A change in size can have a huge impact on an organism’s digestive capabilities and consumption behavior. To explore this, we characterized the midgut of Manduca sexta as a plug flow reactor and parameterized the gut with empirical data to see how different sizes affect digestive performance. Based on our model, we made predictions about how maximal absorption rate, optimal consumption rate, optimal gut content flow rate, gut passage time, and absorption efficiency scale with weight. The predicted optimal consumption rate scaled as weight to the 0.89 power, a good approximation of third, fourth, and fifth instar caterpillar food-intake. This predicted maximal amino acid absorbance rate scaled as weight to the 0.74 power, which overestimated the observed amino acid assimilation to an increasing degree as the caterpillar grew. However, the observed dry growth scaled as weight to the 0.88, which was very close throughout ontogeny to the predicted maximal absorbance rate. This model offers insights into digestion in this insect; we believe our results support the hypothesis that Manduca optimize their behavior to maximize absorbance given their gut morphology.

### Methods

The system of differential equations were solved using a Dormand-Prince numerical approximation (Soetaert et al. 2010) to give us the concentration profiles of “substrate” (S) and “product” (P) along the length of the gut.

- Absorbance rate was calculated using Simpson’s Rule to evaluate the integral.
- By varying consumption rate and keeping all other parameters constant, we could see if there was a maximal absorbance rate, and if so, what the optimal flow rate was.
- Radius was found to be proportional to mass$^{0.40}$ by using a caliper to measure midgut length of dissected Manduca of known weight (unpublished data, Raitheil and Vela-Mendoza, 2011).
- With scaling relationships of radius and length to mass, we found the optimal flow rate and maximal absorbance rate for the different relevant sizes and aspect ratios of the gut.
- Along with maximal absorbance rate and optimal flow rate, we found optimal consumption rate by multiplying the optimal flow rate by the cross sectional area of the gut. Absorption efficiency is simply the maximal absorption rate divided by optimal consumption rate. Gut passage time is the gut length divided by the optimal flow rate at that length.
- Predictions were compared to relevant data gathered by Messerman and Sears (2009).

### Results

- Our plug flow reactor describes continuous “plug” moving through a constant sized tube with a constant velocity profile. A corollary of this is that there is no axial mixing, but there is perfect radial mixing.
- Breakdown from membrane bound peptides and transport by transport proteins are treated as one step.
- Energetic costs of foraging, enzyme production, transport are ignored as are both diffusion and excretion.
- Gut parameters are constant through the length of the gut and through the development of the animal.
- Our model only examines digestion and absorption in the context of proteins.

### Conclusions and Further Work

- For such a simplified model, the plug flow reactor provides a fairly good approximation of gut digestion in Manduca. Perhaps some of our assumptions “cancel” each other out (e.g. neglect of diffusion and our underestimate of gut lumen surface area).
- The deviations from predictions we observe could be due to overly simple assumptions rather than inherent flaws of the plug flow model. By refining the model to deal with more biological complexity (e.g., if parameters changed by size, the gut and excretory diffusion to moist wall or multiple nutrients were considered) we could further test if a plug flow set up is appropriate.
- If we deem the model accurate, then our results strongly suggests that the caterpillars have optimized their consumption behavior to take advantage of their gut morphology.
- As a generalized model, our work suggests that physiological and behavioral processes might compensate for scaling relationships in a complicated fashion (e.g. maximal absorbance rate did not scale as mass$^{0.40}$).