# A Model of Carbohydrate and Protein Uptake in *Manduca sexta*

S.A. Frantz ’15 and Professor Andrew Kerkhoff, Department of Biology, Kenyon College, Gambier, Ohio

## *Introduction:*

Penry and Jumars (1987) developed equations to model several common digestive systems, including the plug-flow reactor model which was then modified by Woods and Kingsolver (1999) to apply it to *Manduca sexta*, a model organism which grows 10,000 fold in mass in just three weeks.

The model has been modified to examine gut function across *Manduca* ontogeny. It incorporates observed allometric scaling of the gut by using two different radii ($r_{area}$ was calculated as if the cross sectional area of the gut was a circle and was used to convert flow rate to consumption while $r_{perim}$ was calculated as if the perimeter of the gut were the circumference of a circle and was used throughout the rest of the model) and varies Wmax based on observed increases in protein transporters in fifth instar *Manduca*.

It has been hypothesized that fifth instar *Manduca* increase their uptake of carbohydrate relative to protein in preparation for their metamorphosis to moth form. Our goal was to determine if data and model results agreed with this hypothesis.

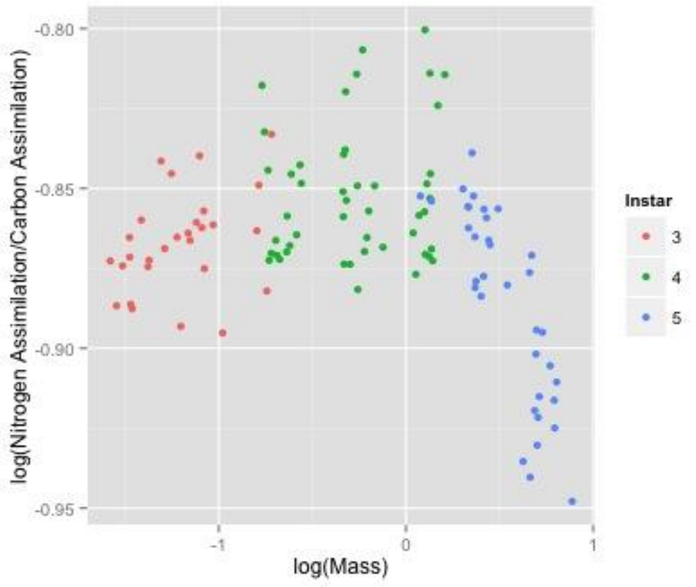



Figure 1. log(Mass) vs. log(nitrogen assimilation/carbon assimilation) for instars three (n=28), four (n=47), and five (n=35). All instars are significantly different from all other instars (α=0.02).

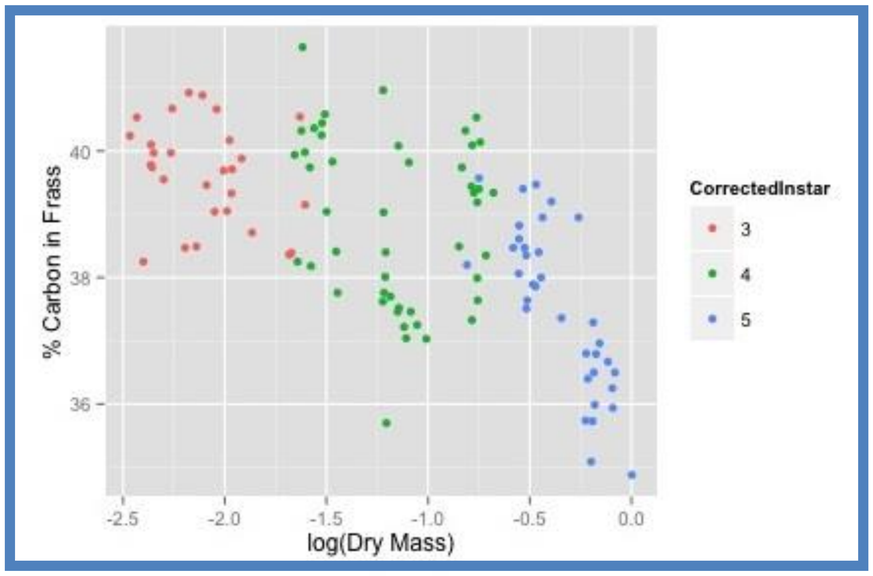



Figure 2. log(Dry mass) vs. percent carbon in frass. All instars are significantly different (α=0.05).

