Recommendations for Breeding and Holding of Regular Mealworm

Recommendations for breeding and holding of regular mealworm, Tenebrio molitor
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1. Introduction
This guide is aimed at farmers and other stakeholders who are interested in starting a production of the ordinary mealworm. As the area is still very new, this is not a final recipe for successful production, but rather a number of recommendations.
The recommendations are based on the Danish Institute of Technology's experience with insect production and on
knowledge of the subject obtained in both the Netherlands and abroad.
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2. General
Common mealworm (Tenebrio molitor) passes through like other insects with complete transformation
(also known as holometabolism) four lifestyles:
Adult - Egg - Larva - Pupae. In the larval stage they will make about 20 skin changes.
The larva of mealworms (also called mealworm) has been used as a source of protein in large parts of the East
and has been sold in the western world for decades as pet food (reptiles, fish, etc.). Since 2013 the insect's great potential as food and feed has come into focus due to global rising demand after protein.
Insects can be in the right conditions to give a much higher protein yield per area than traditional crews. At the same time, insect production uses only a fraction of the water that goes to produce the same amount of meat in conventional production systems. Mealwormic primary biomass growth occurs in larval stages, where larvae can double their weight several hundred times - from an egg on ca. 0.6 mg to a full-fat larva of about 150-200 mg during 7-12 weeks, depending on, among other things, temperature, humidity and feed.

3. Production steps
The production of mealworm can generally be divided into four areas; 1) Reproduction, 2) Production, 3) Separation and 4) Killing

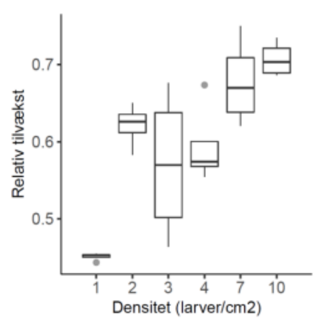
3.1. Reproduction
The reproduction includes the adult beetles (the mother culture) as well as the eggs that are being laid and which are to continue for production. The goal is to get the most possible eggs per production unit (a breeding box in this case), and the highest possible survival of eggs to larvae. There are various factors that affect the adult beetles, and thus influence on how many eggs are being placed. Some of these factors are availability of food as well temperature and humidity both in the surrounding room and in the actual box where the beetles bred. In addition, the density of beetles in the box (beetles per cm2, also called density) is also a big influence.
In order to get the most out of the adult beetles on a given area, it may be an advantage to let them go relatively close. Experiments have shown that the individual female babe is using the most eggs a low density3, but the overall yield of the box is obtained at a density of about 0.84 beetle per cm^2. In practice, this means that there must be about 1700 beetles in a box that measures 40 (W) x 60 (L), or about 200 g when the adult beetles weigh approx. 0.13g.
Normally, the relationship between males and females is approx. 1: 1. Although an increased concentration of female beetles will result in more eggs per tray, the advantage of the 1: 1 ratio is that it gives more genetic variation and increases competition among males. The female beetle lays 5 to 8 eggs in a day and about 300 eggs during a lifetime. The adult beetles will live to be 1-3 months old.

Handling of eggs for launching a box can take place in different ways. You can remove the adult beetles from the box, thus saving eggs and feed together. This method can be beneficial as you also store the eggs that the beetles have glued on the surface of the box. You can also transfer the feed including eggs to another and smaller box (as mentioned below). By this method, however, the eggs that are glued to the box from the production are lost.

If you want better control with the number of eggs in each box, you can choose to sift the eggs from the feed. The eggs are relatively large (1-1.5 mm) and can therefore be sifted from it mostly finer substrate using a 0.5 mm sieve. Thus one will be able to transfer a particular volume (a certain number of eggs) into a new box and thus secure (and know) a particular density of the larvae which are subsequently hatched into the boxes. This can reduce the variation in the production of larvae and thus yield more stable yield, which is advantageous.

3.2. Production

The production of mealworm focuses on the growth of larvae. Just like in the adult beetles there are many factors that affect the larvae growth, including temperature, humidity, feed and larvae density. Density can have both positive and negative influence on the larval development rate, size, survival and tendency for cannibalism. Several studies show that larvae grow best in their first month if they are relatively close together. The graph shows relative growth relative to density larvae that are over 1 month old (bred at 77°F) - and the results show that the larvae that are closest (10 larvae per cm^2), have the largest growth. As larvae grow, they will need more space to achieve optimal growth, and it can therefore be an advantage to have breeding boxes in different sizes so that the larvae can be moved gradually as they grow. Today, standard boxes for larvae are used at 40 (W) x 60 (L) x 8-15 (H) cm. A small box (e.g. 20 (W) x 30 (L) cm) can be used with advantage the first 4 weeks. Then the larvae (including feed) are transferred to larger boxes (e.g. 40 (W) x 60 (L) cm) towards 'harvest' in weeks 7-9. Among other things, it helps to ensure that the larvae go closer while they are small, which promotes their growth, as it minimizes the larvae physical distance to the liquid feed. The development time from egg to fallow larva (larvae that have reached an almost maximum size, but has not yet begun to pupate) is strong depending on the ambient temperature and is around 70 days at 77°F and 50 days at 86°F.



