The Effects of Feed Type on *Tenebrio molitor* Weight

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ABSTRACT

The purpose of this project is to determine if *Tenebrio molitor*, commonly known as mealworms, can gain weight on a diet of soybean stover, a byproduct of farming soybeans, with the intention of becoming a food source for people and livestock. I hypothesized that *Tenebrio molitor* would survive on a control diet and a soybean stover diet, but the mealworms consuming the soybean stover diet would gain less weight than the control diet. A diet of dried, ground soybean stover was tested and compared to a control diet of wheat bran. Each diet had three trials in which mealworms were fed equal masses of carrots as a water source and feed. Variables such as temperature, population density, and container type were controlled among the trials. After forty-five days of experimentation, the mealworms were removed from the feed and weighed to calculate the change in mass. The remaining feed and carrots were also weighed. Based on the results, the hypothesis was supported. The mealworms fed a soybean stover diet grew but consumed less feed and gained less mass than the control diet. Additionally, the mealworms consuming soybean stover were less efficient in terms of mass consumed compared to mass gained. This experiment presents a possible use for soybean stover. The results support the idea that mealworms can biorefine soybean stover into mealworm flesh. Mealworms may provide an alternative to traditional livestock by converting a waste product into a food source for humans or livestock.

INTRODUCTION

Harvesting soybeans from a field leaves behind soybean residue. Research has shown that “Crop residues left on the field represent more than half of the world’s agricultural phytomass” (Wang, ur Rehman, Liu, Yang, Zheng, Li…. Ziniu, 2017). Consequently, there is a large mass left behind after harvesting. Every thirty bushels of soybeans leaves behind one ton of stover, and this stover has limited uses besides preventing some erosion when left on the field (Rees, Wortmann, Drewnoski, Glewen, Pryor,, & Whitney, 2018). It cannot be used as livestock feed because it has a high lignin content that microbes in the livestock’s stomach cannot digest (Rees, Wortmann, Drewnoski, Glewen, Pryor,, & Whitney, 2018). This study aims to explore a potential use for this residual product.

Tenebrionidae, commonly known as darkling beetles, are known as a pest. They are holometabolous, meaning their lives follow a complete metamorphosis. Depending on variables such as temperature, humidity, and feed, tenebrionidae are eggs for 3-9 days, larva for 26-76 days, and pupa for 5-17 days (Adámková, Adámek, Mlček, Borkovcová, Bednářová, Kouřimská,... Vítová, 2017). This study focuses on mealworms in the larval stage when they are called *Tenebrio molitor* or mealworms.

Mealworms could become a future food source for humans. More than two billion people worldwide consume insect-based food (Lee, Kim, Ji, & Lee, 2019). Thus, consuming insects is not a new practice for humans. Studies have shown that mealworms have “a good composition in amino acids (good source of the essential amino acids), vitamins (i.e., vitamin E, vitamin B12, niacin, riboflavin, pantothenic acid, and biotin), and minerals (P, K, Mg, Zn, and Mn)” (Mancini, Fratini, Turchi, Mattioli, Bosco, Tuccindardi,... & Paci, 2019). This makes mealworms a valuable source of nutrients in a human diet. Mealworm’s nutritional content can vary based on diet, age, and other factors, but previous testing has determined mealworms contain 32.9% fat and 51.5% crude protein on a dry-matter basis (Xue, Vázquez-Gutiérrez, Johansson, Landberg, & Langton, 2016). These ratios make mealworms comparable to animal protein, as several studies have discussed.

Raising mealworms may have a lesser impact on the environment than farming conventional livestock. Previous research has shown that animal products require more land than mealworms to produce the same amount of edible protein: 1.81-3.23 times more land for milk, 2.30-2.85 times more land for chicken, 2.57-3.49 times more land for pork, and 7.89-12/12 times more land for beef (Oonincx, & de Boer, 2012). Therefore, mealworms could provide necessary protein to a growing population while using less land than livestock. In addition, mealworms have a higher reproductive capacity and feed conversion ratio than traditional livestock (Mancini, Fratini, Turchi, Mattioli, Bosco, Tuccindardi,... & Paci, 2019). This means that mealworms could develop faster while using less food compared to cows, pigs, or poultry.

