Accepted Manuscript

Microbial counts of mealworm larvae (*Tenebrio molitor*) and crickets (*Acheta domesticus* and *Gryllobates sigillatus*) from different rearing companies and different production batches

D. Vandeweyer, S. Crauwels, B. Lievens, L. Van Campenhout

PII: S0168-1605(16)30595-5
DOI: doi:[10.1016/j.ijfoodmicro.2016.11.007](https://doi.org/10.1016/j.ijfoodmicro.2016.11.007)
Reference: FOOD 7446

To appear in: *International Journal of Food Microbiology*

Received date: 13 June 2016
Revised date: 20 October 2016
Accepted date: 7 November 2016

Please cite this article as: Vandeweyer, D., Crauwels, S., Lievens, B., Van Campenhout, L., Microbial counts of mealworm larvae (*Tenebrio molitor*) and crickets (*Acheta domesticus* and *Gryllobates sigillatus*) from different rearing companies and different production batches, *International Journal of Food Microbiology* (2016), doi:[10.1016/j.ijfoodmicro.2016.11.007](https://doi.org/10.1016/j.ijfoodmicro.2016.11.007)

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

**Microbial counts of mealworm larvae (*Tenebrio molitor*) and crickets
(*Acheta domesticus* and *Gryllodes sigillatus*) from different rearing
companies and different production batches**

Vandeweyer^{a, c, *}, D., Crauwels^{b, c}, S., Lievens^{b, c}, B. & Van Campenhout^{a, c}, L.

^a KU Leuven, Department of Microbial and Molecular Systems (M²S), Lab4Food, Technology Campus Geel, B-2440 Geel, Belgium

^b KU Leuven, Department of Microbial and Molecular Systems (M²S), Laboratory for Process Microbial Ecology and Bioinspirational Management (PME & BIM), Technology Campus De Nayer, B-2860 Sint-Katelijne-Waver, Belgium

^c KU Leuven, Leuven Food Science and Nutrition Research Centre (LFoRCe), B-3001 Leuven, Belgium

**Corresponding author:* Dries Vandeweyer, Lab4Food, KU Leuven, Technology
Campus Geel, Kleinhoefstraat 4, B-2440 Geel. Phone: +32 14 56 23 10. E-mail:
dries.vandeweyer@kuleuven.be.

ACCEPTED MANUSCRIPT

Abstract

The rising interest in insects for human consumption and the changing regulations in Europe require a profound insight into the food safety of insects reared and sold in Western society. The microbial quality of edible insects has only been studied occasionally. This study aimed at generating an overview of intrinsic parameters (pH, water activity and moisture content) and microbial quality of fresh mealworm larvae and crickets for several rearing companies and for several batches per rearer. In total, 21 batches obtained from 7 rearing companies were subjected to analysis of intrinsic parameters, a range of plate counts and presence-absence tests for *Salmonella* spp. and *Listeria monocytogenes*. The microbial counts of the fresh insects were generally high. Different rearing batches from a single rearing company showed differences in microbial counts which could not be explained by variations in intrinsic properties. The largest variations were found in numbers of bacterial endospores, psychrotrophs and fungi. *Salmonella* spp. and *L. monocytogenes* were not detected in any of the samples. Altogether, our study shows that large variations were found between batches from individual rearers. As a consequence, no overall differences between rearers could be observed.

Key words

Edible insects, mealworm larvae, crickets, pH, water activity (a_w), microbial counts

1. Introduction

Interest in human consumption of edible insects (entomophagy) in Western countries is increasing (Caparros Megido et al., 2014; Mlcek et al., 2014) and more and more insect-based food products are being marketed. Compared with Asian, African, Oceanian and Latin American regions, Western society has no history of insect consumption (Siemianowska et al., 2013; van Huis, 2013; van Huis et al., 2013; Yen, 2015). However, insects are a promising and valuable alternative to conventional protein sources such as meat. They provide an opportunity to meet the increased protein demand of the growing world population (Mlcek et al., 2014; Premalatha et al., 2011; van Huis et al., 2013). Moreover, rearing insects for food has a smaller ecological footprint compared to traditional animal husbandry (Oonincx and de Boer, 2012; Oonincx et al., 2010; van Huis et al., 2013).

