Feeding activity of the East African millipede *Omopyge sudanica* Kraus on different crop products in laboratory experiments

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Abstract

Millipedes can cause considerable damage in the production of sweet potato and some other crops in East Africa. Quantitative information on intake of crop diets by and body weight gain of millipedes was collected in short-term no-choice feeding activity laboratory experiments conducted in north-eastern Uganda using female millipedes of the species *Omopyge sudanica*. Diets consisted of sweet potato and cassava storage root material, groundnut seeds, or maize grains. Differences in intake and body weight gain between diets were not statistically different. The consumption index, i.e., the ratio between intake and body weight gain, was significantly higher for sweet potato than for most other diets. The efficiency of conversion of ingested food, i.e., 100 × the ratio between body weight gain and intake, was significantly lower for the root crops – especially sweet potato – than for the grain crops. The research showed how difficult it is to obtain reliable, quantitative data on the feeding habits of millipedes, but also illustrated that *O. sudanica* can cause harm to crops in north-eastern Uganda and elsewhere in East Africa.

Additional keywords: no-choice feeding activity, food intake, body weight gain, consumption index, efficiency of conversion of ingested food

Introduction

In north-eastern Uganda, sweet potato (*Ipomoea batatas* (L.) Lamk), cassava (*Manihot esculenta* Crantz), maize (*Zea mays* L.) and groundnut (*Arachis hypogaea* L.) are important food and cash crops. Subsistence farmers have to grow their crops on the little land they have available (Kisamba-Mugerwa, 2001). Crop rotation is often not practised, which may result in high frequencies of pest-prone crops and in a high incidence of certain soil-borne pests (Ebregt *et al.*, 2004a). Moreover, field hygiene is commonly lacking and farmers cannot afford to buy pesticides (Bashaasha *et al.*, 1995;

Smit, 1997; Abidin, 2004; Ebregt *et al.*, 2004b). So the best strategy is an integrated approach in pest management based on non-chemical control (Smit, 1997).

In north-eastern Uganda, sweet potato, besides cassava and banana, is a major starchy staple in the diet (Smit, 1997). Its storage roots, high in vitamin A (Anon., 1998), are mainly grown as a subsistence crop for home consumption (Smit, 1997; Abidin, 2004), but in some areas are also produced for the market in Kampala (Abidin, 2004; Ebregt *et al.*, 2004a). In the sweet potato production systems, cassava is often the crop preceding sweet potato, whereas millet, groundnut and maize are usually the after-crops (Ebregt *et al.*, 2004a).

Insect pests, such as the sweet potato weevils *Cylas brunneus* and *C. puncticollis*, were identified by farmers to be the most important biological constraint on sweet potato production (Smit, 1997; Abidin, 2004; Ebregt *et al.*, 2004b). Farm visits and field experiments have shown that many crop species are hosts of harmful arthropods, including millipedes. But millipedes mostly affect sweet potato (early planted vines and roots stored in-ground), maize (germinating seeds) and groundnut (germinating seeds and young pods). Interviewed farmers also named cassava as host. The main culprits were *Omopyge sudanica* Kraus (family: Odontopygidae) and *Spirotreptus ibanda* Silvestra (family: Spirostreptidae) (Ebregt *et al.*, 2004a, b; 2005).

Little is known about the preference of millipedes for host crop diets and about intake, digestibility and efficiency of conversion of these crop diets. Quantitative studies about the consumption and utilization by millipedes can provide valuable information on their potential damage in cultivated crops (Band *et al.*, 1976; Somasundaram & Chockalingam, 1981).

This paper presents the results of attempts to quantify in short-term laboratory runs the no-choice feeding activity of the millipede *O. sudanica* when offered different host crop diets. The choice of crops was determined by their presence in the cropping system dominated by sweet potato. Parameters assessed included: (1) intake, (2) body weight gain, (3) consumption index (CI), i.e., the ratio between intake and body weight gain, and (4) the efficiency of conversion of ingested food (ECI) into body substance. The millipedes' feeding activity on the different crop diets and the consequences for pest management will be discussed.