This information made me ask the research question: **Can *Tenebrio molitor* survive and gain weight when fed soybean stover?** *Tenebrio molitor*, unlike livestock, may be able to consume the lignin-rich soybean residue and convert it into possibly nutritious flesh that humans could consume. This is a biotransformation process because the mealworms modify the chemical compounds in the soybean stover. Based on my knowledge, I hypothesise: ***Tenebrio molitor* will survive on the control diet and the soybean stover diet, but the mealworms consuming the soybean stover diet will gain less weight than the control diet.**

METHODS

MATERIALS:

- 2 three-tier plastic containers
- Thermometer
- Scale
- *Tenebrio molitor*
- Soybean stover
- Wheat bran
- Oven
- Food processor
- Freezer
- Carrots

EXPERIMENTAL PROCEDURE

- Obtain soybean stover and weigh it. Dry corn stover at 76.67°C (170°F) for several hours to remove excess moisture. Use a food processor to grind soybean stover into a fine meal. Purchase wheat bran from an online source.
- Weigh 3 equivalent masses of soybean stover (100.00 g) and 3 portions of wheat bran (100.00 g) using a scale. Deposit each mass into a drawer in the plastic container, labeling the containers for data collection (S1, S2, S3, C1, C2, C3). Place equal masses of chopped carrots (5.00 g) in each drawer to provide a water source.
- Order *Tenebrio molitor* at the youngest larval stage from an online source. Equally distribute the larva among the 6 control trials (100 larvae per trial). Record the initial weight of larvae.
- Record the temperature of the environment daily.
- Check for dead larvae daily and remove dead larvae to prevent molding in the habitat. Record the weight and number of dead larvae for each trial.
- Make notes about cannibalism or other observations daily.
- Add equal masses of fresh, chopped carrot every 3 days to provide a new source of water. Record the mass of added carrots and the day of addition.
- Use a sieve to remove all larvae from the drawers after 45 days. Place larvae in labeled plastic containers (at least 1 inch deep) according to the trial. Use sieve to remove all larvae from residual waste and place in labeled plastic containers (at least 1 inch deep) according to the trial. Place containers in the freezer to kill larvae. Record the temperature of the freezer.
- Weigh the mealworms and record the final weight. Weigh the remaining feed and waste products.

CALCULATIONS

- Calculate Efficiency of Conversion of Ingested food (ECI) by dividing weight gained (g) by the weight of ingested feed (g) and multiplying by 100.
- Calculate Feed Conversion Ratio (FCR) by dividing mass of ingested feed (g) divided by mass increase (g).
- Calculate conversion of dietary protein to edible protein (%). Multiply the percentage of protein in the feed by the mass of feed consumed (g) and divide by 100 to find the mass of protein consumed (g). Multiply the mass gained (g) by the estimated percentage of protein in T*enebrio Molitor* (50%) and divide by 100 to find the mass of protein gained (g). Find the conversion of dietary protein to edible

protein (%) by dividing the mass of protein gained (g) by the mass of protein consumed (g) and multiplying by 100.

- Calculate the average mass gained per larvae. For each trial, Divide the larvaes' initial mass (g) by 100, the initial number of larvae, to find the average initial mass per larvae (g). Divide the larvae's final mass (g) by the number of larvae recovered to find the average final mass per larvae (g). Subtract the average initial mass per larvae (g) from the average final mass per larvae (g) to find the average mass gained per larvae (g).
- Calculate average mass gained per larvae (g) on each diet. Add the average mass gained per larvae (g) from trials S1, S2, and S3. Divide the sum by 3 to find the average mass gained per larvae (g) on the soybean stover diet. Repeat the same steps for C1, C2, and C3 to find the average mass gained per larvae on the control diet.
- Calculate average mass ingested (g) on each diet. Add the mass of feed consumed (g) from trials S1, S2, and S3. Divide the sum by 3 to find the average mass ingested (g) on the soybean stover diet. Repeat the same steps for C1, C2, and C3 to find the average mass ingested (g) on the control diet.

