STUDIES ON THE REFLECTION PROPERTY OF LIGHT IN THE SILKWORM EGG, *BOMBYX MORI* L.

By

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INTRODUCTION

It is well-known that there are a number of strains in the domestic silkworm, *Bombyx mori* L., each of which has genetically its own coloration of the egg. The manifestation of color of the silkworm egg is dependent mainly on the color of the chorion and the serosa pigments. And bio-chemical and hereditary contributions have been given on the production of the serosa pigments by many workers (UDA, 1932 : UMEYA, 1938 : FUKUDA, 1940, 1941 : KIKKAWA, 1941 : YOSHITAKE, 1956 and so on).

The egg colorations of native silkworms are generally purplish gray but sometimes tinged with green or pink. Further there are many strains with special egg colors such as brown, gray, dark gray, orange yellow, pale yellow and white (colorless).

Up to the present the egg color used to be discriminated by naked eyes, so there is some ambiguity in its expression. Then, tried to measure the egg coloration quantitatively, the authors pursued the reflection characters of light from the silkworm eggs by using Three-Dimentional Goniophotometer.

Before going further the authors desire to acknowledge their hearty thanks to Mr. S. YASUMURA, Silkworm Breeding Division of Sericultural Experiment Station, Kobuchizawa-machi, Yamanashi-pref., who gave them valuable materials.

MATERIALS AND METHODS

The hibernating eggs used for this experiment were as follows.

Japanese race············4 strains
Chinese race ············4 strains
European race ·········4 strains
Mutant·····················9 strains

Each strain name is given in the respective section (Table 1, 3, 5, 7,).

The measurement of the reflection character was carried out by Three-Dimentional Goniophotometer (GP-meter) as same as in the previous report (TAKIZAWA & KOYAMA, 1969, 1970). A value of the contrast gloss (Gc) was calculated from I-θ curve using the following formula (SAWAJI, 1965).

$$Gc = I_{45^\circ}/I_{0^\circ}$$

Here, I_{45° and I_{0° mean a value of the reflection intensity when the light from the incidence angle 45° is received at the reflection angle 45° and at the reflection angle 0°, respectively.

Besides the superficial egg coloration was identified by the color standard book (1954).

RESULTS

A. REFLECTION INTENSITY

1. Japanese race

Table 1 shows the material eggs used for measurement.

Table 1. Egg coloration in Japanese race

Strain	Hue	Luminosity	Saturation	Standard color name	Color-name in Japanese
Koishimaru	21	17	1	Light purplish gray	Ususakura-nezumi
Kurikokusan	8	16	2	Grayish olive	Namakabe
Aojuku-A	20	16	1	Purplish gray	Fujinezumi
Aojuku-I	20	15	1	Purplish gray	Koifujinezumi

Table 2. Reflection intensity in Japanese race

Incid. angle / Strain	I_{45°		I_{0°	
	Max.	Min.	Max.	Min.
Koishimaru	46.8	41.2	39.3	35.1
Kurikokusan	33.8	31.2	28.7	26.8
Aojuku-A	35.0	32.2	32.8	29.9
Aojuku-I	32.0	27.9	25.7	21.9

The I_{45° reflection intensity is highest (41.2~46.8) in *Koishimaru* and lowest (27.9~32.0) in *Aojuku-I* (Table 2). This tendency is also seen in the I_{0° reflection intensity, of which each value appears much smaller.

In I—θ curve of I_{45° (Fig. 1), three peaks are recognized with the interval of $\theta = 90^\circ$ in each strain, though they are invisible in that of I_{0°.

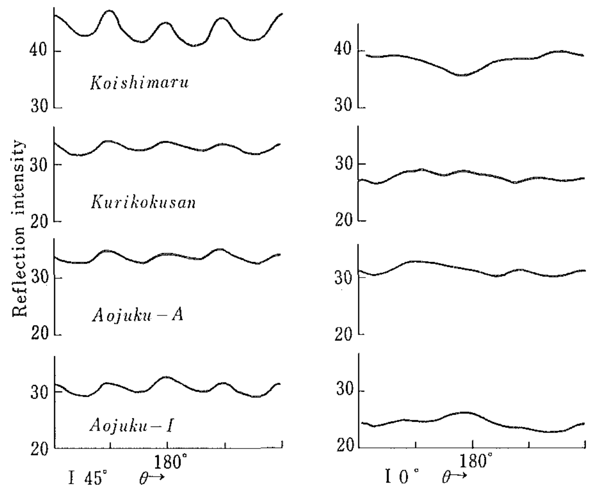

Fig. 1 *I—θ* curve in Japanese race

2. Chinese race

Four strains were used for the experiment (Table 3).

