Development of Autosexing Silkworm Breeds in Japan

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Until the beginning of the present century, only local varieties of silkworms were being reared since its introduction into Japan in the IIIrd or IVth century according to archeological researches. Systematic rearing of hybrids were never known in the past and it was only in the later half of the XIXth century, there is evidence to show that some attempts were made to rear F_1 and F_2 hybrids.

However, in the beginning of the XXth century Dr. Toyama made clear that F_1-hybrids between different silkworm races were remarkably superior in various characters to their parents. He also found that silkworm hybrids were superior only in the F_1-generation and showed gradual degradation in the following generations. In conformity with his proposal, extensive trials on the F_1-hybrids among Japanese, Chinese and European races were carried out at the Sericultural Experiment Station during the period between 1915 and 1920.

When these experiments showed that such hybrids as Chinese × European, Japanese × Chinese and their reciprocal crosses were excellent especially with regard to their short larval period, high viability, rich silk contents etc., popularization of the use of these F_1-hybrids was taken up as a national policy.

Rearing of F_1-hybrids thus came to stay throughout this country, replacing the former uneconomic silkworm varieties, from spring rearing in 1918 and from summer and-autumn rearing in 1927.

The rearing of silkworms and raising of corn generally form the twin pursuits of a farmer in agriculture, but the silkworm takes a place of pride for being the first to use the hybrid.

The silkworm varieties used for rearing by farmers at present in Japan, are only hybrids single cross, three-way cross or double cross. Hybrids other than those authorized by the government are prohibited by law from rearing to raise cocoons for reeling. Newly-bred varieties are closely examined in various places of Japan, and only the ones which have been fully deliberated by a special commission and recognized to be superior to old varieties are authorized by the government.

Sexing of Silkworm

In the preparation of correct hybrids, the separation of male silkworms from female ones to prevent free mating between individuals of the same parental variety constitutes a major item of work. This separation is achieved by employing the technique of sexing at the stage of grown larvae or pupae.

Silkworm larvae have imaginal discs which have relation to the formation of sexual organs viz., one tiny spot (Herold's imaginal bud) in the male and four white spots (Ishiwata's imaginal buds) in the female, on the ventral side of the abdomen. But these spots are difficult to be distinguished, though they are observable with the naked eye. So the practice of sexing larvae, which is carried out by discrimination of these imaginal buds, requires well-trained discriminators to ensure high degree of accuracy. But, this sexing method

sometimes leads to errors and also causes injury to the silkworm.

The body weight difference observed between the male and female worms has facilitated the use of mechanical sexing, but it is limited in scope as it fails to distinguish the individuals of cocoons in the intermediate weight range. These intermediates which show only negligible difference due to racial characters or rearing conditions form quite a large size making mechanical sexing practically useless. Therefore, it follows that such intermediates will have to be separated only by locating the differences in external sexual mark of the male and female pupae.

It is in this context that silkworm varieties with sex-limited characters assume great significance of immense practical value to the egg producers. These varieties with sex-limited guide characters not only render sexing easy and exact but also eventually lead to evolution of autosexing silkworm strains.

Establishment of autosexing silkworm strains

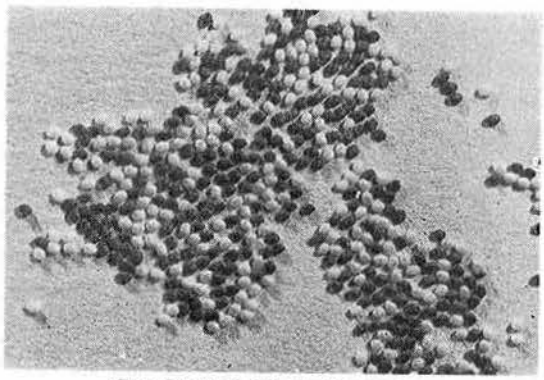
An autosexing silkworm strain was first obtained by Dr. Tazima (1941) as a result of the application of the principle of genetics. The sex-chromosomal type of the silkworm is XY in the female and XX in the male, contrary to the case of Drosophila and other animals. It has such a strong sex-determining potency, that tetraploid individuals are complete females even if the sex-chromosomal constitution is XXXY.

