RESEARCH ARTICLE

Profitability of insect production for T. molitor farms in The Netherlands

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Received 18 July 2023 | Accepted 15 November 2023 | Published online 8 December 2023

Abstract

Insects are increasingly considered as a relevant alternative protein source in the transition to a more circular economy and more sustainable food production. Understanding the profitability of insect farms is crucial for starting entrepreneurs, established rearers, and third parties. In this study we analysed the revenues and expenses of seven T. molitor farms in the Netherlands, representing approximately a quarter of the total sector. We calculated their gross margin and net present value. Revenues came from the sales of fresh larvae and insect frass, and from extension services. Expenses included investments, and non-allocated and variable expenses. Results cover technical and economic results, and a qualitative description of farm operations. The gross margins and net present values ranged from −180 to 2,030 and from −12,359 to 15,535 EUR/tonne fresh larva production, respectively. The main determinants of T. molitor farms’ profitability included the sales price of larvae, and its labour and substrate expenses. Our estimates can be used by decision making of farmers, credit providers, and policy makers to support the growth of this still very small, but emerging sector.

Keywords

insect farm profitability – economic viability – insect rearing – mealworm production – T. molitor farm economics

1 Introduction

(Partial) replacement of traditional protein sources by insects or derivatives in feed and food is regarded as a potential contributor in the ongoing protein transition and pathway towards more sustainable use of resources (Fasolin et al., 2019). Whereas the production and consumption of insects has long been a common practice in regions such as South-East Asia, it emerges to be a major challenge to establish this form of alternative production and consumption in Europe (Raheem et al., 2019). Positive developments have taken place and investments are on the rise in the European insect sector, but upscaling remains a challenge limiting a speedy development of the sector (Montanari et al., 2021; Rabobank, 2021). Previous studies conclude that the main causes of this challenge included the restrictive legislation on the one hand, but also the lack of financial resources for upscaling and stability of supply and demand of this growing industry on the other hand (Niyonsaba et al., 2023; Yang and Cooke, 2020).

Empirical research into the economic viability of the European insect industry is primarily limited to studies on the incorporation of insects and derivatives in feed and food products (see e.g. Arru et al., 2019; Maroušek et al., 2022; Selaledi et al., 2020). We also...
indicated in Niyonsaba et al. (2023) that high prices of insects and derivatives limit their use as ingredients, and regulatory barriers and a lack of demand for insect products impede profitable expansion. Recently, we provided a literature-based overview of farm economic data (Niyonsaba et al., 2021). We concluded that factual data on costs and revenues of operating insect farms are needed to reliably evaluate the economic viability of farm businesses. In addition, these data aid in identifying financial risks, in adjusting potential business models to mitigate these risks, and in increasing the profitability of production (Euchner and Ganguly, 2014). Considering the dynamic nature of the insect sector in fast changing business environments, the call for insights into economic figures becomes even more urgent as it also supports the sector in gaining recognition and further professionalisation.

Empirical evidence on the economic viability of insect farms in Europe is not yet available. In this study we aim to analyse the profitability of Tenebrio molitor (T. molitor) farms in the Netherlands. The yellow mealworm – T. molitor – is regarded as an important species for (industrial) rearing of insects on the European market due the species’ technical feasibility for upscaling and its inclusion in feed and food products. We first present an overview of farm operations and technical data. This is followed by an assessment of the revenues, non-allocated and variable expenses of T. molitor farms in the Netherlands, based on which the gross margin (GM) and net present value (NPV) are calculated. We contribute to the literature by providing first estimates on revenues and expenses of T. molitor1 production as a basis for future research into profitable forms of insect rearing in- and outside the Netherlands. More broadly, we contribute to economic research for this specific sector, which has been limited to date. Results can further guide service providers in decision making on (credit) risk assessment as well as insect rearers in making investment decisions, benchmarking their position in the market, and adjusting their business model to increase profitability. In this way our results can help to upscale the production of alternative proteins.