RESULTS

TEMPERATURE RECORDINGS

Day	1	2	3	4	5	6	7	8	9	10
Temperature (°C)	16.0°C	15.6°C	15.8°C	15.9°C	19.1°C	18.4°C	17.7°C	20.0°C	18.2°C	19.6°C

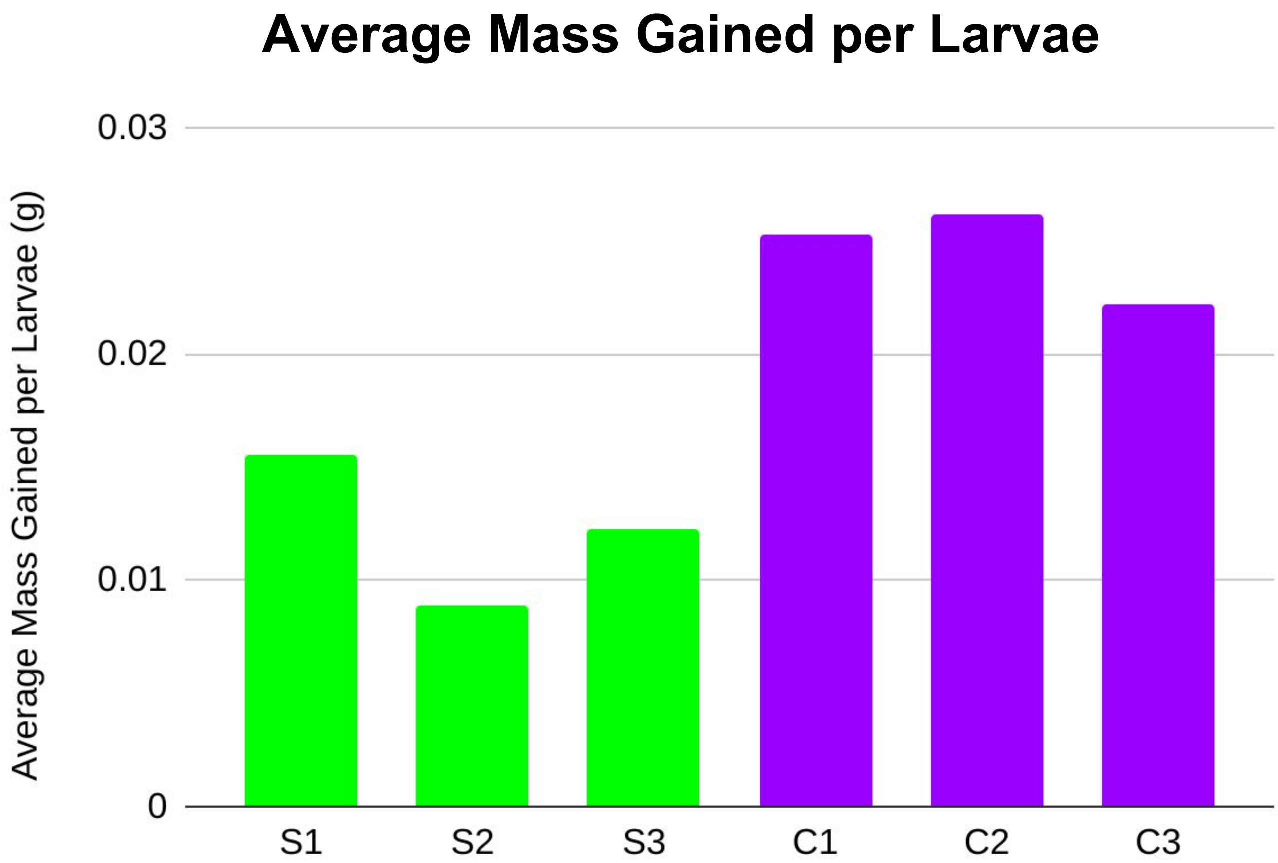
11	13	14	15	16	17	18	19	20	21
19.0°C	19.1°C	18.9°C	17.0°C	19.3°C	18.9°C	18.4°C	18.2°C	17.3°C	19.0°C