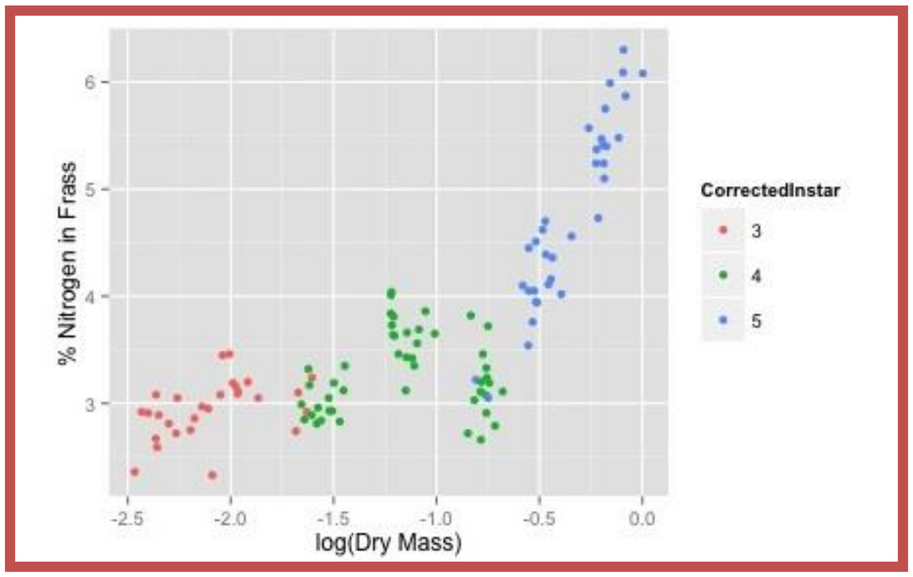
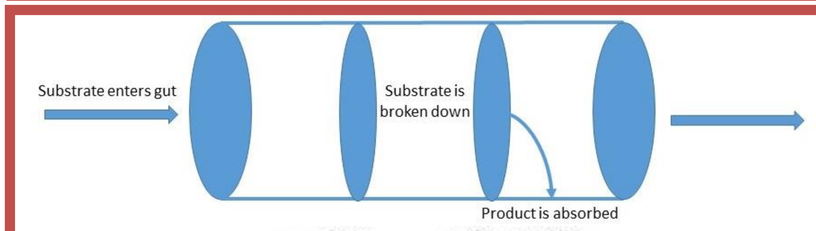



Figure 3. log(Dry mass) vs. percent nitrogen in frass. All instars are significantly different (α=0.05).

## The Woods and Kingsolver (1999) model:




$$(1)\quad \frac{dS(x)}{dx} = -\frac{1}{u}\left(\frac{Vmax S(x)}{Km + S(x)}\right)$$

$$(2)\quad \frac{dP(x)}{dx} = -\frac{1}{u}\left(\frac{2}{r} * \frac{Wmax * P(x)}{Lm + P(x)} - \alpha\frac{Vmax S * (x)}{Km + S(x)}\right)$$

$$(3)\quad A = 2\pi r \int_0^l \frac{Wmax * P(x)}{Lm + P(x)}\, dx.$$

| Model Parameter | Interpretation |
|---|---|
| **dS/dx** | Change in substrate concentration with distance |
| **Vmax** | Maximal rate of substrate breakdown |
| **dP/dx** | Change in product concentration with distance |
| **Wmax** | Maximal rate of product absorption |

## *Results and Discussion:*

From data it is clear that Nitrogen Assimilation/Carbon Assimilation decreases in the fifth instar (Figure 1).

An examination of the percent carbon and the percent nitrogen in caterpillar frass shows that with instar and increasing mass *M. sexta* excrete less carbon and more nitrogen(Figures 2 and 3).

The model was examined to see if trends in the output matched the actual data. WmaxAA doubled with instar for all model observations, but WmaxG was varied by instar based on WGFactor. As an example, if WGFactor equals three then WmaxG triples from the third to fourth instar, then triples again from the fourth to fifth instar.

Nitrogen Absorption/Carbon Absorption varied with WGFactor (Figure 4). A WGFactor of three or greater fit the trends of the real data most accurately, supporting the hypothesis that *M. sexta* increase their carbohydrate uptake relative to protein uptake with instar.

## *Future Research:*

The model suggests that the concentration of glucose transporters more than doubles in the fifth instar, but the exact increase is still undetermined. Looking for these transporters would clarify how glucose absorption changes. More accurate data on instars one and two would also be very informative.

## *Methods:*

We treated nitrogen as a rough estimate of protein concentration and carbon as a rough estimate of carbohydrate concentration since on average protein is 17% nitrogen and 53% carbon while carbohydrate is 0% nitrogen and 37% carbon. We then examined data on carbon and nitrogen content in *Manduca* frass in the third, fourth, and fifth instars.