The dominant and recessive genes which have relation to manifestation of various characters in the egg, larva and others are located on the autosomes as well as X-chromosome. Therefore, if a dominant gene-carrying fragment of an autosome can be translocated to the female-determining Y-chromosome, the dominant gene is expected to be transmitted only to the female progency. As a result thereof, the female progeny is always manifested with the dominant character, while the male progeny always has an allelomorphic recessive character whenever a female with the dominant character is mated with a male with the recessive character. Females can be easily discriminated from males by the marked character and little labor is needed for sexing in such a strain.

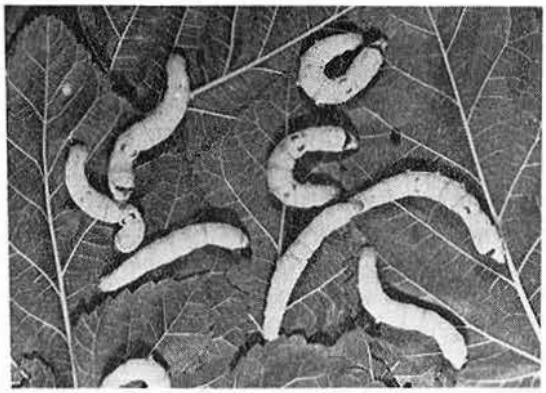
Translocations of chromosome fragments occur even in natural conditions, but Dr. Tazima suceeded in cuting an autosome by X-ray to translocate its fragment to the Y-chromosome. He used the phenomenon of sex-linked inheritance to examine whether the translocation had been successfully induced or not. The fact that the translocation had been successfully induced was observed by him in the progeny resulting from a cross between an X-irradiated female (XY) and dominant heterozygous ($+/p^s$) for the dominant gene and a sex-linked oily male (XX) and ressesive homozygous ($+/+$). The dominant gene in the female progeny was also confirmed to be sex-limited. The first strain with a sex-limited character originated from a sable-patterned individual with an extra fragment of a IInd chromosome translocated to the Y-chromosome. This individual was found among thousands of silkworms examined.

Thereafter, several strains with a sex-limited character (sex-limited strains) were obtained by some researchers. Various kinds of guide characters are used in these strains: normal, moricaud and striped larval markings on the IInd chromosome, zebra on the IIIrd chromosome and black egg on the Xth chromosome (Photographs).

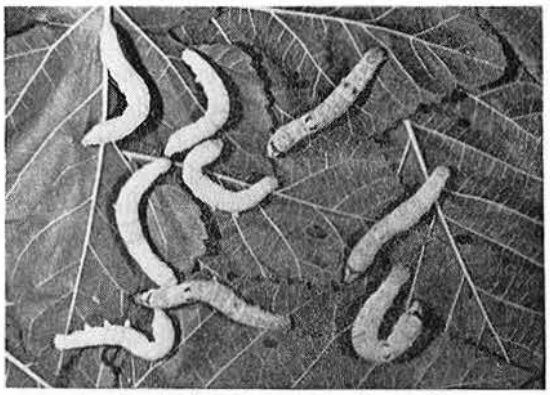
In all the hibernating eggs of the ordinary



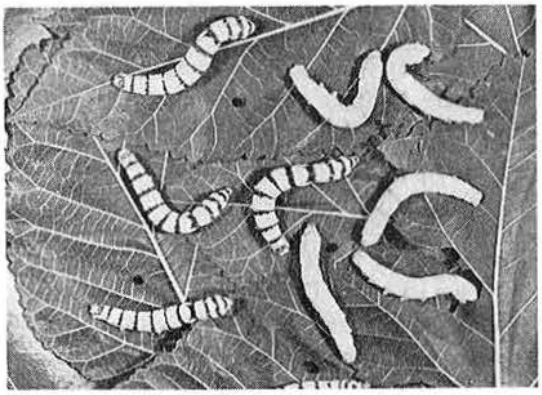
Sex limited black-egg race
Black: female White: male



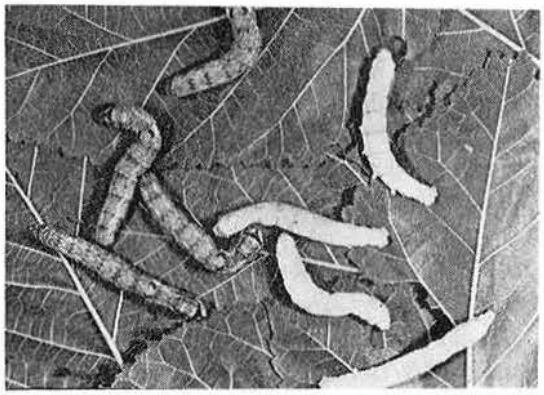
Sex limited nomal marking
normal: female plains: male



