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EGESTION OF CHITIN IN PELLETS OF AMERICAN KESTRELS AND EASTERN SCREECH OWLS

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ABSTRACT.—In studying the digestibility of chitin by American Kestrels (*Falco sparverius*) and Eastern Screech Owls (*Otus asio*), we found portions of ingested chitin not only occurred in excreta but also in pellets. When commercial chitin was fed with turkey or chicken meat, 23.8% (American Kestrel) and 29.6% (Eastern Screech Owl) of the ingested chitin was egested in pellets. In American Kestrels, 59.2% of the total amount of ingested chitin was found in excreta. The percent of chitin egested as pellets as compared to the amount ingested showed a negative correlation ($r = -0.76$, $P < 0.001$). Our results suggest that the lower gastrointestinal tract contributes to total chitin digestion in American Kestrels.

KEY WORDS: *American Kestrel*; Falco sparverius; *Eastern Screech Owl*; Otus asio; *chitin*; *digestibility*; *pellet egestion.*

Residuos de queratina en egragópilas de *Falco sparverius* y *Otus asio*

RESUMEN.—Al estudiar la digestibilidad de la queratina en *Falco sparverius* y *Otus asio*, encontramos que las porciones de queratina ingerida no solo ocurren en las excretas si no que también en las egagrópilas. Cuando la queratina de uso comercial fue suministrada con carne de pavo o pollo 23.8% (*Falco sparverius*) y 29.6% (*Otus asio*) este fue eliminado en las egagrópilas. En *Falco sparverius*, 59.2% del total de queratina ingerida fue encontrada en las excretas. El porcentaje de queratina eliminada en las egagrópilas comparado con el ingerido mostró una correlación negativa ($r = -0.76$, $P < 0.001$). Nuestros resultados sugieren que el tracto gastrointestinal bajo contribuye a la digestión total de queratina en *Falco sparverius*.

[Traducción de César Márquez]

Insect exoskeletons are poorly digested by predators (Kramer and Koga 1986). This is due to the indigestibility of chitin (poly [β-(1-4)-2-acetamido-2-deoxy-D-glucopyranose]) which gives strength and structure to the exoskeleton (Roberts 1992). In spite of its indigestibility, insect chitin is considered a possible dietary source of carbohydrate for predators (Jeuniaux and Cornelius 1978, Weiser et al. 1997).

Eastern Screech Owls (*Otus asio*) and American Kestrels (*Falco sparverius*) are partially or primarily insectivorous (Johnsgard 1988, 1990). When coarse chitin powder was fed, portions were not only found in excreta but also in egested pellets. Chitin egested in pellets is not exposed to digestive enzymes in the lower gastrointestinal (GI) tract where chitinolytic enzymes are found (Jeuniaux 1963). If the lower GI tract contributes to chitin digestion, chitin digestibility would be expected to be higher when all ingesta pass through the whole GI tract.

In this study, we determined the proportion of ingested chitin that was egested in pellets by captive Eastern Screech Owls and American Kestrels. We also determined the chitinolytic capacity of the lower GI tract in American Kestrels by comparing chitin digestibility in two different cases with and without the egestion of chitin in pellets.

METHODS

Four Eastern Screech Owls and three American Kestrels were used. All individuals were permanently crippled but otherwise healthy. Birds were kept separately in wooden chambers (45 cm wide, 48 cm high and 45 cm deep) in an environmentally controlled room (20–22°C, 40–50% relative humidity and 12 hr of light per 24 hr). Between experiments, the birds were fed whole laboratory mice (*Mus musculus*) daily totaling approximately 20% of each bird's body weight at 1700 H for screech owls and at 1200 H for kestrels. The birds has access to mice until the cages were cleaned the next morning.

Pellets consisting of coarse chitin powder were collected in the process of determining chitin digestibility for kestrels or during the period of acclimating screech owls to a chitin-rich diet. For our experiments, we used commercially available chitin (from crab shell, practical grade, Sigma Chemical, St. Louis, MO, U.S.A.). Chitin

content in this product was determined by crude fiber determination (Helrich 1990) to be 68.5% of the weight of the product.

After acclimation to a diet of chicken or turkey meat for 8 d, kestrels were fed an amount of chitin equivalent to 2% (by weight) of their total dried food (2% chitin diet) at the start of each experiment to determine chitin digestibilities. The day before chitin was fed, all excreta were collected and analyzed for chitin content as a control. Chitin was packed in small pieces of meat. Each piece was fed by forceps to each bird to ensure that all the chitin was consumed. During the experiments, the birds were kept on a chicken or turkey meat diet which amounted to 18% of each bird's body weight (wet weight) daily. The chicken and turkey meat each contained 27.7% dry matter.

