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Space Diet: Daily Mealworm (*Tenebrio molitor)* Harvest on a Multigenerational Spaceship

Ruth Sang Jones
The Centre for Interdisciplinary Science, University of Leicester
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Abstract
It has been proposed in recent years that insects are a viable food source that should be seriously considered for the future. Their high nutritional value, small size and rapid reproduction are also promising for space agriculture. In this paper, a possible future Multi-generational Spaceship with sufficient interior room to have an insect breeding room is considered. The insect of interest here is the mealworm *(Tenebrio molitor),* which has a very high protein content. The daily mealworm harvest aboard such a ship that satisfies the protein requirement of a stable crew population of 160 is approximated here to be ~162,000. There is also qualitative discussion of other considerations for a spaceship mealworm colony.

Introduction
Insects are included in the regular diet of approximately 2 Billion people, with a menu of close to 2000 edible species [1]. Yet, insect-eating, or entomophagy, has little popularity amongst Western cultures perhaps because of the perception of the practice being higher in gross factor than comfort factor. With human population growth and corresponding nutrition demands becoming an increasing concern, entomophagy has been proposed as a future sustainable food source [1]. Perhaps insect-eating is also a potential solution to nutrition for crew aboard spaceships, especially for long-duration travel [2].

Aboard spacecraft that are intended for long-duration travel, sourcing food from stored stocks becomes less viable and there is an increased need for growing and harvesting food right there, with the application of bioregenerative models. However, there must be a compromise because there is limited space on the craft and energy consumption involved in agricultural practices is also limited by energy supply of the isolated ship.

The insect that is considered here that can potentially form a staple part of the space crew diet is the mealworm. It is the edible larval stage of the *Tenebrio molitor,* a species of Darkling Beetle [3, 4]. The context for the paper's calculation is drawn from a previously proposed multi-generational spaceship travelling for 200 years. Estimations according to anthropology and genetic studies have found that a minimum of 160 crew will maintain a stable, viable population [5].

The spaceship interior could be designed to include a mealworm breeding room. The main purpose of these mealworms will be to satisfy the protein demands of the crew. Here, the daily protein demand of the crew is estimated and the necessary daily output of the spaceship mealworm 'farm' is calculated.

Daily Protein Requirements
According to the Institute of Medicine, the recommended daily intake of protein for men and women in the age range of 17-90 are 56 and 46 grams/day respectively [6-7]. Assuming there are an equal population of men and women at any time, this means that in the 160 population, there are 80 men and 80 women. The total daily protein intake of the crew is shown in Table 1 below.

Daily Mealworm Harvest
Roasted mealworms have a protein content of 55.43 grams per 100 grams [8]. This is higher than meats such as chicken, pork and beef, which all have protein content in the range of 30-40g per 100g of meat [9].

	Protein intake (grams/day)	
	Men	**Women**
1 individual	56	46
80 individuals	4480	3680
Total 160 crew	**8160**	

Table 1 – Daily Protein demands for 160 crew on Spaceship.

Given the total daily protein demand for the crew is 8160g, the grams of mealworm that are needed to meet this can be calculated. The ratio of protein demand to protein content of 100g of mealworm is 147.2. This ratio multiplied by 100g gives the mass of mealworms needed. This gives 14720g of roasted mealworms consumed daily on the spacecraft.

It is estimated that 1000-1200 medium sized mealworm have a mass of ~100g [10]. For this calculation, the midway value of 1100 mealworms weighs 100g. This equates to 11 mealworms per gram. Thus, the number of mealworms that must be harvested from the spaceship breeding room per day can be calculated as follows:

$$14{,}720 \times 11 = 161{,}920 \text{ mealworms per day}$$

For a 200 year multi-generational trip, this equates to ~12 billion mealworms harvested and consumed during the trip, of course assuming the crew population stays close to the stable 160 count.

Conclusion

What are the implications of this mealworm demand to satisfy the protein needs of the spaceship crew? The breeding of the mealworms requires both room and energy. Using this paper's calculation as a foundation, and once an understanding of the optimised conditions for a mealworm colony are known, the room in the spaceship that must be allocated to their breeding can be found. Mealworm breeding also requires heating and high humidity. Maintenance of optimal conditions requires energy sourced from the fuel on the ship. Thus, the ship's energy budget must account for the energy utilized for mealworm breeding. Respiring mealworms will also require oxygen.

Of course the mealworms also have food demands themselves. They require a food substrate, such as oatmeal or cornmeal, and a water supply, which is sourced from fruits or vegetables [3]. If these supplies are also produced on the ship, that system can be interlinked with the mealworm breeding. It is worth noting that mealworms are natural decomposers. Thus, if the spaceship has a bioregenerative life support system, the mealworms may be able to fill in the role of the decomposers. However, it must be ensured that they are still hygienic for human consumption. Further research of the feasibility of mealworm breeding in spaceships is necessary. Perhaps in the mean time, new tasty recipes incorporating these insects should be developed to make the case for eating them more convincing.

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