2 Analytical framework and profitability calculations

Based on what is commonly used for other livestock sectors, we assessed variables adjusted to mealworm farm operations, and complemented them with sector specific variables (Blanken et al., 2021; Veldkamp et al., 2021). Technical farm data included labour requirements, feed inputs, and production volumes. Farm economic data included initial investments, total revenues, as well as non-allocated and variable expenses. Investments included total investments in buildings, installations, machinery, and other assets. Non-allocated expenses included rent for buildings as well as expenses for administration, marketing, and quality purposes. Variable expenses were related to labour, feed, utilities, and insect health (pest control and hygiene). The profitability of mealworm farms in the Netherlands was assessed through the GM and NPV.

The GM per tonne fresh larvae production in year \( t \) (GM\(_ t \)) was calculated by

\[
GM_t = TR_t - VE_t
\]

Total revenues (TR) result from sales of fresh larvae and frass, and extension services. Variable expenses (VE) for the production of fresh larvae include labour, feed, utilities, and health expenses. Expenses for purchase of young larvae were not included in profitability calculations as most farms largely controlled the reproduction process themselves. Labour was accounted for under VE as the needs increase with production volumes. To account for unpaid labour, the labour expenses per FTE\(^2\) for hired labour have been used to estimate expenses for own and family labour.

The expected annual cash flow per tonne fresh larvae production in year \( t \) (CF\(_ t \)) is given by

\[
CF_t = TR_t - NE_t - VE_t
\]

where NE represents the non-allocated expenses for marketing, quality, and accounting purposes, and, if applicable, rent for the buildings. Maintenance, taxation, and insurance expenses for buildings, cars, and other equipment were not available.

The NPV, then follows from

\[
NPV = -INV + \sum_{t=0}^{t=T} \frac{CF_t}{(1 + r)^t}
\]

where INV are the initial investments for buildings and installations, machinery, and other assets at \( t = 0 \), and \( r \)

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1 T. molitor will be further indicated as “mealworm”.

2 One FTE refers to one working week of 40 hours for 52 weeks in a year.
is the discount factor. For farms that did not have investments for own buildings, only investments for machinery and other assets were considered in the calculation. The rent paid for the building was counted as an expense in NE. Cash outflows and inflows were assumed to be constant over time as the information available was insufficient to estimate future yields, sales prices, and expenses. A discount factor (r) of 10% was used to account for inflation, risk, and interest. The NPV was calculated over an investment period of 20 years (T).

3 Materials and methods

Data collection through structured interviews
Farm economic data were collected through farm interviews as accountancy data were not available for small scale mealworm farms in the Netherlands. Through semi-structured interviews with commercial mealworm rearers operating in the Netherlands we obtained quantitative technical and economic farm data. A data collection sheet for rearers was predesigned by the two interviewing researchers based on literature (Blanken et al., 2021; Veldkamp et al., 2021). Three experts (two from research and one from the industry) reviewed the sheet prior to the data collection to ensure the correct interpretation of variables. The data collection sheet was designed in Dutch.

Contact details of potential participants were obtained via professional networks of the authors. Insect rearers (n = 25) were invited via e-mail and afterwards contacted by phone to confirm participation. Ten rearers agreed to participate: three rearers focussed primarily on reproduction and seven primarily on rearing. Others did not respond to the invitations or indicated they “did not feel confident to participate”. Participants received a shortened version of the data collection sheet in preparation to the interview. The majority of the interviews were conducted on-site by two researchers, one as interviewer and one as notetaker. Consent was signed and a short explanation on the procedure was given at the start of the interview. The interview then followed the structure of the data collection sheet, but if needed the order was adjusted. During the interviews, additional clarifying questions were posed where necessary. Questions which could not be answered were marked as unanswered.

