INTRODUCTION

*IMbrasia belina* (mopane worm, commonly known as *Phane* in Botswana) is the larva of the emperor moth (*Ditlhogo*, 1996). Besides being used as a protein source by people in semi-arid environments of Botswana, Namibia, South Africa and Zimbabwe (*Marais*, 1996; *Moruakgomo*, 1996; *Styles*, 1996), mopane exported to South Africa is used as animal feed (*Mpuchane et al.*, 2000). However, there is limited literature highlighting the performance of livestock fed mopane worm. Use of mopane worm in livestock feeds is appealing in Botswana due to heavy reliance on imports of oil cake meals and fish meal. While Botswana produces blood and carcass meals, inclusion of these products in livestock feeds is prohibited (*Ministry of Agriculture*, 1998). Mopane worm is a high quality nutrient source (*Ohiokpehai et al.*, 1996; *Madibela et al.*, 2007). Comparing the amount of essential amino acids of mopane worm, in a study conducted by *Ohiokpehai et al.* (1996), with those of soyabean meal and fishmeal (*Mcdonald et al.*, 2002) reveals that they are similar to fishmeal but dissimilar to soyabean meal (Table 1). In pursuing the evaluation of the suitability of mopane worm as livestock feed in Botswana, we have shown that crude protein (CP) concentrations of intact mopane samples were lowered by 9% (*Madibela et al.*, 2009) and 26% (*Madibela et al.*, 2007), while neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were increased by 46, 38 and 181%, respectively when the results are compared to evacuated mopane (gut contents removed) samples (*Madibela et al.*).
2007). This suggests that the leafy material inside the gut of mopane worms 'dilutes' CP content but increases NDF, ADF and lignin concentrations.

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Mopane worm</th>
<th>Soya bean meal</th>
<th>White fish meal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histidine</td>
<td>2.9</td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Threonine</td>
<td>4.6</td>
<td>1.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Valine</td>
<td>4.1</td>
<td>2.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Methionine</td>
<td>1.5</td>
<td>0.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>3.0</td>
<td>2.0</td>
<td>2.6</td>
</tr>
<tr>
<td>Leucine</td>
<td>5.0</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>3.8</td>
<td>2.3</td>
<td>2.9</td>
</tr>
<tr>
<td>Lysine</td>
<td>4.7</td>
<td>3.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>1.1</td>
<td>0.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*Obokpocha et al. (1996); †: McDonald et al. (2002).

It was also observed that intact mopane contain more condensed tannins than evacuated samples (Madibela et al. 2009), suggesting existence of secondary compounds in the leafy material in the gut of the worm. Since condensed tannins complex with protein and protect it from rumen fermentation (Ben Salem et al. 2005), intact mopane worm may supply more Rumen degradable crude protein (RUP) to the small intestine than evacuated mopane worm. Although chemical analysis is essential for understanding the nutritional potential of new feed resources, it is not sufficient to mimic processes and dynamics inside the rumen (Hovell et al. 1994; El-hassan et al. 2000). Therefore, the objective of this study was to determine the ruminal DM and CP degradability of intact mopane worm and mopane worm subjected to gut evacuation.

**MATERIALS AND METHODS**

Three steers weighing on average 367±8.7 kg and fitted with a flexible rumen cannula were kept in an open pen (10 m×15 m) with enough space for exercise. The protocol of care for the animals was according to the Council for the International Organization of Medical Sciences (CIOMS, 1985). Steers were fed, on a group basis, a diet consisting of grass / lucerne hay (about 11 kg per animal each morning) containing (g/kg DM) 115 CP, 8.4 Ca and 4.3 P offered at a rate of 3% of their body weight. Clean water was available at all times. Before incubation, the steers were adapted to the new diet for 5 days.

**Experimental Feedstuff**

Samples of mopane worm were sourced from three sites in Botswana as previously described by Madibela et al. (2009). In that study, there were no differences in CP of mopane worms between sites and therefore samples in this study were pooled across sites.

For instance, CP for Maunatlala (22°36’12”S and 27°37’55”E), Moreomabele (22°02’59”S and 27°13’48”E) and Sefophe (22°11’36”S and 27°58’06”E) in Central District of Botswana were 572, 529 and 548 g/kg DM, respectively. Mopane worm samples of 0.5 kg from 5-6 trees were obtained and mixed thoroughly. Samples were divided equally into two portions of either evacuated (EM) or intact (IM) mopane.