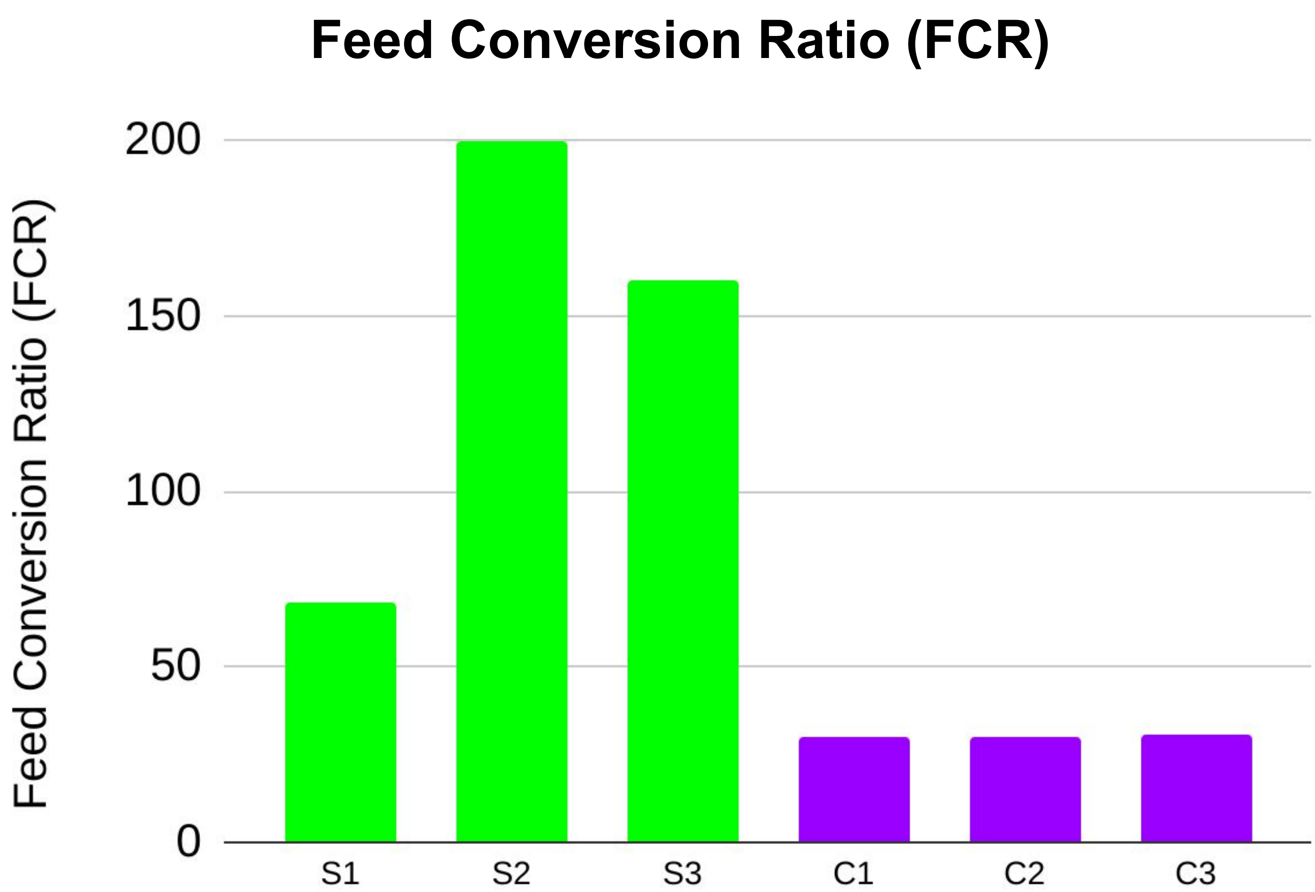
22	23	24	25	26	27	28	29	30	31	32	33
19.1°C	18.7°C	18.4°C	17.9°C	18.0°C	17.1°C	17.6°C	18.1°C	18.0°C	17.8°C	18.0°C	18.6°C