Following the feeding of chitin, all excreta and pellets, if egested, were collected from kestrels daily for 2 d on a polyethylene sheet set on a stainless steel pan in the bottom of each cage. Collected excreta and pellets were separately dried at 50°C for 2 d, weighed and finely ground with a pestle and mortar to pass through a 0.5 mm mesh. These ground samples were analyzed to determine their chitin contents. When we fed screech owls 144.5–170.1 mg of chitin with each feeding, they did not egest pellets. However, when we increased the amount of chitin to 300 mg, they egested pellets. Due to this, we fed each screech owl 300 mg of chitin either in turkey or chicken meat (chitin diet, total 15 g) each day for 6 wk to determine whether acclimation to chitin improved chitin digestibility. During this acclimation period, we also fed the birds mice at night to ensure a proper nutrient supply. The chitin diet was fed to screech owls in the afternoon after the birds egested pellets from mice consumed the night before. On many occasions, the owls did not eat the mice until they egested pellets from the chitin diet. These pellets, which consisted of only coarse chitin powder, were dried at 50°C for 2 d and weighed. Ten pellets were ground and prepared for the determination of their chitin content. No excreta were collected; therefore, chitin digestibilities were not determined.

Kestrels were acclimated the same way, but they tended to eat mice before they egested pellets from the chitin diet. As a result, kestrels egested a mixture of chitin powder and mouse fur as pellets. Since both chitin and hair are detected as crude fiber, determination of chitin contents was not possible by the crude fiber determination used when mouse fur contaminated the pellets. Therefore, no useful pellets were collected from kestrels during the acclimation period.

Chitin content was estimated by using the method for crude fiber determination in animal feeds (Helrich 1990). This method was used to estimate chitin contents in arthropods by Jackson et al. (1992), Nicholson et al. (1996), and Weiser et al. (1997). Since the ground excreta and pellets of kestrels were mixed and analyzed together to obtain their chitin contents in our previous study, six extra chitin pellets were collected from kestrels by feeding a 2% chitin diet to determine the chitin content of pellets. A mean of 69% (by dry weight) of the pellet was chitin in kestrels. Similarly, 10 pellets from screech owls were analyzed and found to have a mean of 68% chitin (dry weight). These values were used to calculate the dry weight of chitin in chitin pellets.

Chitin digestibilities of kestrels were determined by comparing the weight of chitin fed to the weight found in excreta and pellets (if egested). Because this method did not consider chitin retained in the GI tract (not immediately excreted), the chitin digestibilities obtained were referred to as "apparent" chitin digestibilities (Jackson et al. 1992). Chitin egested as pellets was not exposed to the possible chitinolytic enzymes in the lower GI tract. Therefore, we calculated means of chitin digestibilities separately in the two different cases (i.e., with or without egestion of pellets). Apparent chitin digestibilities were calculated based on the ratio of assimilation to ingestion and the ratio were converted to percentages of chitin assimilated to chitin ingested. Chitin ingestion and assimilation calculations were based on either the total dry weight of chitin ingested and excreted, or egested. Similarly, the percent of chitin egested in pellets was based on the total dry weight of chitin in pellets.

A pooled *t*-test (Devore and Peck 1993) was used for comparison of apparent chitin digestibilities with or without chitin pellets. An *F*-test was used to obtain a *P* value for correlation coefficients (Devore and Peck 1993). When $P < 0.05$, statistical comparisons were considered significantly different.

RESULTS AND DISCUSSION

Fourteen pellets were collected from three kestrels. No pellets were egested following three chitin feedings in two kestrels. The percent of chitin egested in a pellet relative to ingested chitin was 23.8% ± 11.0% (±SD) by weight (Table 1). Of total ingested chitin, 59.2% ± 9.9% was in excreta indicating that most of the ingested chitin was lost in excreta rather than egested in pellets or digested.

A total of 49 pellets were collected from four screech owls. A total of 29.6% ± 9.1% of ingested chitin was egested in pellets when 300 mg of chitin was fed per day (Table 1).

The percent of chitin egested in pellets relative to ingested chitin and apparent chitin digestibilities showed a strong negative correlation ($r = -0.76$, $P < 0.001$, Fig. 1) indicating that the more chitin egested in pellets, the less chitin was digested. When pellets were egested ($N = 14$) in kestrels, apparent chitin digestibilities were determined to be 19.5% ± 5.3%. When no pellets were egested ($N = 3$), digestibility was significantly higher at 28.9% ± 3.7% ($P < 0.01$). This suggested that the lower GI tract may contribute in the digestion of chitin in kestrels. Kestrels possess a relatively long colon compared to their body size although the cecum is extremely small (Duke et al. 1997). If the contribution to chitin digestion is due to bacterial enzymes, their large colon might support possible

Table 1. Mean weights of chitin in pellets and percents of chitin egested, excreted and digested in American Kestrels and Eastern Screech Owls. Results are expressed as $\bar{x} \pm 1$ SD. The number in parentheses is the number of samples. The samples of chitin pellets were collected during the chitin feeding trials (American Kestrel) or the acclimation to a chitin diet (Eastern Screech Owl).