Insects will be considered as Novel Food in Europe starting from January 2018, as stated in the new Regulation (EU) 2015/2283 on novel foods. Hence, more research data on the microbial quality of edible insects reared in Europe are necessary to support risk assessments performed by the European Food Safety Authority (EFSA) (Belluco et al., 2013). Additionally, more quantitative data concerning the microbial quality will be needed in order to establish microbial criteria for edible insects in the future, similar to existing criteria for other food products (Regulation (EC) N° 2073/2005 on microbiological criteria for foodstuffs).

Presently, the nutrient composition of several insect species has already been studied extensively (Finke, 2002; Nowak et al., 2016; Rumpold and Schlüter, 2013a; Sánchez-Muros et al., 2014; Siemianowska et al., 2013). Microbiological data, however, are only scarcely available, as highlighted in a recent EFSA opinion (EFSA Scientific

Committee, 2015). Moreover, the few studies available containing microbiological data (Giaccone, 2005; Grabowski et al., 2014; Klunder et al., 2012; Rumpold et al., 2014) do not include analyses of different production batches or insects from different rearing companies. So far, there is only one study including different production batches (Stoops et al., 2016), but they originate from only one rearing company. None of the studies available contain data on intrinsic properties of edible insects, such as pH and water activity (a_w), although those factors have an important impact on the growth and survival of micro-organisms (Madigan et al., 2009) and need to be taken into account when considering insects as a food matrix.

The objective of this study is to investigate the microbial load and intrinsic properties of fresh mealworm larvae (*Tenebrio molitor*) and crickets (*Acheta domesticus* and *Gryllobates sigillatus*) as a food product. In order to obtain a generalized view, different production batches and rearing companies were included in the study. pH, moisture content and a_w were determined, as well as a range of plate counts and presence-absence tests for pathogens typically determined for foods.

2. Material and methods

2.1 Study materials

Three insect species commonly reared for human consumption were investigated: *Acheta domesticus* (house cricket), *Gryllobates sigillatus* (banded cricket) and larvae of *Tenebrio molitor* (mealworm). Samples were obtained from seven rearing companies in Belgium and the Netherlands, including five companies specialized in rearing for human consumption and two companies for pet food. For each company, three production batches (i.e. rearing cycles) were sampled between March and

December 2015, resulting in 21 batches studied, consisting of 12 mealworm and 9 cricket batches (Table 1).

2.2 Sampling and sample preparation

Samples of fully grown and living insects ready for consumption were transported to the laboratory at ambient temperature and immediately processed upon arrival. Prior to analysis, insects were sedated by cooling ($\pm 4\text{ }^{\circ}\text{C}$, 1 h). Subsequently, three subsamples of 30 g were taken aseptically from each batch and pulverized (Bosch CNHR 25, max speed) as described previously (Stoops et al., 2016).

2.3 Intrinsic properties

All subsamples were subjected to measurements of pH, water activity (a_w) and moisture content. pH was measured in threefold using a digital pH meter (Portamess 911, Knick, Berlin, Germany with SI analytics electrode, Mainz, Germany). A single a_w measurement was performed on a 7 g aliquot of each subsample using a water activity meter (LabMaster a_w , Novasina, Lachen, Switzerland), until water activity and temperature ($20\text{ }^{\circ}\text{C}$) were stable for 15 and 5 min, respectively. Moisture content was calculated from the weight loss of 2 to 3 g from each subsample after oven-drying overnight at $105\text{ }^{\circ}\text{C}$.

2.4 Microbial plate counts

Since it was not clear whether pulverization of the insects before homogenization would affect microbial counts, a preliminary experiment was executed. Several counts (mesophilic aerobic count, aerobic endospores and Enterobacteriaceae,

see below) were determined using a procedure with and without pulverization (as described in paragraph 2.2). Both approaches were performed on five subsamples of a mealworm sample obtained from company 4 (Table 1). Because pulverization was found to be necessary for optimal extraction of micro-organisms from their matrix (see paragraph 3.1), the step was included in all further analyses.