Materials and methods

General methodology, crops, diets and millipedes

The experiment consisted of three batches, each with the same six diets, either exposed to millipedes for 24 hours or not exposed, in four replicates. The experiment was carried out to assess no-choice feeding laboratory activity of five millipedes of the same species. Batches of five immature female millipedes of the species *Omopyge sudanica* were offered diets consisting of different fresh crop materials. For each batch and replicate, each combination of diet and millipedes was kept in a separate plastic jar. The experiment was carried out at Arapai, Soroti District, north-eastern Uganda, at the onset (March/April) of the long rainy season when millipedes are available in large numbers.

The experiment included six diets based on four crop species: sweet potato (cv. Osukut/Tanzania), groundnut (cvs. RPM 12 and Rudu-Rudu), maize (cv. Longe I), and cassava (cv. Nigeria). The first three crop species are generally known to host millipedes (Ebregt *et al.*, 2004a, b; 2005). Cassava was included as interviewed farmers suggested that it is a potential host crop too (Ebregt *et al.*, 2004a, b). The storage roots of sweet potato and cassava were cut into pieces of about 1 cm^3. Groundnut seeds and maize grains were soaked in water for 24 (groundnut and maize) or 48 hours (maize) at room temperature (24 ± 3 °C), making the seeds and grains more palatable for millipedes. Shortly before initiating the experiment the seeds and grains were blotted with a dry cloth.

The six diets included: sweet potato storage root, cassava storage root, groundnut seed from cv. RPM 12, groundnut seed from cv. Rudu-Rudu, maize grain soaked for 24 hours, and maize grain soaked for 48 hours.

Immature female millipedes of the species *O. sudanica* were hand-collected from the field and kept in the dark, without food, at room temperature (24 ± 3 °C) for 10 days. This preparation period served to clear their gut and make or keep them hungry. During this preparation period, faeces were removed every other day to prevent coprophagy (i.e., to prevent the millipedes from eating faeces), and water was sprayed to prevent desiccation. The amount of faeces removed during the preparation period was not assessed as during the experiment the millipedes fed a certain diet were always compared with a group of millipedes without any feed. Although the spraying of water may have been a source of uncontrolled variation among the millipedes, it is believed that it actually reduced the variation as the extent of desiccation would certainly have been more variable. After the preparation period of 10 days, the millipedes were allowed to feed on the different diets for 24 hours.

Set-up of the experiments

Wide plastic jars (15 × 12 cm) with well fitting, non-perforated lids (Ø 10 cm) were used for this experiment. Jars were large enough to contain the amount of air needed for five millipedes to breathe normally during a 24-h period.

The experiment consisted of a series of tests comparing a particular crop diet exposed to millipedes with the same diet not exposed to millipedes in quadruplicate. These tests were organized in three batches, which were run at different times. Per batch, 6 tests were carried out, one for each diet. Each individual test consisted of 8 jars, four jars containing 50 g of the crop diet studied plus five millipedes, and four jars containing 50 g of the same diet, but without millipedes. In total the experiment comprised 3 batches × 6 diets × 2 treatments (with and without millipedes) × 4 replications = 144 experimental units. For the treatments with millipedes, each jar had five millipedes. During the 24 hours of the test, the millipedes, after their 10 days of starvation, did not produce faeces, despite their food intake.

Data collection and processing

Data collected at the start of a test

Before starting a test, the weights of four empty jars were scaled down to zero on an electrical digital balance at room temperature. Exactly 50 g of the diet studied was then placed in each jar and jar + diet were weighed for accurate records. These four jars served as controls. This procedure was repeated, but now five millipedes were added to each jar and the weight of jar + diet + millipedes was determined. From these data the initial weights of the five millipedes of each batch × diet × replication were calculated.

Data collected at the end of the tests

The tests lasted 24 hours. At first the 'final' weights (t = 24) of the four control jars were determined. The average weight loss per jar due to water evaporation and respiration of the crop material in the four control jars was then calculated.

Next the weights of the four jars with millipedes (jar + diet + millipedes) of each replicate were determined. Then the millipedes were carefully removed from each jar, using tweezers. In order to prevent additional weight loss due to evapotranspiration, the jars were closed at once, and the 'weights' of the five millipedes collected and of the jar + remaining diet were recorded immediately.