Data collection sheet for farm interviews
The data collection sheet for farm interviews consisted of five parts. In the first part, rearers were asked to introduce their farm and share their vision on the Dutch mealworm sector. The second part aimed to collect quantitative and qualitative information about the farm and its operations, mainly on the activities carried out on the farm, amount of labour (hired and unpaid) expressed in Full Time Equivalent (FTE), and annual labour expenses. The third part comprised questions on the technical details, revenues, and expenses related to the production of larvae, assessing first the type and amount of feed needed annually, the length of one production round, and the volume of fresh larvae produced annually. Furthermore, the revenues from sales of fresh larvae and frass, and additional offered extension services, i.e. education, consultancy, and research participation, were registered. In this part the annual expenses for insect eggs or young larvae, dry and wet feed, insect health, and utilities were assessed as well. In the fourth part of the data collection sheet, rearers were asked to list all investments in buildings, machinery, and other assets. If buildings were rented (not owned), the annual rent was recorded. In the fifth part, other expenses such as those related to administration, marketing, and quality as well as car expenses were collected. Rearers were also given the opportunity to add other expenses, if any, not included in those listed above.

Data analysis
For quantitative variables, the ranges (minimum and maximum values) were calculated. The technical and economic farm values, including the calculated GM and NPV, are presented in unit per tonne production. Averages could not be calculated due to the large heterogeneity across farms in the obtained data. Since farm specific data cannot be displayed for anonymity reasons, the values have been categorised per variable which are displayed as frequency distributions in the form of histograms in the Supplementary Material. This categorisation was only done for variables which were expressed in unit per tonne production to safeguard anonymous presentation of results. The total number of responses (sample numbers, n) differs per variable, as not all rearers could provide all the requested data. For one farm we could not calculate GM and NPV. Preliminary quantitative results (ranges of all technical and economic variables) were reviewed by one expert from research to ensure that no result could be traced back to a single mealworm farm. These preliminary results were then compiled and evaluated in a group discussion with six rearers (participants of this research) to verify whether the ranges are representative of actual practices. Additional qualitative information on farm operations and
the insect sector were used for further interpretation of the data.

4 Results

In this section we show the technical and economic results. There is substantial variation between the farms in our sample, as illustrated by the minimum and maximum values. As both the insect sector in the Netherlands and the sample in our study are relatively small, it is difficult to elaborate on the exact reasons for these (at times) large differences without identifying a specific farm. We therefore discuss causes of variation in a more generic way.

**Technical results of mealworm farms**

The mealworm farms in our sample \((n = 7)\) produced between 28.60 and 62.40 tonne fresh larvae annually (Table 1, Supplementary Figs S1-S5). For most rearers, mealworm production was the main operation and source of income. In addition to rearing activities, the majority of the rearers also (partially) managed the reproduction process. Per tonne production, total labour requirements ranged between 0.02 and 0.14 FTE (Table 1, Supplementary Figs S1-S5) of which a maximum of 71% was classified as own and family labour. The majority – between 66% and 100% – of total labour was on the direct care of larvae. For reproduction, direct care activities included the weekly replacement of beetles, transferring eggs into small crates, and feeding the young larvae. Rearing activities entailed setting up crates with young larvae and feeding, harvesting, and sieving these larvae during the remainder of their life cycle. Indirect care activities, which accounted for a maximum of 34% of the required labour time, included administration, transport, marketing, and sales of mealworms.

The reproduction and rearing of mealworms took place, where possible, under controlled climate conditions (such as temperature and humidity) in designated breeding cells. The methods applied on the different farms were largely similar and most operations were carried out manually. The two-week reproduction phase included the laying of eggs and their hatching into small mealworms. The reproduction and rearing processes were continuous and most rearers applied a weekly set-up (placing the 14-day old larvae on the substrate in a breeding crate) and harvesting schedule. The majority of rearers followed a feeding schedule of dry feed once a week, and wet feed three times a week. Dry feed consisted of a grain-based mixture, and shredded carrots were mainly used as wet feed. The feed conversion ratios, i.e. the intake of dry matter per kilogram of wet weight gain of fresh larvae, ranged from 1.72 and 1.96 (Table 1, Supplementary Figs S1-S5). During harvest, the content of the crates was sieved to separate mealworms from the frass; there was no on-site processing at the time of the interviews. Alive fresh larvae were preferably transported on the day of harvesting as the maximum storage time of fresh larvae under cooled conditions is three days. Fresh larvae were destined for the petfood market and transported to customers in crates, preferably refrigerated. A few rearers were exploring the opportunities to sell their produce on the human food market.