34	35	36	37	38	39	40	41	42	43	44	45
20.0°C	19.4°C	20.0°C	19.0°C	18.3°C	19.1°C	18.0°C	15.0°C	18.0°C	19.0°C	17.9°C	19.0°C

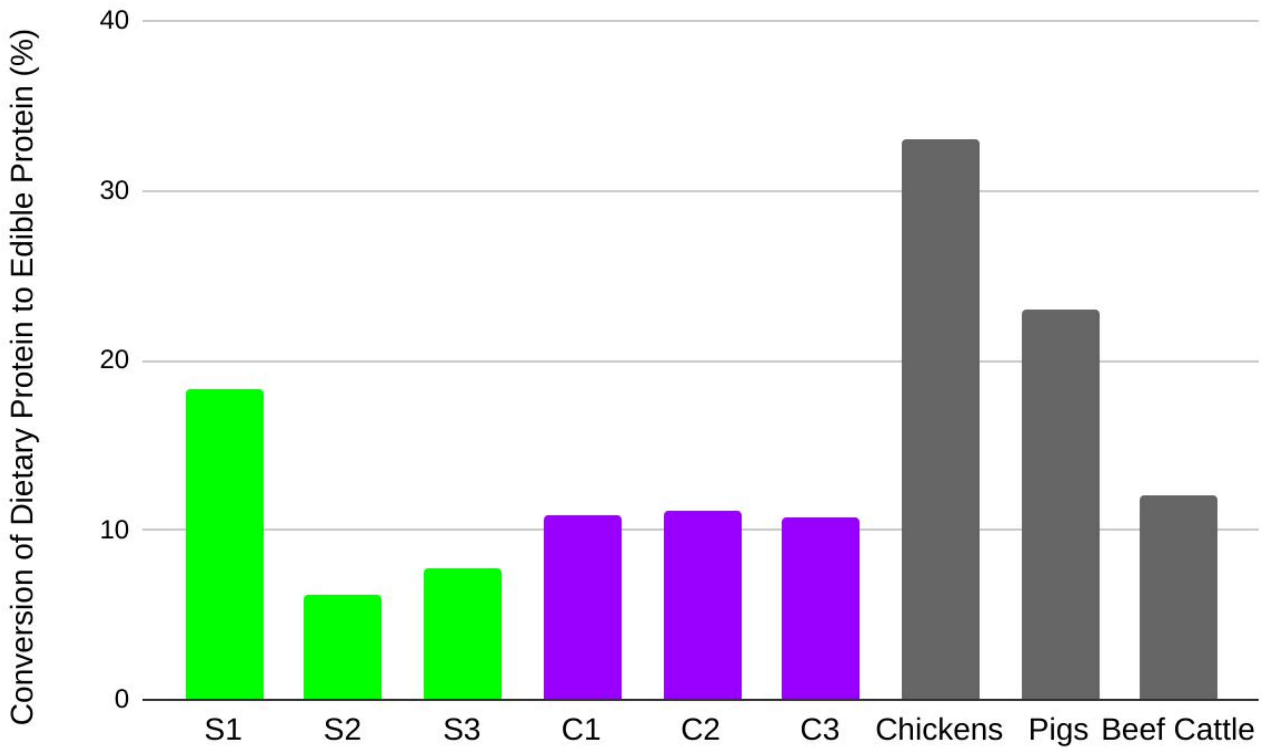
DATA

	S1	S2	S3	C1	C2	C3
Feed type	Soybean stover	Soybean stover	Soybean stover	Wheat bran	Wheat bran	Wheat bran
Initial weight of feed (g)	100.00 g	100.00 g	100.00 g	100.00 g	100.00 g	100.00 g
Initial mass of larvae (g)	1.35 g	1.40 g	1.20 g	1.34 g	1.33 g	1.17 g
Initial number of larvae	100	100	100	100	100	100
Initial average mass per larvae (g)	0.0135g	0.0140g	0.0120g	0.0134g	0.0133g	0.0117
Total mass of carrots added (g)	61.00g	61.00g	61.00g	61.00g	61.00g	61.00g
Total mass added (g)	161.00g	161.00g	161.00g	161.00g	161.00g	161.00g
Number of larvae recovered	73	73	63	86	85	92
Mass of empty larvae bag (g)	1.67g	1.70g	1.69g	1.69g	1.67g	1.70g
Mass of larvae bag with larvae(g)	3.79g	3.37g	3.22g	5.02g	5.03g	4.82g
Final Mass of Larvae (g)	2.12g	1.67g	1.53g	3.33g	3.36g	3.12g
Total mass larvae gained (g)	0.77g	0.27g	0.33g	1.99g	2.03g	1.95g
Average Final Mass per Larvae (g)	0.0290g	0.0229g	0.0243g	0.0387g	0.0395g	0.0339g
Average Mass Gained per Larvae (g)	0.0155g	0.0089g	0.0123g	0.0253g	0.0262g	0.0222g
Initial mass of remains bag (g)	8.35g	8.71g	8.73g	8.73g	8.38g	8.76g
Final mass of remains bag with remains (g)	116.78g	115.65g	116.37	109.07	108.92g	109.48
Final mass of remains (g)	108.43g	106.94	107.64g	100.34g	100.54	100.72g
Mass consumed (g)	52.57g	54.06g	53.36g	60.66g	60.46g	60.28g
Average Mass Consumed per living Larvae (g)	0.7201g	0.7405g	0.8470g	0.7053g	0.7113g	0.6552g
Days of Testing	45	45	45	45	45	45
Average Temperature (°C)	19.1°C	19.1°C	19.1°C	19.1°C	19.1°C	19.1°C
Efficiency of Conversion of Digested Food (ECI) (%)	1.50%	0.50%	0.62%	3.38%	3.36%	3.23%
Feed Conversion Ratio (FCR)	68	200	160	30	30	31
Conversion of Dietary Protein to Edible Protein (%)	18.3	6.24	7.73	10.9	11.2	10.8


Average Mass Gained per Larvae
Average Mass Gained per Larvae (g)
0.03
0.02
0.01
0
S1
S2
S3
C1
C2
C3