Based on these data we calculated the corrected food intake and the final weight of the five millipedes separately for each replicate. The millipede weight calculated in this way might differ slightly from the directly determined weight. During removal and weighing of the millipedes, some imperfections such as defensive body secretions on the tweezers and water condensation on the tweezers' fingers may have occurred. The average difference between the directly determined and the calculated weight of five millipedes was used to correct the directly measured weight gain.

In order to calculate the consumption index (CI) the formula of Waldbauer (1968) was slightly modified:

$$\text{CI} = \text{intake} / [(\text{initial weight} + \text{final weight})/2] \quad (1)$$

The efficiency of conversion of ingested food (ECI; %) into body substance of the five millipedes of each jar was calculated using Equation 2 (Waldbauer, 1968; Chaudhury, 1994):

$$\text{ECI} = 100\ [\text{weight gain (in g)} / \text{intake (in g)}] \quad (2)$$

Data analysis

Initial body weight per five millipedes (at t = 0), their weight after 24 hours (at t = 24), food intake, body weight gain, and CI and ECI were calculated for each of the crop diets. Analysis of variance was used for the statistical analysis. Relations between the parameters were quantified using a correlation matrix. Correlation coefficients (R^2) ≥ 0.25 were considered statistically significant ($P \leq 0.05$). Student's t-test was used to separate the means of CI and ECI of the root crops (cassava and sweet potato) and the grain crops (groundnut cvs. RPM 12 and Rudu-Rudu, and maize soaked for 24 or 48 hours). The computer programme Genstat Release 8 (Anon., 2005) was used for the statistical analyses.

Table 1. Mean scores of ingested crop product (intake), initial and final millipede weights, and body weight gain. Data from laboratory experiments carried out at the start of the first rainy season of 2002 at Arapai station, Seroti District, north-eastern Uganda.

Crop product	Intake	Body weight		
		Initial	Final [1]	Gain
		----------	(g)	----------
Sweet potato storage roots	0.53	6.89	7.26	0.37
Cassava storage roots	0.41	7.20	7.57	0.37
Groundnut (cv. RPM 12) seeds	0.38	7.13	7.47	0.34
Groundnut (cv. Rudu-Rudu) seeds	0.48	7.22	7.66	0.43
Maize grains soaked for 24 hours	0.45	7.51	7.92	0.41
Maize grains soaked for 48 hours	0.36	7.48	7.81	0.33
Mean	0.43	7.24	7.61	0.37
P-value [2]	ns	ns	ns	ns
Coefficient of variation (%)	40.3	13.5	13.5	46.2

[1] After correction for difference between directly measured and calculated weight; see Materials and methods.

[2] ns = statistically non-significant differences within column.

Results

Intake and body weight gain of the millipedes

At the end of the feeding experiments (t = 24) the weights of all diets offered to the millipedes had decreased, suggesting millipede feeding activity. The average decrease in weight of sweet potato, cassava, groundnut and maize varied from 0.36 (maize soaked for 48 hours) to 0.53 g (sweet potato), but the differences among crops were not statistically significant (Table 1). The mean body weight gain of the millipedes after terminating the experiment varied among diets from 0.33 for maize soaked for 48 hours to 0.43 g for groundnut cv. Rudu-Rudu. Here the differences were not statistically different either (see tests and coefficients of variation in Table 1).

The body weight of five millipedes related to the intake and weight gain

For the crop diets cassava and maize grains soaked for 48 hours a statistically significant, positive correlation was found between initial body weight per five millipedes and intake and body weight gain (data not shown). The R^2 values for intake were 0.27 for

Table 2. Mean scores for consumption index (CI) and efficiency of conversion index (ECI) of cop products offered to millipedes. Results from laboratory experiments carried out at the start of the first rainy season of 2002 at Arapai station, Soroti District, north-eastern Uganda.

