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UTILIZATION AND EXCRETION OF ORGANIC NITROGEN BY THE SILVERFISH, *CTENOLEPISMA LINEATA*

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Abstract—Conversion efficiencies of organic nitrogen to live weight have been determined for the silverfish, *Ctenolepisma lineata*. These efficiencies vary from 0·014 to 0·13 mg N/mg live weight between animals and vary similarly within the same animal depending on the diet. The rate of weight gain by animals feeding on a complete diet ranged from 0·25 to 0·67 mg live weight per week. The silverfish can also live for extended periods on a diet of cellulose alone but requires a source of organic nitrogen for growth and other vital processes. Conservation of nitrogen seems to be accomplished by an inherent low turnover of tissue nitrogen when the animal is metabolizing carbohydrates. *C. lineata* may lose from 8 to 20 per cent of its total body nitrogen before expiring.

INTRODUCTION

IT was shown in an earlier study (LASKER and GIESE, 1956) that the silverfish *Ctenolepisma lineata* can digest and efficiently utilize the carbohydrates (cellulose and starch) in its diet, but no information is as yet available on this insect's ability to make use of the organic nitrogen in its diet. This is of interest since the food of the silverfish (e.g. paper) is often low in organic nitrogenous materials. This paper presents quantitative information on the utilization and excretion of organic nitrogen by *C. lineata*.

EXPERIMENTAL METHODS

The methods for keeping silverfish in the laboratory have been described (LASKER and GIESE, 1956). Silverfish are cannibalistic when on a restricted diet, and for this reason they were kept individually in glass vials with food provided as cellulose alone (Whatman No. 43 filter paper) or as a rolled oat grain which had been soaked previously in a solution containing 0·5 per cent yeast extract and 0·02 per cent liver extract concentrate (dipped oat). Oat grains and cellulose strips were dried in an oven at 70°C before being fed to silverfish. Adult animals used in feeding experiments were selected at random. Each of these animals weighed between 15 and 25 mg live weight. Water content of silverfish is approximately 70 per cent.

The animals, their faeces and the food remaining were usually weighed at two-week intervals. Weighing was done on a semi-micro balance sensitive to 0·01 mg. Faeces were not ingested by silverfish at any time, even when no other food was available. Organic nitrogen was analysed by the micro-Kjeldahl technique using a Kirk distillation apparatus (KIRK, 1936). A weighed sample of each oat grain used as food for silverfish was analysed for total organic nitrogen.

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DIPPED OAT AS A COMPLETE DIET

Gain in weight, egg laying, and successive moulting were chosen as criteria for the selection of dipped oat as an adequate diet. On a diet of dipped oat newly hatched larvae moult, develop pigmented scales, and grow successfully even under bacteria-free conditions (LASKER and GIESE, 1956). The data in Table 1 show that

TABLE 1—INCREASE IN LIVE WEIGHT BY ADULT SILVERFISH FED DIPPED OAT
(All weights are given in milligrams)

No.	Initial weight	Final weight	Gain in weight	Time interval	Rate of gain in weight
				(weeks)	(mg/week)
1	16·24	20·20	3·96	6	0·67
2	21·68	28·11	6·43	14	0·46
3	18·56	25·79	7·28	14	0·52
4	20·14	26·01	5·87	14	0·42
5	16·26	19·22	2·96	12	0·25
6	26·10	31·00	4·90	14	0·35
7	22·28	26·90	4·62	8	0·58
8	21·02	27·09	6·07	14	0·43
	Averages		5·44	12	0·46
	Range				0·25–0·67

in periods between moults adult silverfish also gain weight on this diet. Moulting usually occurred between 8 and 14 weeks. The average gain in weight was 0·46 mg per week or a total of 5·44 mg per average 12 week period. In an experiment comparing two groups of 10 animals each, the control group fed only cellulose, the other dipped oat, only one animal was alive in the control group at the end of 14 weeks, while all but one were alive in the oat-fed group after this period of time. In the cellulose-fed group most of the deaths occurred before eight weeks had elapsed. Thus, under the conditions tested, cellulose alone is an inadequate diet.

CONVERSION EFFICIENCY OF INGESTED NITROGEN TO LIVE WEIGHT

Table 2 presents data on the relation of assimilated organic nitrogen to gain in weight. From the data it appears that an actively feeding silverfish requires about 0·06 mg nitrogen to gain 1 mg of live weight. However, variations exist between different animals and within the same animal, depending upon the diet. For example, one silverfish (no. 6, Table 2) starved for nitrogen, when fed oat, soon converted most of the oat nitrogen into its tissues. Thus an average of only 0·03 mg nitrogen was required to produce each milligram of live weight for several weeks after commencement of feeding. This high efficiency was not maintained and at the end of several more weeks 0·13 mg nitrogen was needed by the same animal to produce each milligram of added live weight. Animal no. 7 (Table 2), also starved for nitrogen, showed a similar change.

