REFLECTION PROPERTY OF LIGHT FROM THE WING SURFACE OF THE SILKWORM IMAGO, *BOMBYX MORI* L. (LEPIDOPTERA: BOMBYCIDAE)

By

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INTRODUCTION

It is well known that in most insects the superficial coloration is produced by the physical construction and pigments contained in the epidermis. In Lepidoptera, for example in Pieridae, a white color of the wing is resulted from reflection and absorption of light at the scale surface, and from some whitish pigments contained in the scale (CHAPMAN 1969).

The wing of the silkworm imago takes also a whitish coloration in most of all strains and races with exception of *Kokuga*, which is a kind of mutants having dark brown wing. The reason is known due to white scales covered over the wing surface densely.

Several papers have already been published on the reflection properties of butterfly wings (LUTZ 1933, MAKINO *et al.* 1952, MAZOKHIN-PORSHNIAKOV 1957, OBARA and HIDAKA 1968, 1970, TAKIZAWA and KOYAMA 1974, WAGO *et al.* 1976). Although in moths especially in silkworm moth any report has not yet been concerned with such a problem from photophysical point of view.

In preparing this presentation, the author desires to express his hearty thanks to Prof. Dr. N. KOYAMA for reading the original manuscript and advices.

Thanks are also due to Prof. Dr. E. NAGASHIMA, Ass Prof. Dr. R. TAKEI who assisted throughout the work.

MATERIALS AND METHODS

The adult insects used for the materials were as follows.

Japanese race ··············*Nichi-124* (wing, white)
Chinese race ··············*Shi-108*, *Daizo* (wing, white)
European race··············*0-16* (wing, white)
Indo-chinese race ········*Mysore* (wing, white)

Mutant ························ w_1 (wing, white), *Kokuga* (wing, dark brown)

The moths were obtained from a general rearing with mulberry leaves. Just after emergence each wing of the imago was cut off from the body and set horizontally on the measuring apparatus.

The reflection intensity was recorded as *I–θ* curve at the central part of the upper surface and the under one of wing containing the veins media 3 and cubitus 1 by using of Goniophotometer (GP–meter).

The reflection index was calculated by the same method as mentioned in the previous papers (TAKIZAWA and KOYAMA 1969, 1970, 1972, 1974, 1975).

RESULTS

A. REFLECTION INTENSITY

I–θ curves recorded by GP–meter are shown in Fig. 1~2. The changing phase of the reflection intensity following with the rotation angle varied so much according to strain, sex or part of wing. One peak, however, was recognizable in almost all *I–θ* curves, respectively.

Next, the maximum value of the reflection intensity in each strain is denoted in Fig. 3.

The highest value was recorded at the under sides of the fore and the hind wings in the male *Nichi–124* (4. 12±0. 52mv, 4. 09±0. 14mv), respectively. The smallest value was seen at the upper side of the hind wing in the male *Mysore* (1. 84±0. 05mv). As a whole, the reflection intensity was almost ordered as *Nichi–124>Shi–108≒Daizo>0–16>Mysore.*

Compared the fore wing with the hind wing, the intensity value had no definite relation between the both wings with exception of *Shi–108*, in which it was larger in the former than in the latter.

The value was higher at the upper side of the wing than at the under one in *Shi–108*, on the contrary larger at the under side than at the upper in *Nichi–124*, *0–16* and *Mysore.*

The sexual difference of the intensity value was not so clear in each strain, though that of the male was slightly larger than that of the female.

The reflection intensity in two mutants is shown in Fig. 4. *Kokuga* having black wings showed the smallest value of the intensity (0. 81±0. 03mv) as its hereditary nature. The intensity difference was very faint between the fore wing and the hind wing. Although the intensity value was always larger at the under side of the wing than at the upper side.

The sexual difference was remarkable; the intensity was smaller in the male than in the female.