Table 3. Egg coloration in Chinese race

Strain	Hue	Luminosity	Saturation	Standard color name	Color-name in Japanese
S-No. 1	7	17	1	Light brownish gray	Ususakura-nezumi
Kaijo	8	17	2	Pale olive	Namakabe
Amoy-moricaud	20	15	2	Grayish purple	Fujinezumi
C-kyuken	20	16	2	Purplish gray	Koifujinezumi

Table 4. Reflection intensity in Chinese race

Incid. angle / Strain	I_{45° Max.	I_{45° Min.	I_{0° Max.	I_{0° Min.
S-No. 1	44.0	40.0	38.2	36.7
Kaijo	33.5	30.3	28.2	28.0
Amoy-moricaud	32.8	30.0	31.2	25.1
C-kyuken	35.0	31.1	29.9	25.3

The maximum and the minimum values of the reflection intensity re ceived at I_{45° and I_{0° are described Table 4.

The largest intensity is found in *S-No. 1* (40.0～44.0) and the smallest one in *Amoy-moricaud* (30.0～32.8) at I_{45°, whereas each intensity value becomes evidently smaller at $I_{0°}$ than at $I_{45°}$. Further the $I_{45°}$ reflection intensity seems a little lower in each Chinese strain than in the corresponding Japanese strain except in *C-kyuken* of Chinese strain vs *Aojuku-I* of Japanese strain; the former (31.1~35.0) has a higher value of the intensity than that of the latter (27.9~32.0), even though to the both strains is given the same Japanese color name (Table 1, 3).

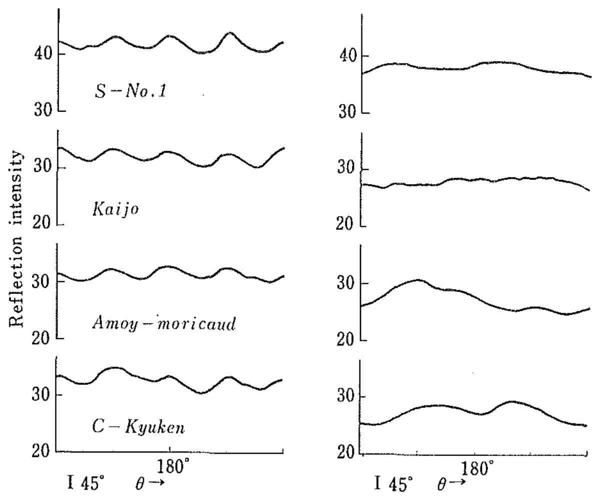

Fig. 2 *I—θ* curve in Chinese race

The changing phase of the reflection intensity followed with the rotation angle of the sample (Fig. 2) is completely agreed with that in Japanese race (Fig. 1).

3. European race

The material eggs used for the experiment are shown in Table 5 and

Table 5. Egg coloration in European race

Strain	Hue	Luminosity	Saturation	Standard color name	Color-name in Japanese
Szegzard	8	17	1	Light olive gray	Ususakura-nezumi
Ioken	8	17	2	Pale olive	Namakabe
Asia-oken	20	16	1	Purplish gray	Fujinezumi
No. 193	20	16	1	Purplish gray	Koifujinezumi

the reflection intensity measured at $I_{45°}$ and $I_{0°}$ is given in Table 6.

The $I_{45°}$ reflection intensity is highest in *No. 193* (38.2~44.5) and lowest

Table 6 Reflection intensity in European race

Strain \ Incid. angle	$I_{45°}$		$I_{0°}$	
	Max.	Min.	Max.	Min.
Szegzard	31.0	27.9	28.9	26.0
Ioken	38.0	34.5	33.9	30.0
Asia-oken	37.2	33.9	32.3	28.2
No. 193	44.5	38.2	32.0	29.5

in *Szegzard* (27.9~31.0), and each value is remarkably smaller at $I_{0°}$ than at $I_{45°}$.

The $I_{45°}$ reflection intensity of *Szegzard* (27.9~31.0) differs greatly from those of *Koishimaru* belonging to Japanese race (41.2~46.8) and of *S-No. 1* belonging to Chinese race (40.0~44.0), though the same Japanese color name as in the latter two strains is given to the former strain. Such a significant difference of the intensity is also detectable between *No. 193* (38.2~44.5) and the both corresponding strains (*Aojuku-I* of Japanese race, 27.9~32.0; *C-kyuken* of Chinese race, 31.1~35,0).