Crop product	CI (g/g)	ECI (%)
Sweet potato storage roots	0.081 a [1]	70.6 (b) [2]
Cassava storage roots	0.053 b	83.7 (a)
Groundnut (cv. RPM 12) seeds	0.052 b	90.4 (a)
Groundnut (cv. Rudu-Rudu) seeds	0.064 ab	89.8 (a)
Maize grains soaked for 24 hours	0.061 ab	88.9 (a)
Maize grains soaked for 48 hours	0.046 b	89.7 (a)
Overall mean	0.059	85.5
P-value [3]	*	(*)
Coefficient of variation (%)	42.9	21.3
LSD [4]	0.021	12.39
Mean		
Root crops (n = 24)	0.067	77.2
Grain cops (n = 48)	0.056	89.7
P-value of contrast between root and grain crops [5]	ns	*

1 Means in this column, followed by a common letter are not statistically different ($P < 0.05$).
2 Means in this column, followed by a common letter in brackets are not statistically different ($P < 0.10$).
3 * = $P < 0.05$; (*) = $P < 0.10$.
4 Least significant difference at $P < 0.05$ for CI and at $P < 0.10$ for ECI.
5 ns = contrast not statistically significant; * = contrast statistically significant at $P < 0.05$.

cassava and 0.25 for maize soaked for 48 hours; for body weight gain R^2 was 0.25 for both diets. The initial body weight per five millipedes and the intake for groundnut cv. Rudu-Rudu were significantly and positively correlated too ($R^2 = 0.25$; data not shown).

A negative correlation was found between initial body weight and intake and body weight gain for the crop diets sweet potato and maize soaked for 24 hours (data not shown). Correlations between the initial body weight and intake with groundnut cv. RPM 12 and between the initial body weight and the weight gain with groundnut cvs RPM 12 and Rudu-Rudu were not significantly correlated (data not shown). As the correlations were relatively weak and inconsistent in sign and significance across diets, these relationships were not used for additional co-variance analysis.

Consumption index

A statistically significant ($P < 0.05$) difference in consumption index (CI) was found between the sweet potato diet and the diets cassava, groundnut cv. RPM 12 and maize soaked for 48 hours (Table 2). The differences in CI between the sweet potato diet and the diets groundnut cv. Rudu-Rudu and maize soaked for 24 hours were not statistically significant (Table 2). Similarly, no statistically significant differences were found among the diets groundnut cv. Rudu-Rudu, groundnut cv. RPM 12 and maize soaked for 48 hours. The difference in CI between the means for root crops and grain crops was not statistically significant either (Table 2).

Efficiency of the conversion of ingested food

The efficiency of the conversion of ingested food (ECI) of the crop diets varied from 70.6% for sweet potato to 90.4% for groundnut cv. RPM 12 (Table 2). ECI was lower for sweet potato than for the other crops ($P < 0.10$) (Table 2). A statistically significant difference in ECI was found between the means for root crops and grain crops (Table 2).

Discussion

General

At the start of the growing season (March/April) hungry millipedes emerge from their quiescence at the soil surface and attack the recently planted crops (Ebregt *et al.*, 2005). Millipedes have a large spectrum of food diets (Dangerfield & Telford, 1993). However, in a study with *Alloporus uncinatus* (Mwabvu, 1998a, b) the feeding behaviour of this millipede was 'non-random': the immature female millipedes showed clearer selective feeding than the adult females and the adult males also showed clearer selective feeding than the adult females (Mwabvu, 1998a, b). The species *Omopyge sudanica* was selected for our experiments because it has a well defined host range and is a pest of sweet potato, maize and groundnut (Ebregt *et al.*, 2005).

In our feeding experiments equally sized immature females of *O. sudanica* were used, as the larvae of different development stages are hard to distinguish from other species (C.A.W. Jeekel, personal communication). Moreover, as observed in earlier studies, at this time of the year few male individuals of this species are encountered (Ebregt *et al.*, 2005). Although they were not fully mature, the individuals could be sexed with adequate accuracy.

Intake and weight gain of the millipedes

The weights of all crop diets had decreased due to feeding activity of the millipedes, but no statistical differences among the diets were found. This indicates that the crops investigated fitted within the range of host crops of *O. sudanica*. That farmers experienced millipede damage in these crops was mentioned in previous publications

(Ebregt *et al.*, 2004a, b; 2005), and in an earlier experiment the groundnut cultivar Rudu-Rudu appeared a potential host crop (Ebregt *et al.*, 2005). The statistically non-significant difference between the two groundnut diets showed that the cultivar RPM 12 could equally well serve as a potential host crop.