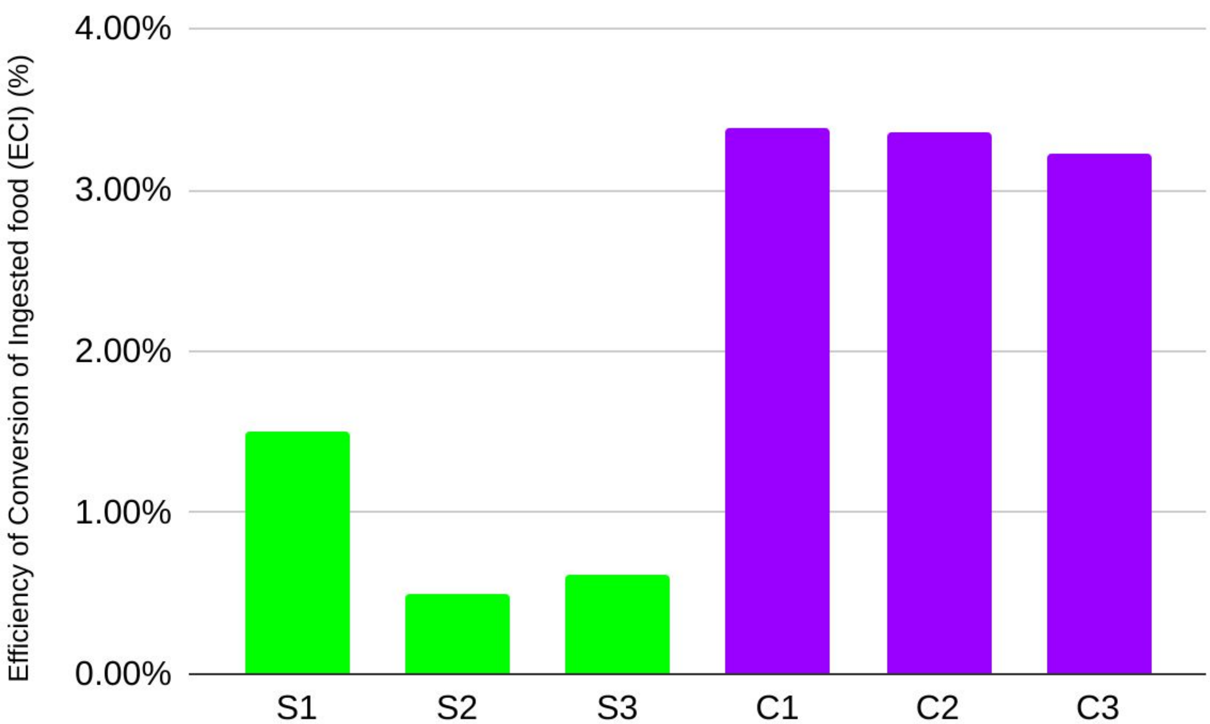

Feed Conversion Ratio (FCR)
Feed Conversion Ratio (FCR)
200
150
100
50
0
S1
S2
S3
C1
C2
C3

Conversion of Dietary Protein to Edible Protein



Livestock conversion of dietary protein to edible protein source: Oonincx, D. G. A. B., van Broekhoven, S., van Huis, A., & van Loon, J. J.

Efficiency of Conversion of Digested Food (ECI)



DISCUSSION

The results of this experiment support the hypothesis. *Tenebrio molitor* did gain weight and survive while consuming a diet of soybean stover. Like predicted, the mealworms consuming stover gained less weight than the control group consuming wheat bran. Mealworms on the control diet gained an average of 0.0246 grams, but mealworms on the soybean stover diet gained an average of 0.0122 grams. Additionally, less mealworms were recovered in the soybean stover trials (ranging from 63 to 73 larvae) than in the control trials (ranging from 85 to 92 larvae). Mealworms consuming soybean stover ingested less feed than the mealworms consuming wheat bran (an average of 53.33 g and 60.47 g, respectively). Further research could determine the ratios in which the larvae consumed carrots and feed in the control trials and stover trials.

A similar study that fed mealworms a diet of corn stover calculated a Feed Conversion Ratio (FCR) of 13.86 (Wang et. al.). This is more efficient than the values found in this experiment: 68, 200, and 160. This may have been because the corn stover study raised mealworms in an environment at a higher temperature and humidity than this experiment. Furthermore, this experiment may have measurement errors because the remaining feed could not be weighed in the mealworm containers. Therefore, some of the remaining feed may not have been included in the remaining feed measurement. A greater amount of unconsumed feed would decrease the FCR.