To obtain a primary dilution, 5 g of each pulverized subsample and 45 g of peptone physiological salt solution (PPS, 0.85% NaCl, 0.1% peptone, Biokar Diagnostics, Beauvais, France) were mixed together in a stomacher bag. After homogenization for 60 s in a Bagmixer® (Interscience, Saint Nom, France), a tenfold dilution series was prepared and plated using the pour-plate technique, according to the ISO standards assembled by Dijk et al. (2015). Bacterial endospores and yeasts and moulds were determined according to Dijk et al. (2007). Total viable mesophilic and psychrotrophic aerobic counts were assessed after aerobic incubation on Plate Count Agar (PCA, Biokar diagnostics) for respectively 72 h at 30 °C and 10 days at 6.5 °C. Lactic acid bacteria (LAB) were incubated on de Man, Rogosa & Sharpe agar (MRS, Biokar diagnostics) for 72 h at 30 °C, Enterobacteriaceae on Violet Red Bile Glucose agar (VRBG, Biokar diagnostics) for 24 h at 37 °C, and yeasts and moulds on Oxytetracycline Glucose Agar (OGA, Biokar diagnostics) supplemented with oxytetracycline (50 mg/550 ml OGA, Biokar diagnostics) for 5 days at 25 °C. Aerobic bacterial endospores were determined on PCA for 24 h at 37 °C after a pasteurisation treatment of the 10^{-1} dilution at 80 °C for 10 min.

2.5 Pathogen detection

Pulverized samples were also used for detection of *Salmonella* spp. and *Listeria monocytogenes*. Detection of *Salmonella* spp. was performed according to ISO 6579 (absence in 25 g) and detection of *Listeria monocytogenes* according to AFNOR BRD 07/4-09/08 (absence in 25 g). A single analysis was performed for all but two samples (one mealworm sample, one cricket sample), which were analysed in fivefold as described in Regulation (EC) N° 2073/2005 on microbiological criteria for foodstuffs..

2.6 Statistics and multivariate analysis

To determine statistical differences between production batches of individual rearing companies, between different rearing companies, and between the different insect types studied, data were analysed with SPSS Statistics 20 (IBM, New York, USA). To determine significant differences in intrinsic factors and microbial counts between rearing companies and between batches, One-way Kruskal-Wallis analysis was used, followed by a multiple comparison using the Dunn-Bonferoni Post-Hoc test. For the Kruskal-Wallis tests, a distinction between weakly significant ($0.05 < p < 0.10$) and significant ($p < 0.05$) was adopted. Mann-Whitney U tests were performed to analyse differences between mealworm larvae and crickets, with a level of significance of 0.05. In the preliminary experiment comparing pulverized and non-pulverized subsamples, an Independent-Samples T-test with significance level 0.05 was used. Additionally, all data (means) from intrinsic and microbiological parameter analyses were used to perform multivariate non-metric multidimensional scaling (NMDS) to visualize differences between batches, rearing companies and insects. Batches lacking one or more

parameters were excluded from this analysis. The NMDS plot was created using the vegan package in R (v12.2.1) (Oksanen et al., 2012; R Development Core Team, 2006).

3. Results and discussion

3.1 *Intrinsic properties and microbial counts*

With total mean pH values of 6.7 and 6.4 for mealworm larvae (Table 2) and crickets (Table 3) respectively, a near-neutral pH was observed for both insect types. Together with a high mean water activity of 0.96 for both insect types, the new food matrices can be considered as well-suitable for the growth of a broad range of micro-organisms. It should be noted that these values only apply for the insect as a crushed matrix and can differ from the intrinsic properties of individual parts. Therefore, conclusions on the distribution and growth rates of micro-organisms within the different parts (e.g. surface *versus* intestinal tract) of the insect cannot be made based on the data presented here.

The preliminary experiment investigating the importance of pulverization demonstrated that microbial counts obtained from non-pulverized mealworm larvae are an underestimation of the total amount of countable micro-organisms. With mean values of 7.0 ± 0.2 (standard error of the mean) log cfu/g for total aerobic count, 2.5 ± 0.2 log cfu/g for aerobic endospores and 5.9 ± 0.2 log cfu/g for Enterobacteriaceae, counts from non-pulverized mealworms were strongly significantly lower ($p = 0.000$ for all counts) than those obtained from pulverized larvae (8.6 ± 0.1 , 4.7 ± 0.1 and 7.7 ± 0.1 log cfu/g respectively). Pulverizing insects as a first step in microbial analysis thus resulted in counts that are 1.6 to 2.2 log cycles higher.