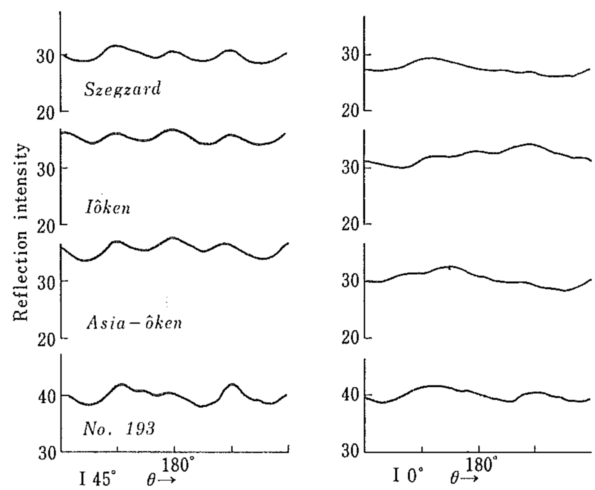

Fig. 3 *I—θ* curve in European race

The shape of *I—θ* curve in European race is entirely the same as in Japanese and Chinese races (Fig. 3).

4. Mutant

Nine strains of egg color mutants were used for the measurement (Table 7). The reflection intensities and *I—θ* curves of their eggs are shown in Table

8 and Fig. 4, respectively.

Table 7. Egg coloration in mutant

Strain	Hue	Luminosity	Saturation	Standard color name	Color-name in Japanese
Taishohaku-Ab	8	19	1	Yellowish gray	Hakuran
Crimson-hakuran	8	19	3	Pale yellow	Kiiro
No. 6	8	19	2	Pale yellow	Tomorokoshiiro
No. 10	6	19	3	Pale yellow orange	Koshoku
Kaishokuran	18	18	1	Light bluish gray	Haiiro
Katsu-H	5	19	3	Pale orange	Tankoshoku
Yasanranshoku	5	18	4	Pale brown	Kasshoku
No. 5	1	16	4	Old rose	Choshunshoku
OC-r	2	16	5	Pull red	Tokoshoku

Table 8. Reflection intensity in mutant

Incid. angle / Strain	45°		0°	
	Max.	Min.	Max.	Min.
Taishohaku-Ab	85.8	81.0	94.2	86.6
Crimson-hakuran	70.9	67.2	68.0	66.0
No. 6	69.2	65.2	68.5	62.1
No. 10	59.8	56.0	57.5	56.3
Kaishokuran	54.0	46.3	75.3	69.0
Katsu-H	48.1	45.2	46.1	43.5
Yasanranshoku	44.0	41.9	40.0	38.2
No. 5	40.0	38.5	41.9	39.9
OC-r	37.7	34.0	34.0	28.5

Among 9 mutants the $I_{45°}$ reflection intensity is largest in *Taishohaku-Ab* (81.0～85.8) and smallest in *OC-r* (34.0～37.7).

A gradient of the light intensity is orderly arranged as in Table 8, but the order is not always coincident according to the reflection angle ($I_{45°}$ and $I_{0°}$). This fact will be caused by the egg form related to the light reflection.

In the egg color mutants 3 peaks usually seen in the $I_{45°}$ I—θ curve do not appear in that of *Taishohaku-Ab*, *Crimson-hakuran*, *Kaishokuran* and *Katsu-H*.

The reflection intensity in each strain has likely some positive relation to the luminosity identified by the color standard.

