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Chino H. Carbohydrate metabolism in the diapause egg of the silkworm, *Bombyx mori*—II. Conversion of glycogen into sorbitol and glycerol during diapause. *J. Insect Physiol.* 2:1-12, 1958.
[Department of Biology, Tokyo Metropolitan University, Setagaya-ku, Tokyo, Japan]

This paper for the first time reported that a unique carbohydrate metabolism takes place concomitantly with the beginning of diapause in insects. The final product of anaerobic breakdown of glycogen during diapause is not lactic acid but sugar alcohols such as sorbitol and glycerol. [The *SCI*® indicates that this paper has been cited in over 125 publications.]

Insect Diapause and Its Unique Energy Metabolism

Haruo Chino
Biochemical Laboratory
Institute of Low Temperature Science
Hokkaido University
Sapporo 060
Japan

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I was once a butterfly collector, when I was a boy. However, World War II interrupted my pleasure, and my dream of becoming a naturalist like J.H. Fabre of France was broken. When I started life as a researcher at the Tokyo Metropolitan University in 1953, I decided to work on insects; perhaps a remaining piece of my childhood dream spurred me to do so.

Many insects survive winter under resting conditions called "diapause." The insect diapause is primarily induced by the photoperiod to which the insects are previously exposed. Quite contrary to what some people may think, diapause is not directly induced by cold as some insects enter diapause even in midsummer. When I knew about the nature of insect diapause, I became very much interested in the problem of how insects manage to survive without ingesting any foods for a long period of time throughout summer, fall, and winter. I wondered if there is any particular regulation of energy metabolism that enables the insects to survive throughout the diapause period.

I decided to use the *Bombyx* silkworm for this study. It enters diapause at the early embryonic stage. However, it is known that after the diapausing eggs are exposed to cold for about two months, diapause is terminated. Soon after I began this study, I noticed that the large amount of glycogen originally stored in the eggs suddenly disappeared at the onset of diapause and that, when diapause was terminated, the glycogen level began to rise and soon regained nearly its initial value. What happened to the glycogen during diapause? I eagerly looked for the metabolic fate of glycogen. Many possible compounds were tested, e.g., lactic acid, metabolic intermediates, other sugars and polysaccharides, fat, and so on. However, all the attempts were unsuccessful and much time passed without any significant progress.

One day in 1956, I unintentionally tasted the concentrated aqueous extract from the diapausing eggs and, to my surprise, I found that it was very sweet! Although I was still a novice in the field of biochemistry then, I knew that glycerol, besides sugars, is a naturally occurring sweet substance. I immediately subjected the concentrated extract to paper chromatography with glycerol as reference. I found one spot exactly equivalent to standard glycerol, but another big spot also appeared. A few days later, the second spot was identified as sorbitol. I published a short communication of this finding in *Nature*,[1] which was the first report describing the existence and accumulation of such sugar alcohols in the animal kingdom. Later, G.R. Wyatt of Yale University reported independently the accumulation of glycerol in the diapausing *Cecropia* pupae.[2] In 1961 I received a prize from the Japanese Biochemical Society for this study.

From the viewpoint of energy strategy, the conversion of glycogen to sugar alcohols seems economical for the insects; the reaction serves to store hydrogen molecules that are then utilized as an energy source during the postdiapause development. Sugar alcohols are also known to be very powerful antifreezes, and, therefore, this study stimulated many researchers to look for similar compounds in different diapausing insects and to test their roles as natural antifreeze in these insects.[3,4] I spent several subsequent years trying to elucidate the mechanism by which glycogen is converted to sugar alcohols at the beginning of diapause.[5,6] This problem has not yet been quite resolved. However, due to many difficulties, I quit this area many years ago. I am currently studying the problem of lipid transport in insects.

For the past 35 years, I've spent my research life on insect biochemistry. But in my private life I returned to being a butterfly collector several years ago. I still hope to encounter an exciting moment when I catch this beautiful creature.

1. **Chino H.** Conversion of glycogen to sorbitol and glycerol in the diapause egg of the *Bombyx* silkworm. *Nature* 108:606-7, 1957. (Cited 60 times.)
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3. **Asahina E.** Frost resistance in insects. *Advan. Insect Physiol.* 6:1-49, 1969. (Cited 125 times.)
4. **Storey K B & Storey J M.** Freeze tolerance in animals. *Physiol. Rev.* 68:27-84, 1988.
5. **Chino H.** Enzymatic pathways in the formation of sorbitol and glycerol in the diapausing egg of the silkworm, *Bombyx mori*. I. On the polyol dehydrogenases. *J. Insect Physiol.* 5:1-15, 1960. (Cited 60 times.)
6. ----------. Respiratory enzyme system of the *Bombyx* silkworm egg in relation to the mechanism of the formation of sugar alcohols. *Arch. Biochem. Biophys.* 102:400-15, 1963. (Cited 25 times.)