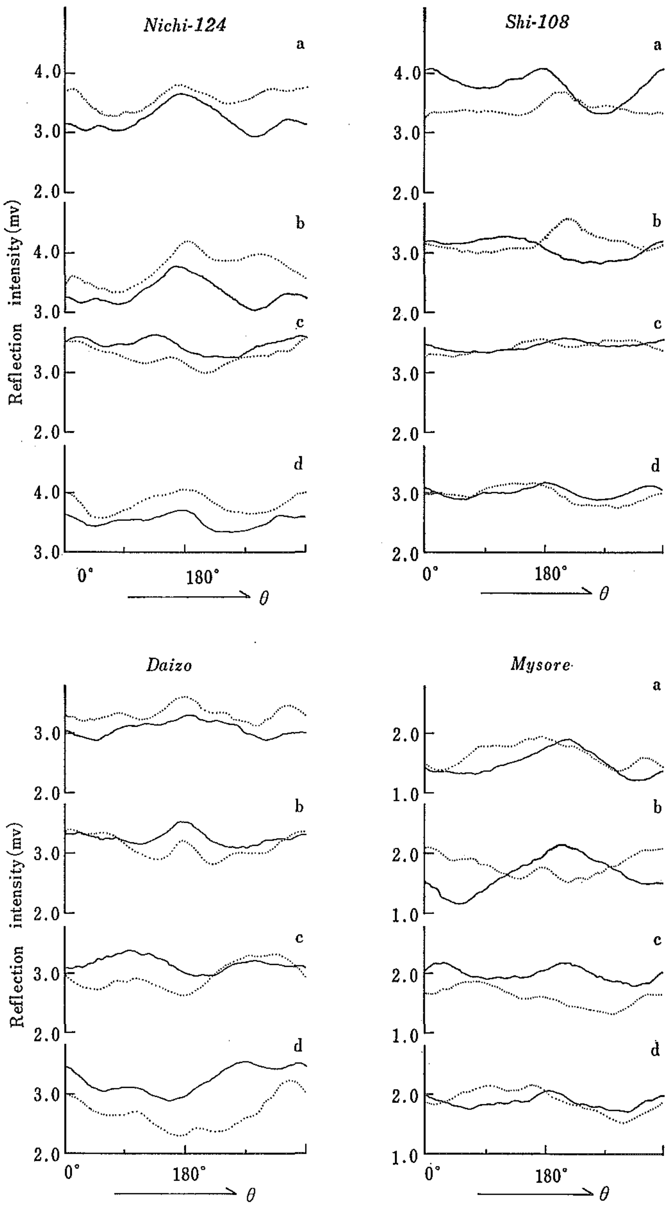

Fig. 1 Reflection intensity in *Nichi-124*, *Shi-108*, *Daizo* and *Mysore*
Dotted line : male, solid line : female.

a: upper surface of fore wing, b: under surface of fore wing, c: upper surface of hind wing, d: under surface of hind wing, θ: rotation angle at sample stage.
These abbreviations were used in the following figures.