### Table 1  Technical results of mealworm farms in the Netherlands

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production volume and labour</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual production volume</td>
<td>Tonne fresh larvae/year</td>
<td>28.60</td>
<td>62.40</td>
<td>7</td>
</tr>
<tr>
<td>Labour per farm</td>
<td>FTE(^1)</td>
<td>0.60</td>
<td>5.00</td>
<td>7</td>
</tr>
<tr>
<td>Hired labour</td>
<td>FTE(^1)</td>
<td>0.65</td>
<td>4.50</td>
<td>7</td>
</tr>
<tr>
<td>Own and family labour</td>
<td>FTE(^1)</td>
<td>0.00</td>
<td>3.00</td>
<td>7</td>
</tr>
<tr>
<td>Labour per tonne</td>
<td>FTE(^1)/tonneproduction</td>
<td>0.02</td>
<td>0.14</td>
<td>7</td>
</tr>
<tr>
<td>Direct care</td>
<td>% of total FTE(^1)</td>
<td>66</td>
<td>100</td>
<td>6</td>
</tr>
<tr>
<td>Indirect care</td>
<td>% of total FTE(^1)</td>
<td>0</td>
<td>34</td>
<td>6</td>
</tr>
<tr>
<td><strong>Feed input</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry feed</td>
<td>Tonne input/tonneproduction</td>
<td>1.67</td>
<td>1.76</td>
<td>6</td>
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<tr>
<td>Wet feed</td>
<td>Tonne input/tonneproduction</td>
<td>1.70</td>
<td>3.59</td>
<td>6</td>
</tr>
<tr>
<td>Feed conversion ratio(^2)</td>
<td></td>
<td>1.72</td>
<td>1.96</td>
<td>6</td>
</tr>
</tbody>
</table>

\(^1\) One FTE refers to one working week of 40 hours for 52 weeks in a year; \(^2\) Feed conversion was calculated as kilogram intake of dry matter per kilogram wet weight gain of fresh larvae, assuming that dry feed consists of approximately 90% and carrots of 11% dry matter.

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### Table 2 Economic results of mealworm farms in the Netherlands per tonne of fresh larvae production