A study feeding mealworms various food byproducts calculated a protein conversion ratio ranging from 22 to 58%, and the researchers noted that low protein diets were associated with a longer development period (Oonincx, D. G. A. B., van Broekhoven, S., van Huis, A., & van Loon, J. J.). The protein conversion ratios found in this study (6.24%, 7.73%, and 18.3%) were lower than the cited study. This may have been because soybean stover may be a lower quality protein than a diet of food byproducts. An experiment comparing a food by-product diet to a soybean stover diet using the same methods could provide more understanding.

The unrecovered mealworms are another possible error in this experiment. Some mealworms may have died due to cannibalism. As noted in previous studies, poor-quality feed can lead to cannibalism (Adámková et. al.). More research is needed to determine if and when cannibalism occurred in this study.

The purpose of this experiment, to investigate the possibility of feeding *Tenebrio Molitor* soybean stover to transform a waste product into a food product, was successful. Mealworms consuming soybean stover were able to survive and gain weight, though at a slower rate than the control groups. Therefore, mealworms can be utilized to biorefine soybean stover into a more useful product. This ability to transform a waste product into food could be used in regions with food insecurity. Populations lacking access to animal proteins could consume insect proteins.

Farming mealworms may also have a positive impact on the environment. By consuming a waste product, mealworms could make soybean farming more productive by using the entire plant. This would result in less waste of the resources used to grow the whole soybean plant. With a relatively short life cycle and the ability to live in small, enclosed spaces, mealworms may have less impact on the environment than animal agriculture. Additional experiments could further study mealworms’ efficiency and emissions compared to livestock.

CONCLUSION

Mealworms consuming soybean stover were able to survive and gain weight, though at a slower rate than the control groups consuming wheat bran.

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