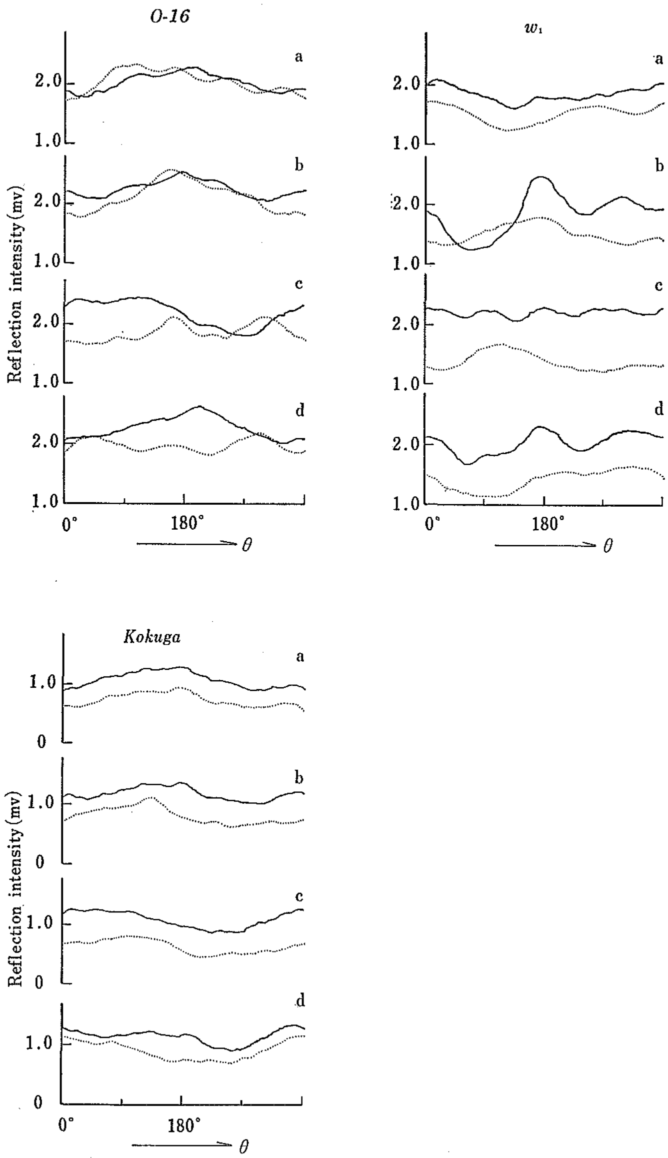

Fig. 2 Reflection intensity in *0–16*, w_1 and *Kokuga.*

B. REFLECTION INDEX

The index value of each strain is shown in Fig. 5. It varied 1.05~1.25 and was hardly detectable the difference between the fore wing. The difference of the index value between the upper side and the under side of the wing was

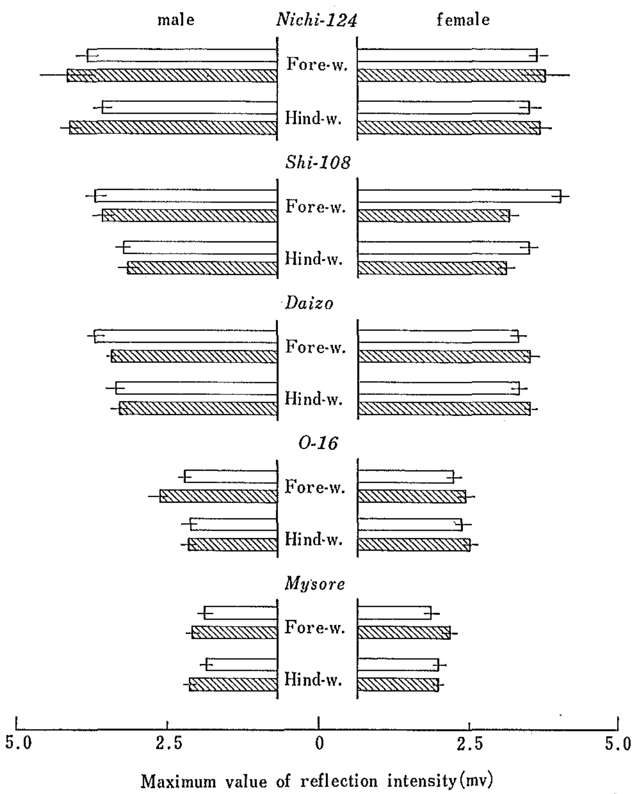

Fig. 3 Maximum value of reflection intensity at wing surface in strains (*Nichi-124*, *Shi-108*, *Daizo*, *0-16* and *Mysore*) □……upper surface, ▨……under surface.