The percentage of ingested nitrogen assimilated by the animals is also given in Table 2. The average of these figures for a number of animals is 47 per cent.

TABLE 2—NITROGEN ASSIMILATION AND GAIN IN WEIGHT BY ADULT SILVERFISH FED DIPPED OAT
(All weights are given in milligrams)

No.	Gain in weight	Nitrogen consumed	Nitrogen excreted	Nitrogen assimilated	mg N required for gain of 1 mg live weight	Per cent of consumed N assimilated
1	3·96	0·348	0·224	0·124	0·031	37
2	6·43	0·933	0·530	0·403	0·063	43
3	7·23	1·06	0·572	0·490	0·068	47
4	5·87	1·07	0·658	0·410	0·070	48
5	2·96	0·522	0·185	0·337	0·110	65
6a	6·21	0·388	0·210	0·178	0·030	46
6b	2·62	0·724	0·394	0·330	0·130	46
7a	8·00	0·192	0·077	0·115	0·014	60
7b	2·70	0·453	0·353	0·100	0·037	22
8	6·07	0·685	0·277	0·407	0·067	60

Nos. 6a and 7a indicate animals fed dipped oat after a 12-week diet of cellulose.
Nos. 6b and 7b indicate the same animals after feeding on dipped oat for several weeks.

Two animals which were studied after they fed on cellulose showed interesting variations in this percentage (nos. 6 and 7, Table 2). Animal no. 6 assimilated the same percentage of nitrogen throughout (46 per cent) while no. 7 dropped from 60 per cent assimilation to 22 per cent (average 41 per cent).

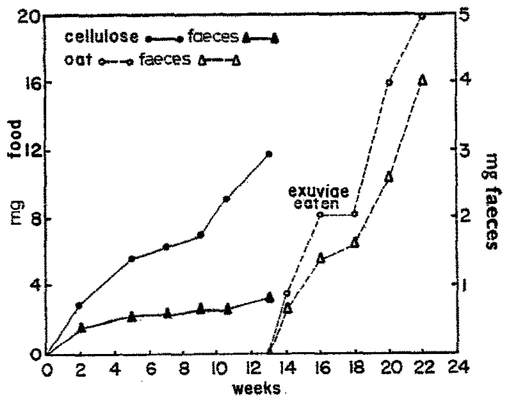

FIG. 1. Food consumption and faecal production of a silverfish.

Several animals fed exclusively on cellulose for 13 weeks were then fed dipped oat. Organic nitrogen intake and excretion was followed over the entire experimental period (22 weeks). Fig. 1 shows the faecal production, cellulose, and oat intake, and Fig. 2 shows the weight changes of the same animal over the 22 weeks. Although feeding on cellulose was continuous and finally amounted to 12 mg ingested, no sizeable increase in weight was made. Dipped oat was added to the diet toward the latter part of the cellulose feeding period when the animal appeared to be losing weight rapidly. The animal preferentially ate the oat and neglected the cellulose. Within a few weeks a substantial weight gain was made after which

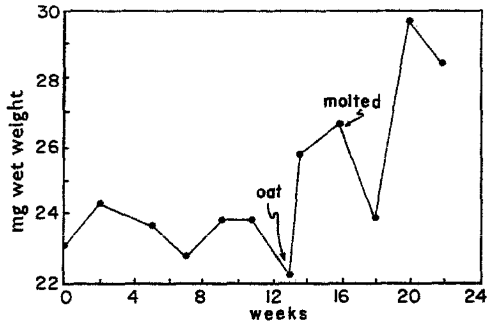

FIG. 2. Weight changes of a silverfish on a diet of cellulose, then oat.

the animal moulted. The exuviae were promptly eaten. During the period of cellulose feeding, faeces production was slight. When oat was eaten, a great increase in faeces (hence excreted nitrogen) was evident. It appears that the silverfish does not excrete nitrogen to any great extent when eating a digestible carbohydrate like cellulose. When fed a rich nitrogen source they excrete more faecal material and more nitrogen, presumably due to more undigested food and increased nitrogen metabolism. The ratio, *weight of nitrogen/weight of faeces*, is about the same with both diets; 0·081–0·129 mg N/mg faeces by eight cellulose-fed animals and 0·079–0·138 mg N/mg faeces by eleven oat-fed animals).

NITROGEN BALANCE OF SILVERFISH ON A COMPLETE DIET

Nitrogen intake and excretion by a number of silverfish was followed for three months. After this time each animal, its faeces and the remaining food were analysed for total nitrogen. In this, as in all of the experiments reported here, it was assumed that nitrogen fixation does not occur in the silverfish. This would seem to be borne out by the generally poorer condition that a silverfish reaches when feeding chiefly on a carbohydrate diet. From the values obtained it was possible to calculate nitrogen intake and excretion for each animal. The data are summarized in Table 3.

