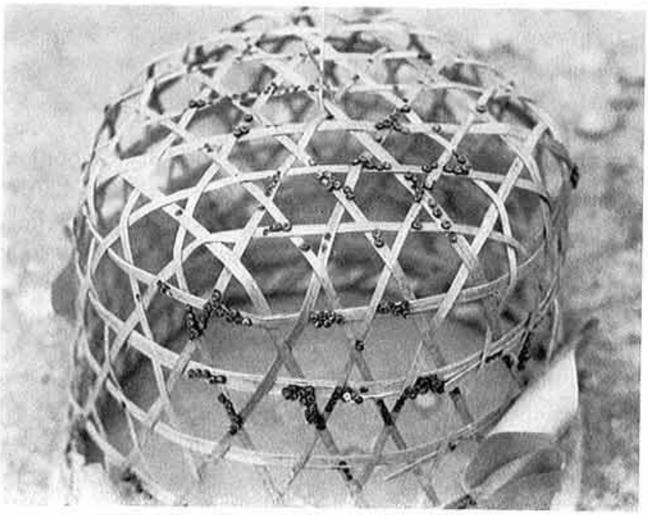

Plate 6. Eggs laid outside of basket.

Plate 7. Tensan imago

fertilized eggs causes multiplication difficult. h) Wing color is widely different with individuals (Plate 7).

4) Characteristics at egg stage

a) Egg hibernates, with embryo already developed to larva. b) Although Tensan is of uni-voltinism, two generations can be repeated in a year by breaking diapause with low temperature treatment. Hydrochloric acid treatment which induces hatching in silkworm is not effective to Tensan eggs. c) Hatching percentage on food leaves on trees is low.

5) Characteristics of cocoon

a) Cocooning is made in the space surrounded by 2–3 leaves connected each other. Cocoon has peduncle (Plate 8). b) Cocoon color is dark green in case of outdoor rearing while it is yellowish light green in case of indoor rearing. c) Space between cocoon shell and pupa is narrow. d) Double cocoon is produced very rarely. e) Cocoon filament is not broken by adult emergence, and ready for reeling.

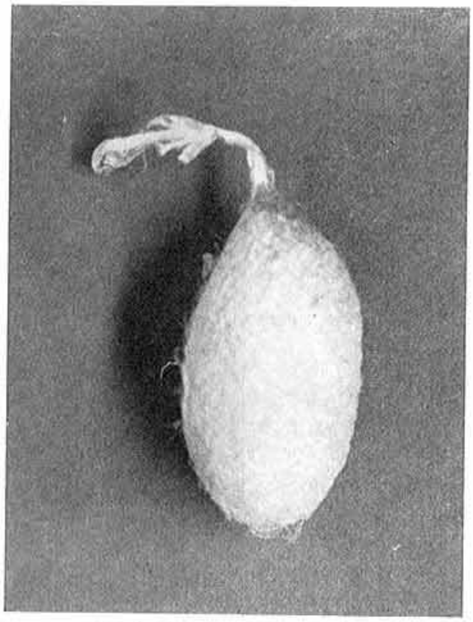

Plate 8. Tensan cocoon

Environmental conditions suitable for growth of Tensan

To find out the environmental conditions suitable for the growth at each stage, Tensan was reared under different conditions with varying air temperature, humidity, photoperiod, air current, water supply and population density.

The climatic conditions which gave the best growth are shown in Table 1. The optimal temperature for growth was about 29°C at the 1st–2nd instar, about 27°C at the 3rd instar, and 25°C at the 4–5th instar. The favorable humidity seems to be about 80% at the 1st instar, and it decreased by 5–6% with the advance of instar, reaching about 60% at the 5th instar. As to the photoperiod, the cycle of 10–12 hr of light and 14–12 hr of darkness was most effective in shortening the growth duration of larval and pupal stages and produced cocoons of good quality. Continuous air current at the rate of 0.1–0.2 m/sec was good for larval growth, particularly at the advanced instar, but it showed an adverse effect at higher rates.