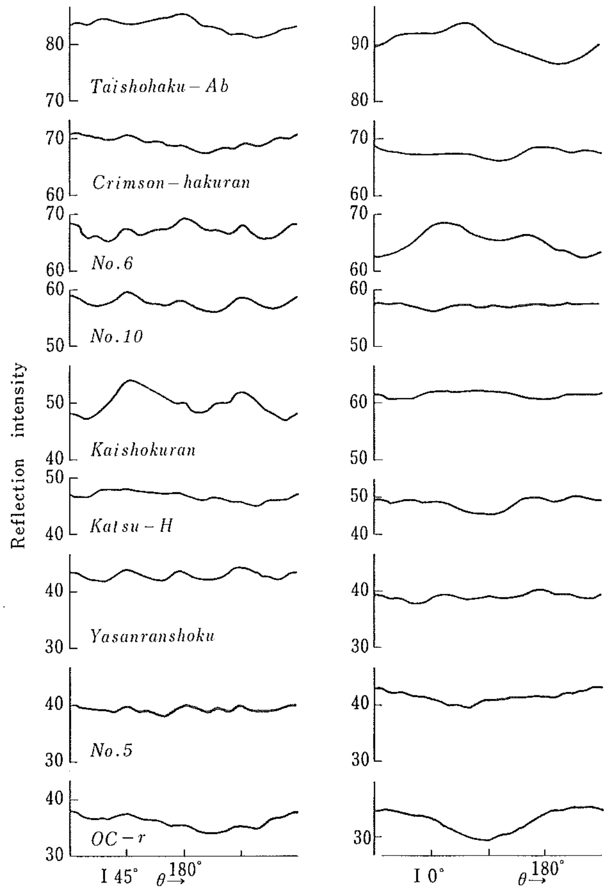

Fig. 4 *I—θ* curve in mutant

B. CONTRAST GLOSS

The contrast gloss (Gc) calculated from *I—θ* curve is denoted in Fig. 5.

1. Japanese race

Gc value is highest in *Aojuku-I* (1.28) and lowest in *Koishimaru* (1.12), indicating that each takes an adverse value to the reflection intensity (Table 2).

2. Chinese race

Gc value is orderly arranged as *C-kyuken* (1.20)>*Kaijo* (1.14)≒*Amoy-moricaud* (1.13)>*S-No. 1* (1.08). The order is almost adverse to the case of the reflection intensity (Table 4).

3. European race

Gc value order is as *No. 193* (1.29)>*Asia-oken* (1.17)>*Ioken* (1.13)>*Sze-*

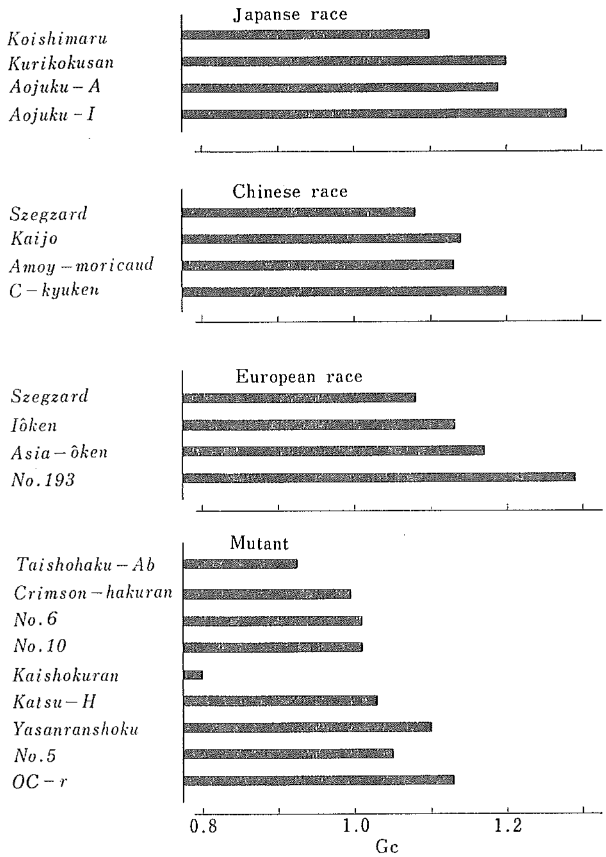

Fig. 5 Gc values of the sample eggs

gzard (1.08); the first strain has a remarkable high index. The adverse tendency of Gc value to the reflection intensity (Table 6) is recognized also in this case.

4. Mutant

Gc value is largest in *OC-r* (1.13) and smallest in *Kaishokuran* (0.80); the latter takes an extremely small value.

The order of Gc value in these mutants is almost adverse to that of the reflection intensity (Table 8) except for *Kaishokuran*.

Compared Gc with the luminosity by the color standard, the both values are known to take a negative relation in almost all strains.

CONSIDERATION

The superficial coloration of the silkworm egg is expressed mainly by colors of the chorion and of the serosa pigments, concerning which biochemical and genetical investigations have been carried out by many workers as described in the above. A practical discrimination of the egg color has been done by naked eyes, so it lacks definiteness in naming of color depending on personal difference.

In this experiment the authors measured the egg coloration photophysically, to which the quantitative indicators such as the reflection intensity and the contrast gloss were given.

According to these indicators, it is ascertained that very delicate difference is detectable even in the same color. Though it is quite difficult that the delicate coloration of the egg is suitably expressed only by Japanese color name, a more exact expression would be possible if the reflection intensity (Ri) and the contrast gloss (Gc) are added to the color naming.