It should be noted that the lack of statistically significant differences could also have been caused by the short period of our feeding trials. However, extending the experiment would have undoubtedly introduced other inaccuracies and sources of variation. Precision could also have been improved by increasing the number of replicates or the number of batches to obtain even more than the 24 experimental units per diet (12 with and 12 without millipedes) obtained in this experiment.

We assumed that millipedes find it difficult to gnaw at freshly planted maize grains. So the maize grains were soaked before being used in the experiment. Imbibition might induce changes in chemical composition of the dry matter, for example by inducing activity of various enzymes, thus changing intake or weight gain. Heimsch (2003) and Villela *et al.* (2003), however, showed that the water uptake by maize grains during soaking does not affect their quality in terms of dry matter composition and that after 48 hours of soaking, the process of water uptake in the endosperm is not yet completed. In our experiments there was no statistically significant difference in intake by the millipedes between 24 h and 48 h of soaking (Table 1). This may suggest that millipedes can start to gnaw and ingest the seed shortly after planting, even within 24 hours, thanks to their ‘strong jaws’ (Lawrence, 1984; Hopkin & Read, 1992).

Consumption index

The statistically significant difference in consumption index (CI) was due to the differences between the sweet potato diet and the diets cassava, groundnut cv. RPM 12 and maize soaked for 48 hours. We assume that peeled and cut sweet potato storage root material does not differ from storage roots stored ‘in-ground on plants’ at the end of the dry season. In an earlier study (Ebregt *et al.*, 2005) it was suggested that sweet potato weevils cause damage during the dry season and consequently provide the millipedes with easy access to the storage roots.

Efficiency of the conversion of ingested food

The data on the efficiency of the conversion of ingested food (ECI) suggest that *O. sudanica* efficiently utilized the grain crop diets groundnut and maize for its growth. With regard to this feeding behaviour, this millipede species is less ‘interested’ in the ‘clean’ root crops cassava and sweet potato (Ebregt *et al.*, 2005), but rather prefers to feed on groundnut and maize. The hungry millipedes usually appear from their quiescence at the end of the dry season. Hungry as they are, they will devour anything eatable. They are in need of energy-rich diets, and consequently are often found in neglected fields with in-ground on-plants stored sweet potato. After being satisfied with the energy-rich food, the then planted groundnut seeds will supply the millipedes with the necessary proteins needed for their growth.

Practical implications

The damage to planting material of groundnut and maize can be economically serious. Earlier observations showed that millipedes pierced or completely consumed the cotyledons of germinating groundnut seeds, only leaving behind some remains of the testa. The cotyledon of maize was preferred most and as a result germination failed. Radicles and plumules were also damaged, seriously impairing emergence (Ebregt *et al.*, 2005).

As part of their traditional practices farmers in Zimbabwe prime the maize seeds by soaking them in water overnight before sowing (Clark *et al.*, 2001). Clark *et al.* (2001) argued that this method enhances emergence, ensures an adequate plant stand when planting is done into residual moisture and may assist in catching up with the other plants when soaked seed is used for gap filling. Given the long time required to complete endosperm imbibition (Heimsch, 2003), this traditional practice may not be very advantageous. However, it could make the maize grains a more attractive food for millipedes of the species *O. sudanica*. Priming is not commonly practised in north-eastern Uganda.

Ebregt *et al.* (2005) stated that millipedes are not interested in sweet potato storage roots in crops that have been growing for 5 months after planting. Careless weeding and loosening and earthing up the mounds, resulting in damaged storage roots can nevertheless attract millipedes and provide access to these roots. The damage to the storage roots by millipedes will influence the quality of the roots as a source of human food.

With respect to planting material, sweet potato farmers in north-eastern Uganda usually do not depend on storage roots, but mostly use the vines. Even partly damaged storage roots, often left behind in previous sweet potato fields, are able to produce volunteer plants. These volunteer plants are habitually used as planting material to establish new sweet potato plantings (Bashaasha *et al.*, 1995; Smit 1997; Abidin, 2004; Ebregt *et al.*, 2004a).

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