Using a microsyringe 4–5th instar larvae were forced to drink water (Plate 9). As

Table 1. Environmental conditions suitable for the growth of Japanese oak silkworm

Climatic factor	Growth stage of larva					Pupal stage
	1st	2nd	3rd	4th	5th	
Temperature (°C)	29	→	27	→	25	25
Humidity (%RH)	80	→	70	→	60	60
Photoperiod (h/day)	L (100 Lx) = 10∼12, D = 14∼12				→	L* = 10∼12, D* = 14∼12
Air current (m/sec)	0.1∼0.2				→	

*: photoperiod L = lighting, D = darkness

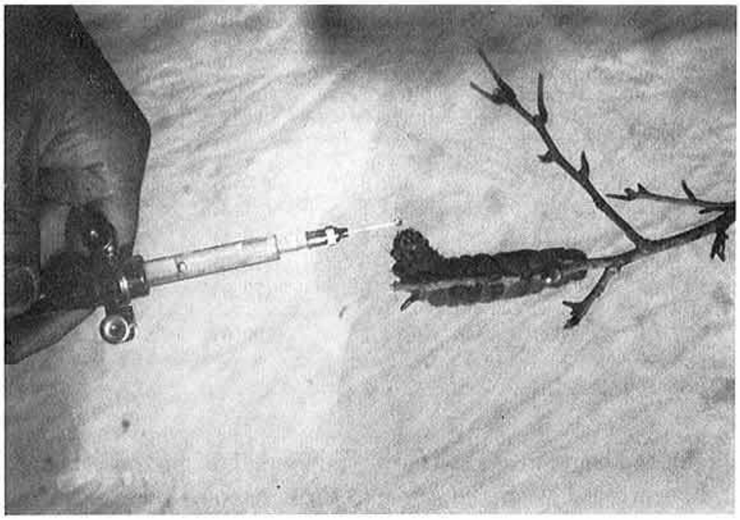

Plate 9. Experiment of forced water drinking of Tensan larva.

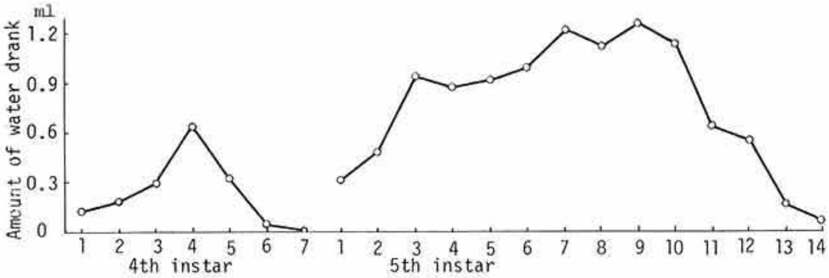

Fig. 1. Amount of water drank at one time in each day by one larva at 4th–5th instar.

shown in Fig. 1, the larva at the end of the 5th instar took 1.2 *ml* of water at one time. The forced supply of water resulted in better growth and better quality of cocoon. It is desirable, therefore, to supply water by installing drinking water tank or by spraying water to food leaves in the rearing place, at the advanced instar.

Population density suitable for box rearing was examined at each instar (Table 2). Rate of 0.04 m^2 per 100 larvae was sufficient at the 1st instar, but wider area was required at advanced instar, i.e. 0.7 m^2 per 100 larvae at the 5th instar.

When such favorable conditions as above were given, Tensan produced cocoons of good quality after about 34–42 days of larval period. Amount of food ingested and digested, and its digestibility at each instar are shown in Table 3. Food ingested during the whole larval stage was about 43 g/larva, about 74% of which was ingested at the 5th instar.

Table 2. The area* of rearing bed required in case of box rearing

1 st instar	2 nd instar	3 rd instar	4 th instar	5 th instar
0.04m^2	0.08m^2	0.18m^2	0.35m^2	0.7m^2

*: per 100 larvae

Table 3. Amount of food supplied, ingested and digested

instar	duration	amount of supplied leaves*	amount of food ingested	(index)	amount of food digested	digestibility
	d.h.	g	g	%	g	%
1	3.19	77.0	12.8	(0.3)	5.1	40.1
2	3.03	143.0	63.1	(1.5)	26.3	41.7
3	4.11	583.0	264.2	(6.1)	92.7	35.1
4	8.07	1500.0	785.0	(18.2)	141.6	18.1
5	18.00	7250.0	3189.0	(73.9)	449.7	14.1
Total	37.16	9553.0	4314.1	(100.0)	715.4	—

*: fresh leaves per 100 larvae

Digestibility was highest, about 40%, in the 1st–2nd instar, but it decreased with the advance of instar reaching only 14% at the 5th instar.