A maximal rate of glucose absorption (WmaxG) and a half-saturation constant for glucose (lmG) were calculated and included in the model alongside the maximal rate of amino acid absorption (WmaxAA) and the half-saturation constant for amino acids (lmAA).

All calculations and models were run in R and all graphs were created in R. The deSolve, ggplot2, and psych packages were used.

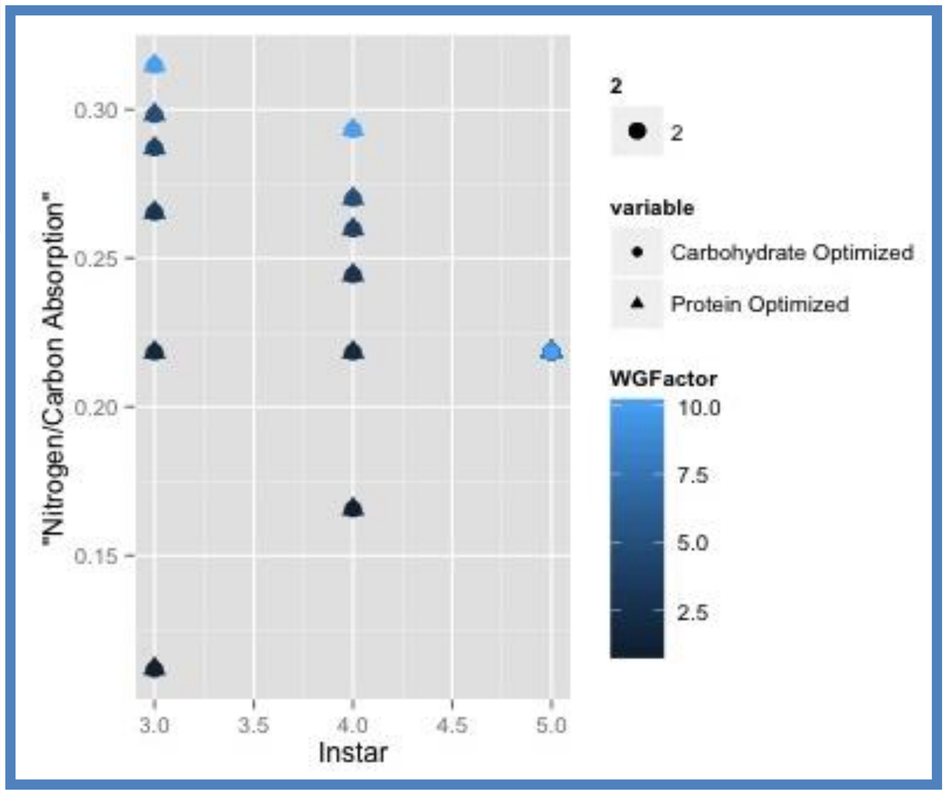



Figure 4. Instar vs. nitrogen absorption/carbon absorption as determined by the allometric model. A WGFactor of 3 or more produces results similar to observed results.

***Acknowledgements: Katie Sears and Arianne Messerman collected data on Manduca sexta carbon and nitrogen assimilation and body composition. Allison Vela-Mendoza collected data used to empirically determine the scaling relationships in the gut. Stephen Raithel developed the R code used in all variations of the model.***

## *References:*

Alexander RM. 1998. News of chews: the optimization of mastication. Nature 391:329.

McWilliams SR, Karasov WH. 1998. Test of a digestion optimization model: effect of variable-reward feeding schedules on digestive performance of a migratory bird. Oecologia 114:160-169.

Pascual I, Berrjón A, Lostao MP, Barber A. 2006. Transport of D-galactose by the gastrointestinal tract of the locust, *Locusta migratoria*. Comp Biochem Physiol 143:20-26.

Penry DL, Jumars PA. 1987. Modeling animal guts as chemical reactors. Am Nat 129:69-96.

Reuveni M, Dunn PE. 1994. Proline transport into brush border membrane vesicles from the midgut of *Manduca sexta* larvae. Comp Biochem Physiol 107A:685-691.

Sterner RW, Elser JJ. 2002. Ecological stoichiometry: the biology of elements from molecules to the biosphere. Princeton University Press, Princeton, New Jersey, USA.

Woods HA, Chamberlin ME. 1999. Effects of dietary protein concentration on L-proline transport by *Manduca sexta* midgut. J Insect Physiol 45:735-741.

Woods HA, Kingsolver JG. 1999. Feeding rate and the structure of protein digestion and absorption in lepidopteran midguts. Arch Insect Biochem Physiol 42:74-87.