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildings and installations</td>
<td>EUR/tonne production</td>
<td>2,159</td>
<td>6,817</td>
<td>3</td>
</tr>
<tr>
<td>Machinery and other assets</td>
<td>EUR/tonne production</td>
<td>841</td>
<td>4,747</td>
<td>6</td>
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<tr>
<td><strong>Non-allocated expenses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Administration, marketing, and quality</td>
<td>EUR/tonne production</td>
<td>0</td>
<td>1,122</td>
<td>6</td>
</tr>
<tr>
<td>Rent of buildings</td>
<td>EUR/tonne production</td>
<td>58</td>
<td>769</td>
<td>4</td>
</tr>
<tr>
<td><strong>Variable expenses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young larvae</td>
<td>EUR/tonne target produce</td>
<td>1,000</td>
<td>1,980</td>
<td>6</td>
</tr>
<tr>
<td>Dry feed</td>
<td>EUR/tonne production</td>
<td>638</td>
<td>883</td>
<td>6</td>
</tr>
<tr>
<td>Wet feed</td>
<td>EUR/tonne production</td>
<td>108</td>
<td>437</td>
<td>6</td>
</tr>
<tr>
<td>Hired labour</td>
<td>EUR/tonne production</td>
<td>400</td>
<td>1,282</td>
<td>6</td>
</tr>
<tr>
<td>Hired and own labour</td>
<td>EUR/tonne production</td>
<td>677</td>
<td>2,913</td>
<td>6</td>
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<tr>
<td>Utilities (energy, gas, water)</td>
<td>EUR/tonne production</td>
<td>42</td>
<td>225</td>
<td>6</td>
</tr>
<tr>
<td>Health (pest control and hygiene)</td>
<td>EUR/tonne production</td>
<td>0</td>
<td>90</td>
<td>6</td>
</tr>
<tr>
<td><strong>Revenues</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales of fresh larvae</td>
<td>EUR/tonne production</td>
<td>3,100</td>
<td>4,278</td>
<td>7</td>
</tr>
<tr>
<td>Frass</td>
<td>EUR/tonne production</td>
<td>0</td>
<td>28.85</td>
<td>7</td>
</tr>
<tr>
<td>Extension services</td>
<td>EUR/tonne production</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a</td>
</tr>
<tr>
<td><strong>Profitability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GM without accounting for own labour</td>
<td>EUR/tonne production</td>
<td>1,113</td>
<td>2,307</td>
<td>6</td>
</tr>
<tr>
<td>GM after deducting “expenses” for own labour</td>
<td>EUR/tonne production</td>
<td>-180</td>
<td>2,030</td>
<td>6</td>
</tr>
<tr>
<td>NPV without accounting for own labour</td>
<td>EUR/tonne production</td>
<td>-7,281</td>
<td>17,893</td>
<td>6</td>
</tr>
<tr>
<td>NPV after deducting “expenses” for own labour</td>
<td>EUR/tonne production</td>
<td>-12,359</td>
<td>15,535</td>
<td>6</td>
</tr>
</tbody>
</table>

1 n.a. = not applicable because of too few observations.

**Economic results of mealworm farms**

*Investments* differed between farms (Table 2, Supplementary Figs S6-S21). For *machinery and assets*, this variation was related to the purchase of new or second-hand material of varying quality. The main types of *machinery* used were carrot shredders, crate washing machines, sieves in various types and sizes to separate the mealworms from the frass, and forklifts. *Other assets* comprised climate control chambers, cooling systems, crates, and trolleys. *Non-allocated expenses* reported were those for *administration, marketing, and quality purposes*. The difference between the minimum and maximum value for these expenses was mainly caused by reporting differences.

The revenue streams originated from *sales of fresh larvae* and *frass*, as well as from the provision of *extension services* (Table 2, Supplementary Figs S6-S21). The large variation in *revenues* resulted from different *sales prices* for fresh larvae. Larvae were commonly sold in larger quantities for the petfood market. Rearers with longer rearing experience and presence in the sector had larger networks and appeared to have more bargaining power in sales price negotiations. *Revenues from frass* were not substantial, and some rearers did not receive any monetary compensation for frass which was partly due to the strict hygiene requirements for the (commercial) use of frass as fertiliser. The *revenues for extension services* are not specified in Table 2 and Supplementary Figs S6–for reasons of anonymisation, but are included in the *total revenues*.