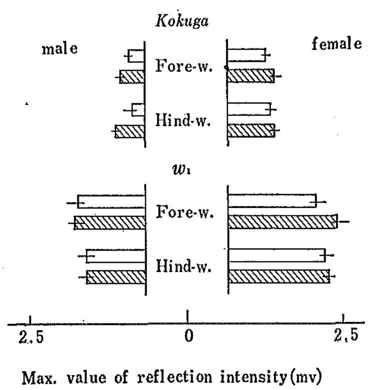

Fig. 4 Maximum value of reflection intensity at wing surface in mutants (w_1, *Kokuga*)

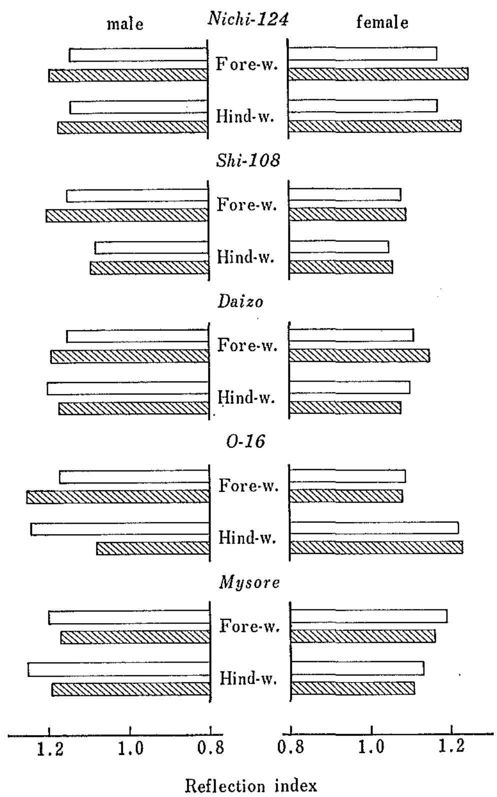

Fig. 5 Reflection index at wing surface in strains (*Nichi-124*, *Shi-108*, *Daizo*, *0-16* and *Mysore*)

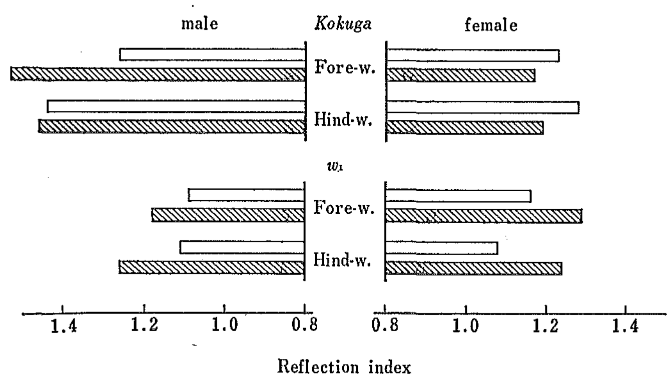

Fig. 6 Reflection index at wing surface in mutants (w_1, *Kokuga*)

very faint, though it was a little larger at the under than at the upper in *Nichi-124* and *Shi-108*.

The sexual difference was not clear also in the reflection index with exception of *Shi-108*, *Daizo* and *Mysore*, in which that of the male was slightly higher than that of the female. Fig. 6 shows the reflection index of each mutant.

The index value was, as a whole, high ranging 1.27~1.53 in the male wing of *Kokuga*.

A definite difference was difficult to see between the both values of the fore wing and the hind wing, but the index was larger at the under side than at the upper side of wing except in the female wing of *Kokuga*.

The sexual difference was significant in the index value of *Kokuga*, viz. larger in the male than in the female, while not recognized in that of w_1.

C. RELATION BETWEEN REFLECTION INTENSITY AND REFLECTION INDEX

The relationship between the reflection intensity and the reflection index was pursued from the above-mentioned data. It is indicated in Fig. 7~12.