Key point of indoor rearing method of Tensan

The key point is to provide the favorable condition under which the Tensan can take fresh leaves, not too hard and nutritive, whenever it wants to take, in an environment with climatic condition adapted to its growth, and hygenic condition free from the risk of diseases and insect pests. As the indoor rearing has advantages that it is easy to control climatic condition, keep hygenic condition, select suitable leaves, and to regulate amount of leaves to be supplied, these advantages should be fully utilized to enable the maximum manifestation of potential of Tensan. Details of the key point are as follows:

1) Protective measures

Rearing tools and rooms are disinfected thoroughly with formalin. Disinfection of body surface of larvae should also be practiced. As insects inhabiting on food trees often cause diseases of Tensan, leaves showing insect damage or with insect corpses should not be used as food.

2) Conditioning of environment

Air temperature, humidity, illumination, air current, etc. in the rearing room are kept as close as possible to the condition shown in Table 1. Population density shown in Table 2 is applied.

3) Beginning of rearing

When 4–5 leaves developed from new buds of food trees, the rearing is started, by hatching eggs. As the larvae move around actively to search for feed immediately after hatching, care should be taken not to get them tired due to delayed supply of food.

4) Food supply

Food is supplied once a day in case of the box rearing, and every 2–3 days in case of the cut shoot rearing. After the larvae moved to newly supplied leaves, old leaves and feces are removed.

5) Handling after cocooning

At about 8–10 days after cocooning, pupation occurs. Then, the cocoons are collected and kept in a room of about 25°C with 12 hr of photoperiod, waiting for eclosion. The cocoons for silk reeling are collected and dried for storage after treated by heat or steam to kill pupae and to disinfect germs.

6) Handling at eclosion, copulation and oviposition

When the imagoes emerged, they are placed into baskets for copulation and oviposition (Plate 6) at the rate of 1–2 males to 1 female in a basket. During the copulation, care is taken not to give sound or light. To increase percentage of fertilization, male(s) and female are kept together for 2 successive night, and then male(s) is removed, leaving a female for oviposition. The oviposition lasts for 3–4 nights.

7) Handling of eggs laid

Eggs laid outside of the baskets were preserved, either on the basket or after scraped off, under the natural condition, and transferred into the room of 2.5–5°C and about 80% RH at middle-late March. To enable the rearing started at about early May, when 4–5 new leaves develop on food plants, the eggs were moved to a room at 10–15°C for one day, then transferred to the incubation at 25°C at 6 days prior to the start of rearing.

Comparison between Tensan and silkworm

Morphology, physiology, ecology, genetics, etc of silkworm (*Bombyx mori*), akin to Tensan, have been made clear in considerable details although Tensan has not been studied so much. It is considered that not a few research results obtained with silkworm may be applicable to Tensan. Therefore, comparison of characters between silkworm and Tensan was made as shown in Table 4.

Table 4. Comparison of characters between Tensan and silkworm

Characters	Tensan (Japanese oak silkworm)	Silkworm
Zoological name	*Antheraen yamamai* Guérin-Méneville	*Bombyx mori* Linnaeus
Taxonomic position	Insects, Lepidoptera, Bombycoides, Saturniidae	Insects, Lepidoptera, Bombycoides, Bombycidae
Native land	Japan	Japan, China, Italy, France
Voltinism	uni-	uni-, bi-, multi-
Diapause stage	egg (embryo of the egg developed to the stage just before hatching)	egg (early stage of embryo development)
Food plant	*Quercus* (oak)	*Moraceae* (mulberry)
Egg		
size (mm)	2.8×2.6×1.8	1.4×1.1×0.6
weight (mg)	7.3	0.6
artificial hatching	stimulus of low tempperature	hydrochloric acid treatment or low temperature
incubation period (day)	6∼10	10∼13
hatching season	late April–early May	mid-May, early July, early Sept., etc.
market price (yen/one egg)	12	0.2
Larva		
size (mm)		
full grown	8.2×1.4	6.8×0.9
weight (g)		
newly hatched	0.006	0.0005
full grown	17∼20	4∼6
color		
newly hatched	head...brown body...green	head...black body...black
full grown	head...green body...green (plain)	head...brown body...white
duration (day)	out door...48∼60 in door...34∼42	in door...21∼23