The main *variable expenses* included those for *labour, feed, utilities, and health maintenance* (Table 2, Supplementary Figs S6-S21). *Young larvae* (approximately 2 weeks old) were occasionally bought – e.g. when the volumes of young larvae from own reproduction were insufficient – at prices between 1.00 and 1.96 EUR/kilogram of fresh larvae target produce. Rearers indicated that at the time of the interview, it was more costly to buy young larvae externally than doing the reproduction in-house, yet it comes with a trade-off. On the one hand, the external purchase of young larvae entailed risks such as deviating larvae quality as well as...
the introduction of transmission of pests and diseases. On the other hand, the reproduction process is labour intensive, requiring advanced expertise. Labour and feed were the two largest variable expenses, also showing a high variation between farms. The large range (from 771 to 1,217 EUR/tonne production) for total expenses for feed resulted from differences in the amount of feed per tonne production (see Table 1, Supplementary Figs S1-S5) as well as varying availability and quality of wet feed. The large spread in labour expenses was related to the substantial difference between the amount of labour used per tonne production, from 0.02 to 0.14 FTE (Table 1, Supplementary Figs S1-S5). In addition, it was common for mealworm rearers to work with cheaper labour: employees with “a distance to the labour market”, who have difficulties qualifying for a regular job, but are often good at performing routine work. Further variable expenses included those for utilities, in particular the electricity used for climate control and to a small extent gas use. The total water use was low as water was only used for cleaning the rearing crates and not recorded by farmers. Expenses for larvae health included pest control (moths) and maintenance of good hygiene in the facility. Expenses for disease prevention and treatment were not included in this category, as there were – according to participating rearers – no prevalent diseases for mealworms. Total variable expenses amounted to ranges between 1,693 and 2,444 EUR/tonne production and between 1,836 and 4,430 EUR/tonne production, with the first values not corrected and the second ones being corrected for unpaid (own and family) labour.

The NPV was negative before and after labour correction for three farms, and positive for two farms. For one farm the NPV turned into a negative value after labour correction. Farms with the lowest NPVs were characterised by both high investments and a relatively low GM due to lower sales prices of larvae. Those with a higher NPV mostly had relatively low investments and/or higher cashflows resulting from higher sales price of larvae and low variable expenses.

5 Discussion and conclusions

In the current study, we analysed profitability for small scale mealworm farms in the Netherlands with annual production volumes between 28.60 and 62.40 tonne fresh larvae. Production set-ups were largely similar and most rearers managed both the reproduction and rearing processes. Technical results showed large variations in labour requirements, wet feed input, and feed conversion rates. Economic results (initial investments, non-allocated and variable expenses) showed a large spread for nearly all elements of farm profitability. GM and NPV were calculated with and without accounting for own and family labour. In the latter situation, i.e. without accounting for the family hours spent, 3 out of 6 farms exhibited a positive NPV value. The large heterogeneity among farms was mainly related to the investment approach (new or second hand), fresh larvae sales prices, as well as feed and labour expenses. Comparing our GM range, i.e. from –180 to plus 2,030 EUR/tonne production of fresh larvae, with the feed and labour margins presented in Niyonsaba et al. (2021) of 7,620 to 13,770 EUR/tonne production, we find that these large differences are mainly rooted in the additional cost components we included in the gross margin and in different sales prices in the current study. Sales prices in the current study refer to farm-gate prices, whereas in Niyonsaba et al. (2021) these refer to market prices mostly in different European countries.

The negative NPV for four farms suggests that most insect farms are not profitable based on current investments, expenses, and revenues. A number of considerations should be taken into account when interpreting the NPV values. First, most farms rely on a relatively high share of own and family labour, which has been corrected for to allow for farm-to-farm comparisons. In reality, this labour is often unpaid, which may enable insect rearers to sustain production, even with low profitability. Second, farms with higher NPVs mostly had relatively low-cost investments. If such farms want to stay in the mealworm business, they probably have to invest in due term, while farms who already made more expensive investments (currently resulting in a lower NPV) are ready to scale up, likely leading to higher revenues and lower expenses. Third, the assumption of constant cash flows over the coming 20 years was based on a lack of information. In fact, market developments could lower future sales prices when production volumes increase, but prices could also rise as a result of increased demand. In addition, 2022 peaking feed and energy prices also illustrated that cash flows may actually differ over the years.