Nichi-124 (Fig. 7)

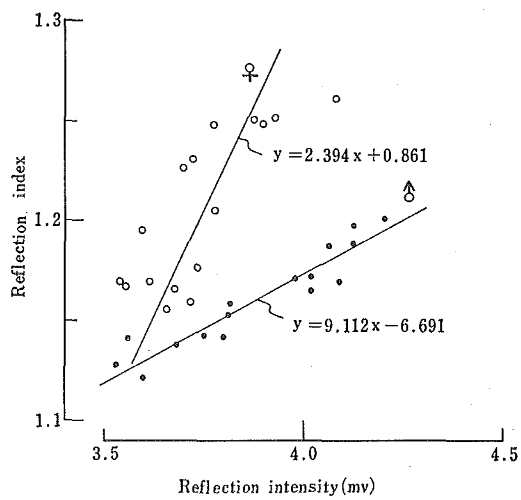

Fig. 7 Correlation between reflection index and reflection intensity in *Nichi-124*

The dual factors were closely related to each other. The correlation coefficient (r) was 0.944 in the male wing and 0.783 in the female wing, respectively. Such a relation was expressed by the regression formula Y=9.112X—

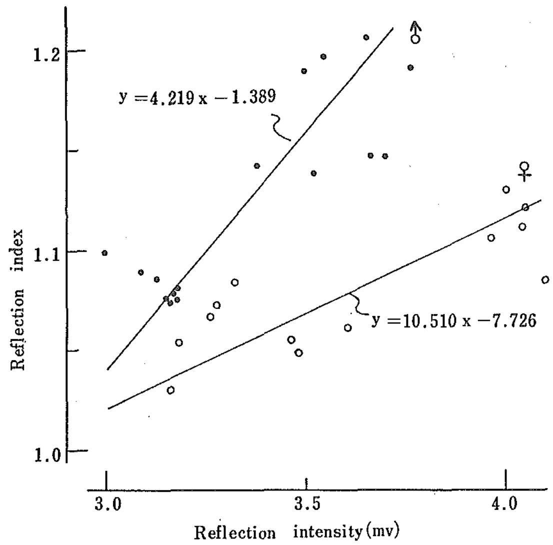

Fig. 8 Correlation between reflection index and reflection intensity in *Shi-108*

6.691 in the male and Y=2.394X+0.861 in the female, respectively.

Shi-108 (Fig. 8)

The correlation (r) was calculated as 0.865 in the male and 0.806 in the female. The index and the intensity had positively a close relationship. In the male Y=4.219X−1.389 and in the female Y=10.510X−7.726 were given to each relationship as the regression formula.

Daizo (Fig. 9)

The relation between the index and the intensity was intimate but showed a negative direction. The correlation coefficient r was −0.903 in the male wing and −0.792 in the female wing, respectively. The relationship expressed by the regression formula was Y=−4.843X+9.124 in the male and Y=−3.449 X +7.255 in the female.

0-16 (Fig. 10)

The correlation coefficient of the male wing was 0.711 and that of the female wing 0.862. The intensity and the index showed a positive correlation. The relation between the two factors was as follows; male Y=1.984X+1.339, female Y=2.419X+1.272.

Mysore (Fig. 11)

The correlation coefficient between the reflection intensity and the reflection index was so small as −0.464 in the male wing and 0.517 in the female wing,