Relationship between relative growth and density (larvae/cm2) for larvae between 4-6 weeks. Shown as mean, 95% confidence interval, and the total spread.

3.3. Separation
Separation (or sorting) is when the larvae must be sent to killing and when pupae are gathered for the mother culture.

3.3.1. Separation of larvae
Once the larvae have grown large (about 170 mg per larva) they must be sorted from residues and frass before they can be used. There are currently no fully automated mealworm separation devices. The Danish market, however, is being experimented with different methods in both established and newly established insecticides. An on-going project (inVALUABLE), is currently developing a semiautomatic method for the separation of larvae.
By manual separation, the best method to use is sifting with different mesh sizes. A sieve with a mesh size of about 1.5-2 mm will sort leftovers of feed as well feces from the larvae. If you use a piece with a mesh size of 4 mm, you will keep the largest lumps of feed while the larvae will fall through. However, there may be fine and dried leftovers of wet substrate that also falsl through a 4 mm sieve. It can generally be difficult to separate wet feed residues completely from the larvae. If you keep your own culture of beetles, you can save 5-10% of the larvae for further discussion.

3.3.2. Separation of Pupae
When the first pupae show up among the larvae can be sorted from by using a sieve. The pupae have one
relatively large 'head' relative to the larvae, and the majority of the pupae cannot therefore come through a sieve with a mesh size of 3-4 mm. Most people, on the other hand, are good at it, but there will probably be some rigid and inactive larvae back in sight. These will often turn into pupae within a short period of time. It may be advantageous to have some "grab material" in the boxes of the dolls (eg paper, egg tray, fabric) that the adults can get stuck on and then easily sorted off the pupae that cannot hold onto the surface.
Development from pupae to adult beetles takes about 7 days at 77°F and 5 days at 86°F. Freshly emerged adult beetles are very light, but cure quickly and become completely dark after a few days. When the beetles are black and no longer change color, they are sexually mature. The residual product from the production (frass) can be used for fertilizers or in a biogas plant. The exact value of the residual product is not yet known.

3.4. Killing
There are no fixed procedures for killing insects yet, but the Danish Veterinary and Food Administration is in process of clarifying which killing method(s) to be implemented in order to produce food-approved products. Insects are currently being regarded as domestic animals, and you must therefore have divided slaughtering facilities so that they live and dead animals do not cross roads.
The killing of insects typically takes place by first having insects walking in a cool room (approx. 59°F) without food for about a day, where they empty their intestines. Then they are killed in a freezing room (0°F) for at least two days. For a further review of rules and laws in relation to the production of insects, refer to the Danish Veterinary and Food Administration's guidance document.

4. Important Production Parameters
There are many parameters that influence insect production. Some of the most important are feed, temperature and humidity. Density is also important, as described during production steps 3.1 and 3.2.

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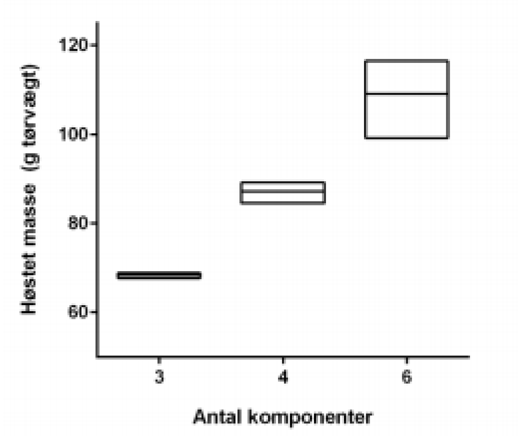
4.1. Feed

The substrate of the tray consists of two parts, namely dry fodder and wet substrate. The dry feed is the insects primary source of energy and constitutes the bulk of the feed. The wet feed serves a substantially smaller role, but acts as the water source for the insects and also influences larval growth (see figure under 4.1.2. Wet feed).

4.1.1. Dry food

Feeding of ordinary mealworm largely consists of residual products in the form of bran from various cereals. Over the past few years research has examined the importance of the feed composition for the larvae's growth - and the results are that a varied feed with several different components (including pea, wheat, oats and rye flour) gives a higher yield because the larvae grow faster and get bigger before drowning.