continued

Characters	Tensan (Japanese oak silkworm)	Silkworm
grasping power of legs	very strong	weak
peculiar feeding habit	eat exuvium, petiole, paper and drink water	not eat exuvium, petiole, and paper, drink water only forced application
movability	large, especially before cocooning	small
optimum temperature and humidity for growth	1st instar...29°C, 80%RH 5th instar...25°C, 60%RH	1st instar...28°C, 90%RH 5th instar...23°C, 60%RH
suitable photoperiodic condition for growth	lighting...10~12hr/day dark......14~12hr/day	lighting...6~9hr/day dark.....18~15hr/day
amount of food ingested and digestibility		
1st instar	0.13 g, 40.1%	0.02 g, 63.8%
5th instar	31.9 g, 14.1%	18.25 g, 38.6%
1st~5th instar	43.1 g, 29.8%	20.7 g, 47.8%
Pupa		
size (cm)	♀4.0×1.8, ♂3.6×1.6	♀3.0×1.3, ♂2.8×1.2
weight (g)	♀7.3, ♂5.4	♀1.9, ♂1.5
duration from spining to pupation (day)	6~8	3~4
pupal period (day)	24~52	11~13
summer diapause	pass the summer season in a state of pupal summer diapause	non
Imago		
body size (cm)	♀4.5×1.5, ♂3.7×1.0	♀2.0×0.9, ♂1.6×0.7
wing expansion (cm)	12~15	4~5
wing color	yellow, yellowish brown, reddish brown, etc.	white
flying	can fly sunset—midnight	can not fly
emergence time (JST)		6:00~10:00
copulation time (JST)	from sunset to midnight, and separated in early dawn	generally in morning, and separated in 3~4 hours after copulation by artificial separation
oviposition time	from sunset to midnight of next day after copulation	any time just after copulation
egg laying	single egg or mass eggs irregularly laid	orderly laid
glutinosity of eggs laid	very strong	not so strong
number of eggs laid	150~250	450~600
survival period of imago after emergence (day)	♀5~7, ♂3~5	♀5~8, ♂3~6
Cocoon		
size (cm)	4.8×2..5	3.6×2.0
shape	elongated oval (pendant with peduncle)	generally oval (floss covering outer cocoon shell)
color	yellowish green	various (generally white)
making double cocoon	very rarely	sometimes
cocoon weight (g)	♀8.0, ♂6.0	♀2.2, ♂1.8
cocoon shell weight (g)	♀0.7, ♂0.6	♀0.5, ♂0.45

continued

Characters	Tensan (Japanese oak silkworm)	Silkworm
cocoon shell ratio (%)	♀8.8, ♂10.0	♀22.7, ♂25.0
market price (yen/one cocoon)	60	5
Silk		
size (denier)	5～6	2.8～3
length (m)	600～700	1200～1500
color	yellowish light green	various (generally white)
cross section	flattened triangle	circular triangle
strength (g/d)	3.55	4.14
elongation (%)	40.5	21.6
impurities	attached calcium oxalate with some ash	non
gloss	strong	weak
dyeing	very difficult	easy
amount of raw silk (g/100 cocoons)	25～30	35～40
raw silk percentage of cocoons (%)	4～5	18～21
market price (yen/1 g silk)	1000	15

Closing remarks

Tensan, originally a wild insect, has been considered to be more adapted to outdoor growth, but it was shown that good growth can be obtained by indoor rearing. By adjusting indoor environment to give a favorable conditions for growth, stable production and better quality of cocoon were obtained. However, the singularities of Tensan, such as that it dislikes aggregation, it is extremely precautious and it has very strong grasping power of legs, make the simplified, mechanized, or large-scale indoor rearing quite difficult. It is also a demerit that indoor rearing needs facilities and more labor. The future task is to develop labor-saving rearing method and increase cocoon producing efficiency to compensate these demerits. As compared with mulberry trees, a food plant for silkworm, red oak, nara, and other food plants for Tensan are slow-growing with low regenerating ability after cutting and their leaves are liable to become hard, and less nutritive. Therefore, breeding and improvement of cultural and harvesting method are required. Breeding for better strains of Tensan, development of large scale multiplication technique, method for hatching any time, and all year round rearing by the combination of fresh leaves and artificial diets are desired to be done. With the achievement of these improvements, the cocoon-producing efficiency of Tensan will be greatly increased.

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