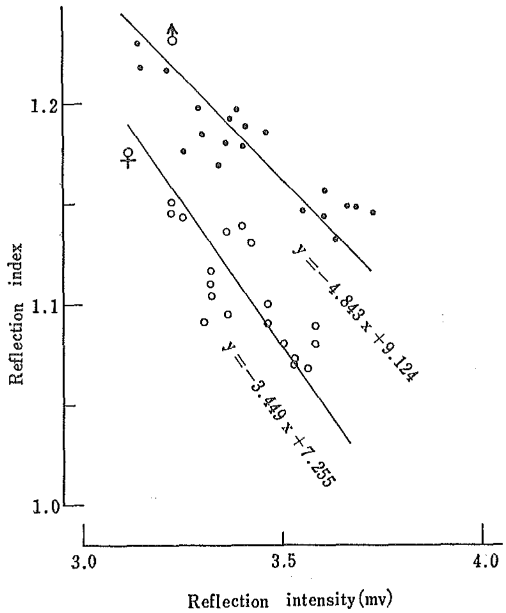

Fig. 9 Correlation between reflection index and reflection intensity in *Daizo*

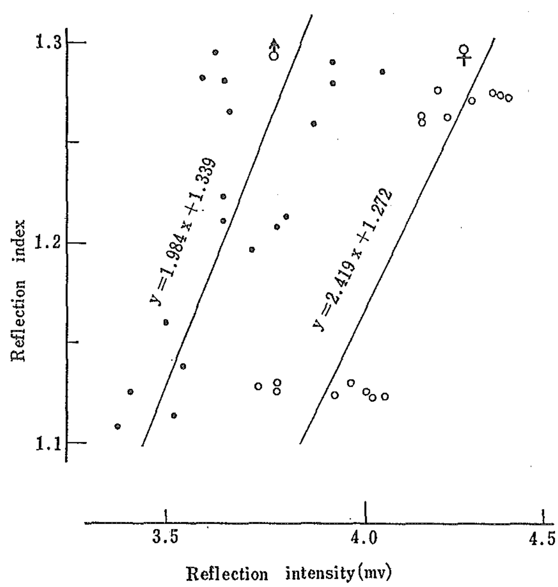

Fig. 10 Correlation between reflection index and reflection intensity in *O-16*

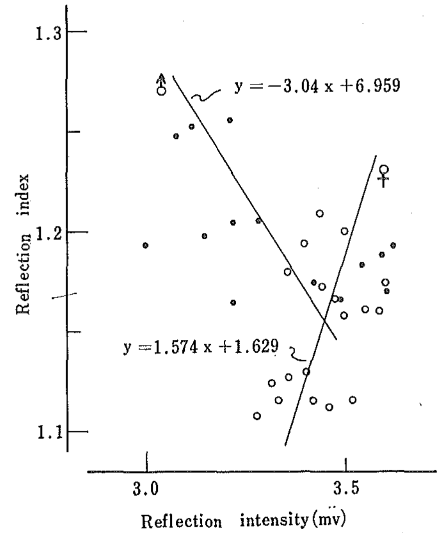

Fig. 11 Correlation between reflection index and reflection intensity in *Mysore*

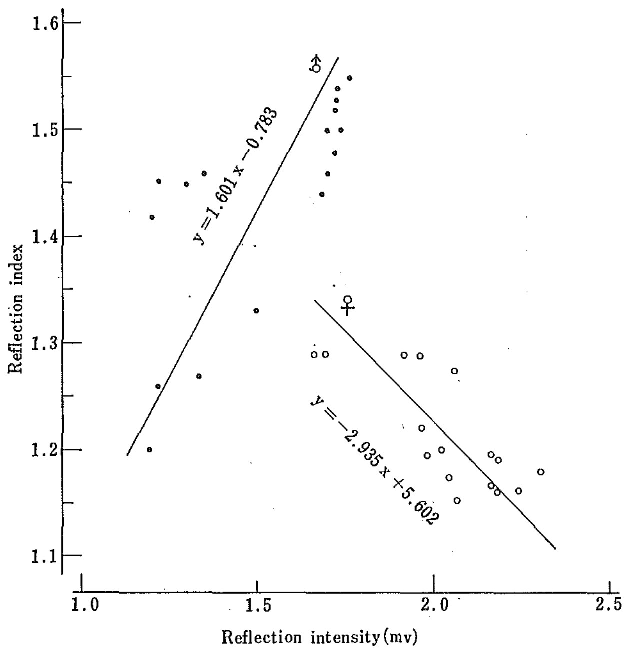

Fig. 12 Correlation between reflection index and reflection intensity in *Kokuga*