In view of the success of ZABINSKI (1929) in rearing cockroaches on a diet of glycine, a similar attempt was made with silverfish. One group of animals was fed dry filter paper previously soaked in 0·1 per cent glycine solution. Analyses were made of nitrogen ingested, excreted and total body nitrogen after the experiment.

The oat-fed group in all cases showed a positive nitrogen balance with an incorporation of nitrogen equal to about half the quantity ingested. Moulting intervened in most cases, and in every instance except those indicated in Table 3 exuviae were eaten by the animal so returning any lost nitrogen to it. It would seem that the exuviae were preferred food because an animal would usually eat them in preference to the dipped oat which was available at the same time. Should the exuviae be lost to the animal, the loss in nitrogen is about 7–8 per cent of the total nitrogen in the animal. LINDSAY (1940) reported a nitrogen loss of 6 per cent for the exuviae of *C. longicaudata*, a related species.

The animals fed cellulose-glycine fared poorly, and at the end of eight weeks all but two of these animals had died.

TABLE 3—NITROGEN BALANCE OF ADULT SILVERFISH FED A COMPLETE DIET
(All weights are given in milligrams)

No.	Initial Animal N	Final Animal N	Ingested N	Excreted N	Lost moult N	Gain in N	Time (weeks)
1	0·462	0·600	0·408	0·224	0·046	0·138	6
2	0·406	0·822	0·946	0·530	—	0·416	14
3	0·863	0·976	0·705	0·592	—	0·113	14
4	0·224	0·714	1·06	0·571	—	0·490	14
5	0·350	0·760	1·07	0·658	—	0·410	14
6	0·233	0·630	0·582	0·185	—	0·397	14
7	0·189	0·909	1·10	0·381	—	0·720	14
8	0·451	0·687	0·520	0·175	0·061	0·284	10

TABLE 4—NITROGEN LOSS BY ADULT SILVERFISH ON A NITROGEN-FREE DIET
(All weights are given in milligrams)

No.	Original live wt	Original Animal N	Final Faeces N	% loss of nitrogen
1	25·62	0·600	0·093	15·5
2	15·67	0·431	0·085	19·8
3	17·51	0·511	0·039	7·6
4	21·20	0·483	0·042	9·5
5	25·38	0·733	0·107	14·6
6	23·51	0·580	0·090	15·5
7	19·58	0·642	0·102	15·7
8	21·05	0·527	0·070	13·1
9	19·34	0·613	0·058	9·4
10	20·15	0·537	0·094	17·3
			Average	13·8

TOTAL NITROGEN LOSS BY SILVERFISH ON A CELLULOSE DIET

Animals fed only cellulose can lose a considerable amount of body nitrogen before expiring. Table 4 gives percentage figures of the total loss of nitrogen by a number of animals fed exclusively on cellulose for several weeks. These animals averaged almost a 14 per cent loss in total body nitrogen before death occurred.

DISCUSSION

The experiments described above show that the usually high carbohydrate diet of the silverfish *C. lineata* must be accompanied by sources of digestible nitrogenous material for growth and other essential metabolic activities. This agrees with the study of LAIBACH (1952) who concluded that *Lepisma saccharina*, another species of silverfish, must have carbohydrate, protein, and fat in its diet for normal growth and development. However, *C. lineata* can survive for a considerable period of time on a diet low in, or devoid of utilizable organic nitrogen. Similarly, COOK and SCOTT (1933) found that termites can exist for considerable periods on pure cellulose. However, for growth they too must have a source of organic nitrogen in the diet.

The low quantity of nitrogen required to produce a gain in live weight indicates a high conversion efficiency by the silverfish, particularly after a prolonged diet of cellulose. The reduced production of faecal material by silverfish on a carbohydrate diet appears to be a combined result of almost complete metabolic utilization of the carbon source (cellulose) and a slow turnover of tissue protein nitrogen; hence an inherent conservation of nitrogen.

The tolerance of silverfish to long periods of nitrogen-lack is not exceptional. Cockroaches can maintain their body weight for many months on a nitrogen-free diet and can be reared on a diet of glycine alone, indicating an elaborate synthetic ability (ZABINSKI, 1929).

The high efficiency with which the silverfish can digest and metabolize cellulose (see digestibility coefficients, LASKER and GIESE, 1956), coupled with its low requirement of organic nitrogen for maintenance and growth, may have adaptive significance. In an environment where cellulose is a predominant substance and where organic nitrogen is limiting, silverfish can compete successfully against forms which are incapable of surviving on a diet of cellulose and low nitrogen. The silverfish has achieved a unique niche by virtue of its ability to utilize cellulose, to survive for long periods of time without organic nitrogen in the diet, and to utilize with high efficiency the organic nitrogen which is available to it.

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