Sex limited pale moricaud marking
pale moricaud: female plain: male



Sex limited zebra marking
zebra: female plain: male



Sex limited moricaud marking
moricaud: female plain: male

silkworms, the serosa formed after fertilization being white in the beginning, changes gradually into blue-black or black within the course of a week. But in the sex-limited varieties, this change is observed in the female eggs only. In the sex-limited black egg strain, sexes are therefore discriminated by egg color so long as a black-egged female is mated with a white-egged (w_2) male. Males are usually higher in viability and cocoon shell percentage, giving higher productivity for cocoons, than the females. So, if eggs are produced at a low price in this strain, it will be possible to rear only males for practical cocoon production. However, sex-limited black-egged breeds are not economical at present, because they are inferior in hatchability and viability etc.

Effects of excess chromosomes

The usual chromosome number of all organism is well-balanced as a set. However, in general, an excess or deficiency of a chromosome (or its fragment) often has an ill effect on the survival of living things. Consequently, the bad effects were evident in the original autosexing silkworm strain. Females in this strain showed a decrease in body weight, sometime being smaller thna males, besides they were lower in survival rate than normal race, showing an unusual sex ratio same as in unfavorable environmental conditions. It was especially interesting that females in this strain were inferior to males in neatness character of raw silk which is said to be

heritable.

To minimize the bad effects on the female, further efforts have been carried out to cut the extra fragment as short as possible by X-rays. However, chromosomal mutations often occur even in natural conditions, and finally a "pale moricaud" strain was obtained as a natural mutation in the course of the improvement of sex-limited varieties. This strain was considered to have an extremely short extra fragment of a chromosome, and never showed defective characters in females.

Establishment of economical autosexing breeds

As shown in Table 1, N117 × C116 for rearing in spring was authorized as the first hybrid between autosexing varieties in 1944, and N120 × C116 for summer and autumn rearing in 1945. These hybrids, however, had many defects as mentioned above, and could not be popularized. Though these defects were thought at first to be not improvable, efforts of breeders during the last twenty years have met with success in obtaining many defectless sex-limited varieties to be authorized.

Silkworms of the Chinese race are favorable materials to be marked with sex-limited larval marking characters, because most of the larvae are plain (recessive). So most of the authorized autosexing varieties were at first Chinese ones, that is, only one parental variety for crossing. Both Japanese and Chinese defectless sex-limited varieties for crossing were first obtained by the Sericultural Experiment Station in 1967, and the hybrid between them N131 × C131 was authorized. These parental varieties are free from the defects related to chromosomal imbalance, and the hybrid has excellent characters as shown in Table 2: good in health, high in cocoon production and superior in reelability and neatness. It is felt that the present silkworm varieties will be replaced in future by these sex-limited excellent varieties in Japan where labor is hardly obtainable.

Table 1. Autosexing silkworm breeds in Japan

Year of authorization	Varieties (hybrids)				Rearing season
1944	N117	×	C116	(both)	Spring
1945	N120	×	C116	(〃)	Summer and Autumn
1954	Shûko	×	Gingyoku	(Chinese)	〃
1963	Shunzan	×	Hôgyoku	(〃)	Spring
1966	Tama	×	Ayanishiki	(〃)	Summer and Autumn
1967	N131	×	C131	(both)	Spring
1969	Shûho	×	Ginka	(Chinese)	Summer and Autumn
1969	Ban	×	Dai	(〃)	Spring

both: Both parental varieties are autosexing.
Chinese: Only Chinese variety is autosexing.

Table 2. Comparision in main characters between an autosexing variety and ordinary ones.

Varieties (hydrids)	Hatchability	Survival	Cocoon production per 10,000 worms	Reelability	Raw silk percentage	Neatness	Remarks
N124×C122 (Futo)	97%	96.5%	20.1kg	75%	19.80%	94.8	Control
N131×C131	96	96.8	20.5	79	20.16	94.7	Autosexing
Shungetsu×Hôshô	97	94.7	19.5	77	21.22	93.8	Most popular