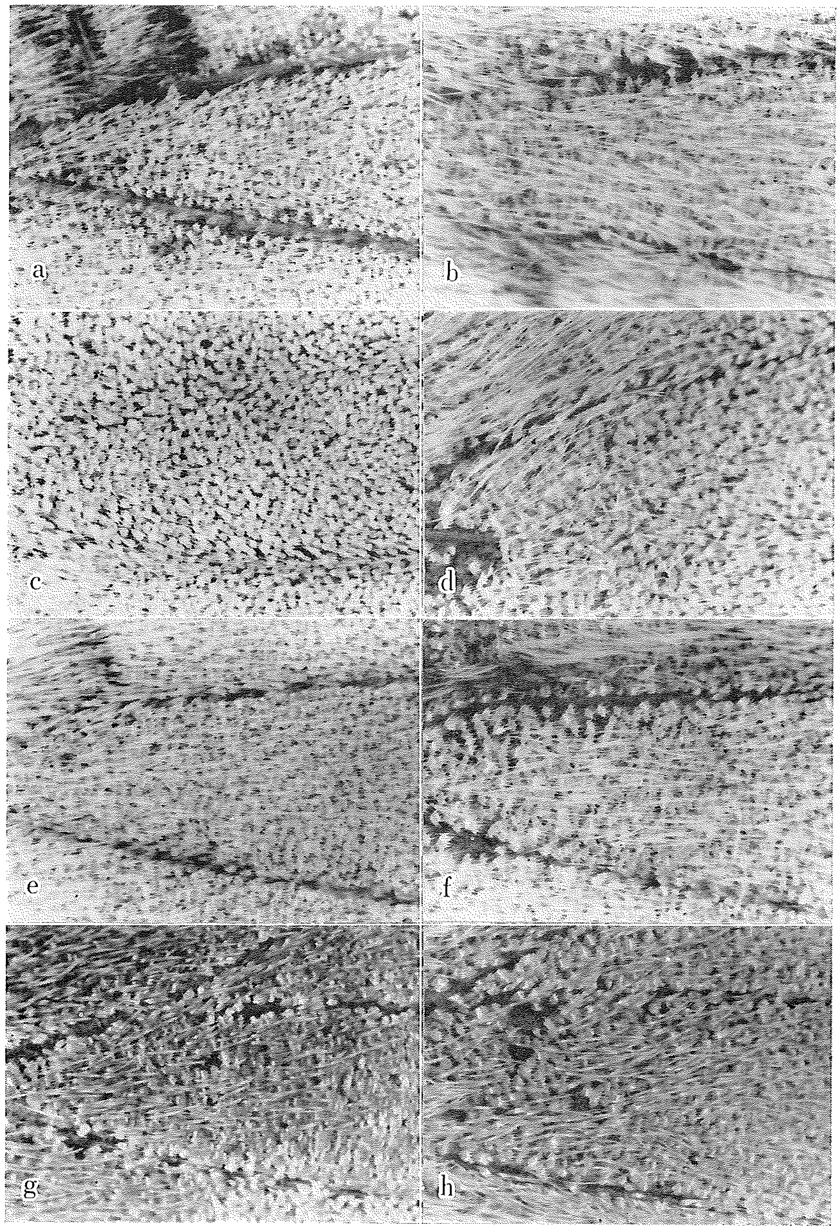

Fig. 13 Scales covering upper surface of right fore wing in 3 strains and one mutant
a: *Nichi-124* ♂, b: *Nichi-124* ♀, c: *Shi-108* ♂, d: *Shi-108* ♀, e: *0-16* ♂, f: *0-16* ♀, g: *Kokuga* ♂, h: *Kokuga* ♀.

that unable to recognize a significant correlation between them.

w_1

The relationship of the reflection intensity with the reflection index was quite separated because of such small correlation coefficients as r=0. 328 in the male and r=0. 348 in the female, respectively.

Kokuga (Fig. 12)

In the male wing the both factors were positively related to each other, but the relation being not so close (r=0. 691). On the other hand, in the female wing the correlation coefficient (r=−0. 757) suggested existence of a deep but negative relation between the intensity and the index.

To the male was given Y=1. 601X−0. 783 and to the female Y=−2. 935X+5. 602 as the regression formula, respectively.