Here in Table 9 such an attempt will be given to the strains with the same Japanese color name.

Table 9. Examples of the color names to which Ri and Gc added.

	Race	Strain	Color name in Japanese	Ri	Gc
A	Japanese	*Koishimaru*	Ususakura-nezumi (light purplish gray)	45	1.10
	Chinese	*S-No. 1*	〃	44	1.08
	European	*Szegzard*	〃	31	1.08
B	Japanese	*Kurikokusan*	Namakabe (pale olive)	34	1.20
	Chinese	*Kaijo*	〃	34	1.14
	European	*Ioken*	〃	38	1.13
C	Japanese	*Aojuku-A*	Fujinezumi (purplish gray)	35	1.19
	Chinese	*Amoy-moricaud*	〃	33	1.13
	European	*Asia-oken*	〃	37	1.17
D	Japanese	*Aojuku-I*	Koifujinezumi (purplish gray)	32	1.28
	Chinese	*C-kyuken*	〃	35	1.20
	European	*No. 193*	〃	45	1.29

In A group, each color name is samely Ususakuranezumi (light purplish gray), but *Szegzard* with the smallest Ri value (31) means it has a less brightness than the other strains, though Gc is almost similar.

In B group, of which the color name is Namakabe (pale olive), *Kurikokusan* and *Kaijo* are equal in Ri but differ in Gc, showing the former bears

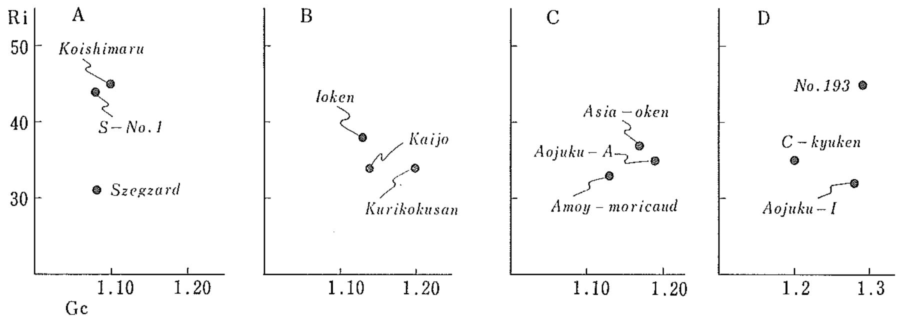

Fig. 6 Relation between Ri and Gc in the strains with the same egg color name

a higher glossiness (1.20). *Kaijo* and *Ioken* with the same Gc are different to each other in Ri, which indicates the latter is more bright in coloration than the former.

In C group, 3 strains with the same color name are different in Ri and Gc with each other, among which *Amoy-moricaud* has the smallest value of Gc.

In D group, which has Koifujinezumi color egg (purplish gray), *No. 193* is highest in Ri and Gc. It shows that each strain has a quite different element in the light reflection.

These relationships of Gc and Ri are more clearly expressed in Fig. 6.

As above-mentioned, if Ri and Gc are taken into consideration to the color name hitherto given, a more definiteness would be expected in discrimination of the egg coloration.

SUMMARY

The refection property of light was quantitatively measured on the hibernating eggs of various strains in the silkworm, *Bombyx mori* L. As the result it was ascertained that the egg coloration was more definitely expressed by taking the reflection intensity (Ri) and the contrast gloss (Gc) into consideration to the color name decided by naked eyes.

LITERATURES CITED

FUKUDA, S. (1940) Zool. Mag. Japan, 52(11):415–429.

—— (1941) J. Genet. Japan, 17:97–108.

KIKKAWA, H. (1941) Zool. Mag. Japan, 53:507–509.

SAWAJI, M. et al. (1965) J. Cotton Tech. Inst., 62:1–86.

TAKIZAWA, T. & KOYAMA, N. (1969) J. Facul. Text. Sci. & Technol. Shinshu Univ., No. 51, Ser. A, 14:53–68.

——·——(1970) Ibid., 15:17–25.

UDA, H. (1932) Memor. Publ. 10th Anniv., Mie Agricul. & Forest. Col., 1–42.

UMEYA, Y. (1938) J. Genet. Japan, 14(6):278–288.

WADA, S. (1954) Guide to color standard, Nippon Shikisaikenkyu-jo, Tokyo.

YOSHITAKE, N. (1956) J. Sericult. Sci. Japan, 25 (6):430–434.