	AMERICAN KESTREL	EASTERN SCREECH OWL
Dry weight of chitin in chitin pellet (mg)	28.4 ± 14.3 (14)	88.9 ± 27.3 (49)
Percentage of chitin egested as pellet compared to total ingested chitin (%)[a]	23.8 ± 11.0 (14)	29.6 ± 9.1 (49)
Percentage of chitin excreted in excreta compared to total ingested chitin (%)[b]	59.2 ± 9.9 (17)*	
Apparent chitin digestibilities when chitin pellets were egested (%)[c]	19.5 ± 5.3 (14)**	
Apparent chitin digestibilities when no chitin pellets were egested (%)[c]	28.9 ± 3.7 (3)**	

[a] 100(Chitin pellet/Chitin in).
[b] 100(Chitin out − Chitin pellet)/Chitin in.
[c] 100(Chitin in − Chitin out)/Chitin in.
Chitin pellet = total dry weight of chitin in chitin pellet.
Chitin in = total dry weight of ingested chitin.
Chitin out = total dry weight of excreted or egested chitin.
* Including three cases where no pellet was egested.
** Digestibilities when no pellets were egested were significantly higher than when pellets were egested ($P < 0.01$).

chitinolytic bacterial populations. Screech owls have a pair of relatively large ceca with the potential for bacterial fermentation indicating that enteric bacteria probably contribute to chitin digestion (Akaki 1997).

Chitin digestibilities determined using chitin powder are probably higher than digestibility of flakes or pieces of chitin obtained by eating insect prey. However, we felt that by feeding chitin with a uniform particle size and source our results would be more consistent between experiments and species.

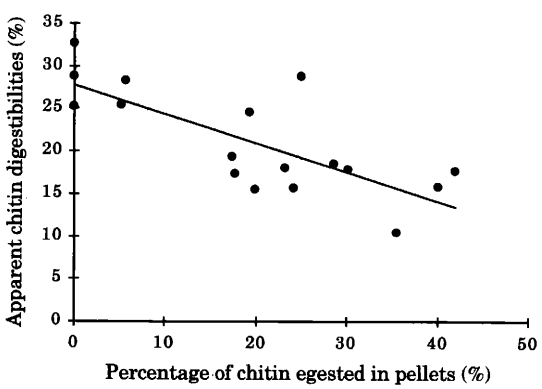

Figure 1. Relationship between apparent chitin digestibilities and percentage of chitin egested in pellets in three American Kestrels.

We found variation in the size of pellets (0–41.9% of ingested chitin by weight) egested by kestrels. We found similar variation in the pellets of one screech owl which egested 10.5–46.3% of ingested chitin in its pellets ($N = 36$), although the same amount of chitin was given to the bird everyday. The causes of this variation are unknown.

Since pellets were collected under different conditions for kestrels and screech owls, it was impossible to compare the data obtained for the two species. Screech owls, however, appeared to egest chitin in pellets only when they were fed a relatively large amount of chitin (300 mg). In 80% of the feeding trials, kestrels egested chitin in pellets even when they were fed the 2% chitin diet (97.4–131.4 mg of chitin). Kestrels appear to be more sensitive to a small amount of undigested material remaining in the gizzard, but reasons are unknown.

The oral egestion of coarse chitin powder in pellets of kestrels and screech owls suggests that chitin is difficult to degrade and tends to be eliminated by raptors with other undigestible material such as hair and bones. Both species egested chitin in pellets 6–12 hr and 6–10 hr, respectively, after the feeding of chitin. In spite of their retention of chitin in their stomachs, chitin powder was still rec-

ognizable in the pellets and appeared macroscopically to be not significantly different from the original size indicating that the digestion of chitin in the stomach of these two species is very limited.

Although our results indicated that the lower GI tract contributed to chitin digestion in kestrels, chitin powder was still easily recognized in excreta indicating that chitin is difficult to digest even after exposure to digestive enzymes in the lower GI tract.

It has not been determined why raptors digest chitin despite the difficulty of its degradation. One possible reason is that chitinous exoskeletons of prey need to be digested to expose soft tissue to digestive enzymes (Gooday 1990). Since mechanical digestion in the stomachs of raptors appears to be limited due to a less muscular gizzard as compared to fowl (Duke 1986), more chemical digestion may be required. It is possible that chitin itself is utilized as an energy source by raptors, although the final products of chitin hydrolysis are difficult to absorb in the intestine (Capps et al. 1966, Crane 1968, Jackson et al. 1992). Since the absorption and metabolism of digested chitin by screech owls and kestrels has not been studied, further investigation is required in order to determine the value of chitin as an energy source for these species.

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