CONSIDERATION

As above-described, the reflection intensity of the wing varied so much according to strains or mutants, though the wing coloration was seen samely as white with naked eyes. In *Kokuga* having dark brown wings, however, it showed the smallest value of the reflection intensity corresponding to its wing coloration. Besides the intensity difference was not so evident between the fore and the hind wings, the upper side and the under side of the wings or between sexes, though exceptionably *Kokuga* was remarkably larger in the female wing than in the male wing. The difference in *Kokuga* is caused by the fact that the female wing has lighter color than the male one.

According to the previous paper on *Pieris rapae crucivora* (TAKIZAWA and KOYAMA 1974), a significant difference was pointed out in the reflection index between the sexes, the fore and the hind wings and between the upper and under sides of the wing. Although the index in the *Bombyx* moths showed few evidential differences between the fore wing and the hind one, the upper side and the under side of the wings, and between sexes. In only *Kokuga*, however, the sexual difference was great, viz. the male wing had a larger value of the index than the female one. The reflection index which means gloss of wing seems to be higher in a darker wing than in a lighter wing in color.

A close relationship was recognized between the reflection intensity and the reflection index in most strains except in *Mysore* and w_1. The correlation, however, was positive in *Nichi*-124, *Shi-108* and *0-16*, whereas negative in *Daizo*. And in *Kokuga* it was positive in the male wing and negative in the female wing, respectively. Why no correlation existed in *Mysore* and w_1, or why negatively related in *Daizo* and in the female wing of *Kokuga* ?

Observing the upper surface of the wing with microscope, a considerable difference exists in the scale form and distribution between the male and the female. For example, in *Nichi-124*, *Shi-108* and *0-16* long-slender scales are grown more densely in the female wing than in the male one around media 3 and cubitus 1. Such a tendency is also seen in the other strains and mutants (Fig. 13 a~h).

Although no common key is given to solve the above question from the scale form and distribution. The problem remains unsolved in this study.

Generally the morphological difference was difficult to distinguish among strains of the silkworm moths with naked eyes. The present investigation revealed some racial differences in the maximum value of the reflection intensity and the reflection index of the wing. These differences, therefore, will be estimable as the genetic characters of the wing.

SUMMARY

In the present paper, an account is given of the results on the reflection property of light from the wing surface of the silkworm moth, *Bombyx mori* L., using 5 strains and 2 mutants for the material. The results obtained are summarized as in the followings.

1. The changing phase of the reflection intensity took almost the same shape with one modal peak in all samples. The peak was seen at about 180° of the rotation angle (θ).
2. The maximum value of the reflection intensity was highest (4. 12±0. 52mv) at the under surface of the fore wing in the male *Nichi-124*, whereas smallest (0. 81±0. 03mv) at the upper side of the hind wing in the male *Kokuga*. As a whole, it was arranged orderly such as *Nichi-124* > *Shi-108* ≒ *Daizo* > *0-16* > *Mysore* > w_1 > *Kokuga*.
3. The sexual difference in the maximum value of the intensity was remarkable as being smaller in the male than in the female.

   The reason seemed to be attributted by some photoreflective difference in the scale between the both sexes.
4. The reflection index kept a constant value of 1. 05~1. 25 in most materials excepting that in *Kokuga*, in which the male wing showed such a high value as 1. 27~1. 53.
5. The difference of the index value between the upper side and the under side was very faint, but in the mutants especially in w_1 it was larger at the under side than at the upper side.
6. The sexual difference in the reflection index was not clear with exception

of some strains.

7. A close correlation was found between the reflection intensity and the reflection index in most strains and mutants except for *Mysore* and w_1. The correlation was positive in *Nichi-124*, *Shi-108* and *0-16*, while negative in *Daizo*. In *Kokuga*, however, it was positive in the male wing and negative in the female one, respectively. The problem why no correlation existed in *Mysore* and w_1, or why negatively related in *Daizo* and in the female wing of *Kokuga* remains unsolved in this study.

Generally the morphological difference was difficult to distinguish among strains of the silkworm moths with naked eyes.

The present investigation revealed some racial differences in the maximum value of the reflection intensity and the reflection index of the wing. These differences, therefore, will be estimable as the genetic characters of the wing.

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