Evacuation entails forcibly squeezing the gut contents from the body of the mopane worm by pushing the head towards the anal region (Siame et al. 1996). After evacuating and cleaning with water, both samples of EM and IM were placed in boiling water for 30 min to kill the worms, sun dried for 4 h and taken to the laboratory within 72 h for oven drying at 105 °C for 48 h. Samples were then ground to pass a 2 mm screen.

**In situ incubation**

Rumen incubation was according to the methods of Ørskov et al. (1980) without a lag time. Two grams of feed material was placed in nylon bags made of white polyester monofilament (10x20 cm; 53 μm; ANKOM Technology Corp, Fairport NY, USA).

Each treatment group had 42 samples (6 replicates×7 incubation periodsx3 steers) in individual nylon bags. Samples were incubated in the ventral sac of the rumen for 0, 3, 6, 12, 24, 48 and 72 h. For ease of withdrawal, the nylon bags were fastened and secured to the fistula with length of nylon string. After removal from the rumen, bags were immediately rinsed in cold tap water and immediately placed in a deep freezer at -20 °C until the incubation period was completed. Thereafter the bags, together with the zero hour bags were washed under tap water until the water ran clear.

**Analysis**

Dry matter (DM) for mopane worm residues were determined by weighing samples after drying at 105 °C for 24 h. The DM degradability was expressed as the amount of DM that disappeared after weighing the residue. The CP of the experimental feed and residues used a Kjeldahl procedure according to AOAC (1990). As variation of 3.3% between concentration of CP in the initial sample and that of the residue. The RDP was estimated as the amount of CP multiplied by its effective degradability at assumed rumen outflow rates of 0.05/h while rumen undegraded protein (RUP) was calculated as CP minus RDP (Marichal et al. 2000).
Statistical analysis
Degradation constants \((a, b, c)\) of DM and CP were estimated by general non-linear models (NLIN) procedures (SAS, 2004) using a SAS program written by the Rowett Research Institute (Osuji et al. 1993) and modified for the current data set by including the following derivatives between the model and the output statements:

\[
der_{a} = 1; \quad der_{b} = 1 - \exp (c x t e m i t e); \quad der_{c} = b x t i m e x \exp (-c x t e m i t e)
\]

The calculations were without a time lag. The constants were generated by fitting the degradation data for both DM and CP at various stages of incubation to the Ørskov and McDonald (1979) exponential model:

\[
P = a + b (1 - e^{-ct})
\]

Where:
- \(P\): DM or CP which has disappeared at time.
- \(t\): the zero-time intercept.
- \(a\): the slowly degradable fraction.
- \(b\): the rate of degradation.

The effective degradability (ED) of DM and CP was calculated using the equation:

\[
ED = a + bc / (c + k) \quad (Ørskov, 1992)
\]

Where:
- \(k\) is the fractional outflow rate from the rumen, which was assumed to be 0.03/h or 0.05/h. These constants \((a, b, c, ED_{0.03} \text{ and } ED_{0.05})\), RDP and RUP were analyzed using GLM in SAS (2004), as a randomized complete block design using steers as blocks.

Differences in means between treatments were tested for significance by least significance difference and those with \(P>0.05\) considered not significant (Sokal and Rohlf, 1996).

RESULTS AND DISCUSSION
The amount of the soluble fraction, the slowly degradable fraction, \(ED_{0.03}\) and \(ED_{0.05}\) of DM between evacuated mopane (EM) and intact mopane (IM) samples was similar (Table 1, \(P>0.05\)). Additionally, there were no differences in degradation rates between DM of EM and IM samples (Table 3). But EM had significantly more (\(P<0.01\)) RUP than IM samples.

**Table 2** Dry matter degradability constants of evacuated and intact mopane worm samples

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Evacuated</th>
<th>Intact</th>
<th>SEM</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>23.1</td>
<td>23.8</td>
<td>0.43</td>
<td>0.324</td>
</tr>
<tr>
<td>(b)</td>
<td>43.6</td>
<td>43.7</td>
<td>0.10</td>
<td>0.376</td>
</tr>
<tr>
<td>(c)</td>
<td>0.06</td>
<td>0.05</td>
<td>0.002</td>
<td>0.099</td>
</tr>
<tr>
<td>(ED_{0.03}) (%)</td>
<td>51.5</td>
<td>51.3</td>
<td>0.37</td>
<td>0.749</td>
</tr>
<tr>
<td>(ED_{0.05}) (%)</td>
<td>46.2</td>
<td>45.8</td>
<td>0.37</td>
<td>0.519</td>
</tr>
</tbody>
</table>

\(a\): water soluble fraction which is rapidly washed out of bags and assumed to be completely degradable; \(b\): the slowly degradable fraction; \(c\): the rate of degradation per hour.