To increase the viability of mealworm farms, rearers would benefit from selling their larvae in niche markets in which they could potentially sell at higher prices. Rearers believed that sale prices are higher on the food market in particular. Enhancing consumer acceptance to insects and derivatives could aid to increase demand on the food market (Alhujaili et al., 2023).
Additional revenue streams, such as offering extension services, could also increase the viability of the business model in the future. Revenues from frass may only substantially add to total revenues if its valuation for commercial sales increases. Insect frass is considered a promising alternative fertiliser, but the required sanitising treatment could eliminate its beneficial effect and therefore its commercial promotion and value (Poveda, 2021). To reduce variable expenses, feed and labour expenses require attention. Using side streams as a feed source could for instance provide opportunities for rearers to reduce feed expenses. However, the use of these streams as substrates poses challenges including constraints in European legislation, their applicability in terms of insects’ dietary requirements, length of development cycle, variable quality, and their local availability (Ites et al., 2020; van Peer et al., 2021). Additionally, it is expected that with the move towards more circular agricultural activities, the demand for these waste streams will increase, as will their price (van Huis, 2022). Hall et al. (2021), Niyonsaba et al. (2021), and Yang and Cooke (2020) already recognised that insect farming based on manual activities is labour-intensive. Investing in mechanisation may reduce labour expenses, give opportunities to increase production volume, and decrease the cost price per unit due to economies of scale and scope (Hall et al., 2021; Rumpold and Schlüter, 2013). However, since market demand is still relatively low and unstable, high capital investments are perceived as a high financial risk (Niyonsaba et al., 2023).

The main limitation of this study is the small and heterogeneous sample. The emerging nature of the mealworm sector, and the lack of standardisation in terms of for instance production processes, quality, and end-products could explain the observed heterogeneity. The small and heterogeneous sample limits the informative value of the calculated ranges as a benchmark. Despite these constraints, our sample reflects the realities of the sector and can serve as an indicative benchmark. This was confirmed by rearers during and after the group discussion on preliminary results of this work. Furthermore, our sample included only small-scale farms (FTE < 5). As such, the results cannot be considered representative for the whole mealworm sector in the Netherlands (the sector comprises 25-30 mealworm farms), in which also a few larger scale insect farms operate. In addition, rearers currently do not separate expenses for reproduction and rearing processes, which prevents a comparison of external purchase and in-house reproduction. The inclusion of more and also larger farms would allow to make this separation and would provide valuable insights in the profitability potential of new business models, e.g. a decentralised model, in which reproduction and rearing are separated in specialised farms. Despite these limitations, our results provide the first important insights into mealworm and other insect farms’ profitability. Extending the results to production of multiple insect types such as H. illucens, A. domesticus, and L. migratoria which follow different production systems and need different investments, will aid in the comparison of profitability between the different insect types.

The results of the current study aid in decision making for investors, credit providers, and other service companies, for instance as a benchmark in credit provision or insurance schemes design. The overview of technical and economic ranges provides these parties both insights in farm operations and estimates of the profitability of mealworm farms. The results further serve as a benchmark for mealworm rearers to guide them in making investment decisions or business model adjustments to increase profitability. Considering the high labour expenses, support through policy interventions could prioritise on subsidising mechanisation. Interventions should also focus on standardising for instance the insect rearing methods and quality of output. This will not only affect the uniformity of production processes, but also positively impact the consistency in quantity and quality of supply, which would further benefit actors downstream in the supply chain. Discussions with the participants revealed a strong need for chain coordination to increase the viability of mealworm farms, for instance when it comes to the facilitation of sales on the food market. Governmental agencies could play a role in promoting insects for food to stimulate the demand for insect-based products.

Supplementary material

Supplementary material is available online at: https://doi.org/10.6084/m9.figshare.24581595

Acknowledgements

This work was supported by the Dutch Ministry of Agriculture, Nature and Food Quality under Grant BO-43-111-040-WLR and the European project SUSINCHAIN, funded under Horizon 2020 under Grant num-
The authors kindly thank all experts and insect rearers who participated in the interviews.

**Conflicts of interest**

The authors declare no conflict of interest.

**References**