Mass of Worm Related to Number of Components in Substrate

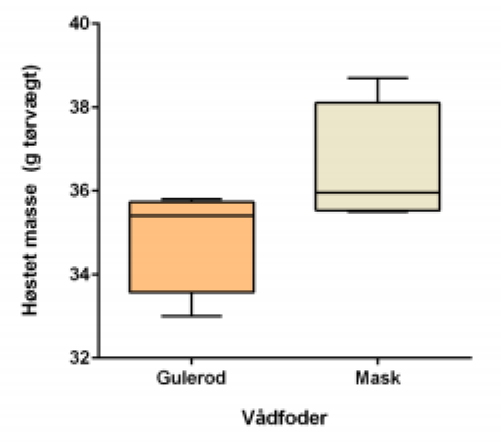


Chicken feed has been among the most effective but also most expensive compound foodstuffs for larval breeding. These mixtures are also used in breeding other insects. However, feed mixes are now being developed specifically for mealworm, and will in all likelihood yield a higher yield at the same or lower price after further adjustments. The same feed is often used for larvae and adult beetles, but at present there is a focus on developing lifestyle-specific compound feed. The larvae have a high feed conversion rate (2:1), while adult beetles eat only a fraction of the feed that the larvae consume. At the same time both larvae and adults need a wet feed like water source to optimize both the yield of larva biomass and the number of eggs.

4.1.2. Wet

Like the dry food, the type of wet food is high importance for larval growth. Typically, fruits and vegetables have been used in high degree due to availability, price and not least convenience. However, it has been shown in Several cases that wet food in the form of a mash (waste product from breweries, for example) has a great potential compared to carrots alone. To date not much research has been made on wet food, but it is expected that the final yield of ordinary mealworm could be significantly increased for future use of an optimized wet feed.

Mass of Worms Using Wet Food – Carrots vs Mash



4.2. Temperature

Common mealworms have a wide range of temperatures in which they thrive, but with considering the production of larvae for feed and food, it is most interesting to apply the temperature that gives the fastest growth. Insects are alternating animals, which means that they are very close to the temperature in the environment, and only to a limited extent can adjust their body temperature. Alternate animal metabolism increases with the animal's (environmental) temperature, which means that the animal has faster growth and higher activity at higher temperatures. However, if the temperature becomes too high a number of negative effects occur that will ultimately result in the insects dying. It is thus important find the optimal temperature for the surroundings; i.e. the temperature that gives fast growth, but do not have negative consequences for the larvae.

There are many older and recently published studies, showing that ordinary mealworm optimal temperatures are between 86°F and 90°F. Here, however, it should be noted that even though the individual larva does not generate measurable heat, 10,000-20,000 large larvae in a box will together theoretically generate around 3-8 watts with which the temperature in the box becomes higher than the temperature in the surroundings. Thus, the optimal temperature in the surrounding spaces depend on the density of larvae, humidity and air exchange over the boxes.

Research in the heat development of larvae is relatively inadequate. Several studies have measured isolated animals or only catered for the larvae, and not the combination of larvae and feed. In fact, heat development in the box is far more complicated because the wet feed to the larvae has a significant heat development in itself even because of large microbial activity. The Danish Technological Institute is currently examining temperature development in the production box under different conditions (feed types, larval density etc.) as well as in production settings ('layer on layer' and 'shoulder by shoulder'). Looking forward to this one type of data could significantly improve the advice in the field.

4.3. Humidity

Humidity is very important for survival, especially the small larvae and eggs. Insects are generally very well protected from drying out, but until the larvae reach a certain amount size, they are far more sensitive to low humidity than they are when they stay bigger and have completed their exhaust shaft. The larvae can downregulate their body temperature by evaporating water from their respiratory system, which means that if the temperature is too high, larvae will try to lower their body temperature at the expense of their water balance. Previous studies have shown that normal mealworms have the greatest survival at relative humidity around 50-70%, where eggs have an improved survival rate of 70% over 50%, albeit minimally improved. The downside of keeping the humidity too high in a stable environment is that microorganisms and especially fungi will get very good growth conditions, and dry food, but especially wet food, will be 'attacked' to a very high extent by very high humidity. It will be an advantage in the individual farms to know and adjust their humidity to check how often to supplement the larvae wet food and how much to feed. Lower humidity will require more frequent wet feeding, as both the feed and the larvae lose fluid faster than at higher humidities. Maintenance of 50-70% relative humidity will therefore reduce work, and ensure that the larvae do not thirst, which might adversely affect the welfare of the animal and thus on the final dividend from the individual boxes. A detailed review of the influence of different temperatures and humidity on eggs, larvae and beetles can be found in the scientific article by Punzo from 1975.

5. Example of production cycle of Tenebrio molitor
Starting box: 20x30 cm
Final box: 60x40 cm
Temperature: 86°F
Survivor larvae: 10,000
Estimated output: 1800 g wet weight

Relationship between relative growth and density (larvae / cm2) for larvae between 4-6 weeks. Shown as mean, 95% confidence interval and the total spread (unpublished data - Danish Technological Institute).