**Table 3** Protein degradability constants, RDP and RUP of evacuated and intact mopane worm samples

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Evacuated</th>
<th>Intact</th>
<th>SEM</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>5.1</td>
<td>4.3</td>
<td>0.38</td>
<td>0.188</td>
</tr>
<tr>
<td>(b)</td>
<td>35.4</td>
<td>39.7</td>
<td>2.24</td>
<td>0.246</td>
</tr>
<tr>
<td>(c)</td>
<td>0.010</td>
<td>0.012</td>
<td>0.0013</td>
<td>0.136</td>
</tr>
<tr>
<td>(ED_{0.03}) (%)</td>
<td>13.3</td>
<td>15.5</td>
<td>1.10</td>
<td>0.240</td>
</tr>
<tr>
<td>(ED_{0.05}) (%)</td>
<td>10.6</td>
<td>12.0</td>
<td>0.827</td>
<td>0.304</td>
</tr>
<tr>
<td>RDP (g/kg)</td>
<td>60.9</td>
<td>62.4</td>
<td>4.70</td>
<td>0.872</td>
</tr>
<tr>
<td>RUP (g/kg)</td>
<td>512.1</td>
<td>457.8</td>
<td>4.70</td>
<td>0.001</td>
</tr>
</tbody>
</table>

\(a\): water soluble fraction which is rapidly washed out of bags and assumed to be completely degradable; \(b\): the slowly degradable fraction; \(c\): the rate of degradation per hour.

The present study is the first to report protein degradability of mopane worm and there is currently no information on the attributes of mopane worm as an ingredient for livestock feed. Proteins that are extensively degraded in the rumen can be protected from rumen degradation but it is important to evaluate the extent of that degradation before any intervention could be made to protect the protein from being extensively degraded.

**Dry matter degradability**
Evacuating of mopane worm did not have any effect on DM degradability constants. Rasengwatshe and Madibela (2005) found a higher water soluble fraction for mopane worm that was sourced from rural harvesters. Though mopane worm harvesters roast the worms on hot ash or cook it in brine, these processing methods may not be providing sufficient protection at the rumen. The potentially degraded fraction “\(b\)” of DM for EM and IM in the present study was found to be similar, implying that there was degraded to a similar extent. The values of “\(b\)” in the present study are comparable to that found by Rasengwatshe and Madibela (2005). Evaluating different proteins from Turkey,
Kamalak et al. (2005) observed similar degradation rates (0.05/h) for DM between blood meal and fish meal; this rate is similar to those of EM and IM samples in the present study. Degradation rates of DM for mopane samples were slower than those recorded by Rasengwatshe and Madibela (2005).

Crude Protein Degradability
Kamalak et al. (2005) found protein degradation rate (0.05/h) for blood meal and fishmeal which was higher than the rates of mopane worm. These results reported by Kamalak et al. (2005) indicate that protein from blood meal and fish meal would possibly be more available in the rumen than that from either EM or IM. Since fish meal is commercially used to provide undegraded protein, the mopane worm which has proven to have similar amino acids profile as fish meal (Table 1) would need protection to have similar value as fish meal post-ruminally. Rumen protein profile as fish meal (Table 1) would need protection to have commercial use to provide undegraded protein, the more than that from either EM or IM. Since fish meal is commercially used to provide undegraded protein, the mopane worm which has proven to have similar amino acids profile as fish meal (Table 1) would need protection to have similar value as fish meal post-ruminally. Rumen protein profile as fish meal (Table 1) would need protection to have commercial use to provide undegraded protein, the more than that from either EM or IM. Since fish meal is commercially used to provide undegraded protein, the mopane worm which has proven to have similar amino acids profile as fish meal (Table 1) would need protection to have similar value as fish meal post-ruminally.

Evacuating mopane worm had no effect on the DM and protein effective degradability of mopane worm at both 0.03/h and 0.05/h ruminal outflow rates. Evacuation of mopane worm increased amount of RUP. Future research should determine the quantity and intestinal digestibility of amino acids from mopane worm post-ruminally because increased supply of RUP to the duodenum does not directly translate into high digestibility and absorbability.

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REFERENCES