Average counts for mealworm larvae and crickets were generally high (Table 4), with total counts of at least 8 log cfu/g for all samples. For mealworm larvae, Klunder et al. (2012) found 7.7 log cfu/g for total viable count, 6.8 log cfu/g for Enterobacteriaceae and 2.1 cfu/g for bacterial spores in a single sample analysis. Those values are lower than the averages obtained in this work (see Table 4: 8.4, 7.4 and 3.1 log cfu/g). That can be explained by the fact that insects were not pulverized in the study of Klunder et al. (2012), likely resulting in an incomplete extraction of countable micro-organisms from the matrix. A complete recovery during analysis is of utmost importance as insects are consumed or processed into foods as a whole, i.e. without prior removal of the intestines. The same remark can be made for the data obtained from the cricket sample by Klunder et al. (2012). Sample preparation in Stoops et al. (2016), however, was done the same way as in our study and their values for total viable count, LAB, Enterobacteriaceae, and yeasts and moulds of mealworm larvae are highly comparable to the data obtained in this work.

Psychrotrophic counts were never investigated before on edible insects, although it is an important parameter regarding chilled conservation of edible insects. Crickets contained on average 4.5 log cfu/g psychrotrophic organisms, but the average for mealworm larvae was 6.6 log cfu/g (Table 4), with some batches even up to 9.1 log cfu/g (Table 2). That might involve a risk of spoilage in a chilled environment as well as the outgrowth of psychrotrophic pathogens such as *L. monocytogenes* (which was not detected in this study though, see Paragraph 3.5) or *Bacillus cereus* (Hwang and Tamplin, 2005; Martínez et al., 2007).

3.2 Variation between batches of individual rearing companies

Although insects are generally reared using established protocols, variation between batches from the same company was commonplace (Fig. 1), especially for bacterial endospores, psychrotrophic counts, and yeasts and moulds (Table 2 and 3). By contrast, variation in intrinsic properties was only marginal (Table 2 and 3), suggesting that the differences in microbiological parameters are caused by other variables such as feed supply and/or rearing practices. For example, mealworm larvae batches from company 1 showed a significantly lower endospore count ($p = 0.039$) and a higher number of psychrotrophs (weakly significant, $p = 0.055$) for one particular batch (MW 1.3) compared to the other two batches. Furthermore, company 3 produced a mealworm batch (MW 3.3) which showed significantly higher counts than the other two for almost all microbial parameters ($p = 0.027$ for total aerobic count, Enterobacteriaceae, psychrotrophs, yeasts and moulds). That was in line with deviating visual (moister) and olfactory (staler odour) observations for this sample. Additionally, batches MW 3.1 and MW 3.2 differed from each other, numerically but not significantly, in counts for psychrotrophs and yeasts and moulds (Table 2). The findings on the overall variation are in agreement with Stoops et al. (2016), who particularly found variation in the number of bacterial endospores, ranging from not detected ($< 1.0 \log \text{ cfu/g}$) to $3.5 \log \text{ cfu/g}$. In our study, spore counts even ranged from 1.7 to $5.0 \log \text{ cfu/g}$ over all samples investigated.

Similar observations were made for crickets (Table 3; Fig. 1). For example, for company 5, batch CR 1.3 diverged from the other batches, mainly for the yeast and mould count ($p = 0.044$). The insects from batch CR 1.3 were younger (subadult) than those from the other two batches, which may have influenced their microbiota (Yun et al., 2014). Further, batch CR 2.2 from company 6 was different from the other two

batches, particularly for its low amount of psychrotrophs (around or below detection limit) ($p = 0.044$) and the high number of yeasts and moulds (not significant). Company 7 provided samples which were particularly different in the amount of psychrotrophs (weakly significant, $p = 0.077$) and yeasts and moulds ($p = 0.027$). The highest amount of yeasts and moulds was observed in batch CR 3.3, which may be related to the (slightly) lower water activity measured (Madigan et al., 2009).

3.3 Variation between rearing companies

Large differences between different insect batches from each individual company resulted in large standard errors of the mean and hence few statistically significant differences between rearing companies. For mealworm larvae (Table 2; Fig. 1), only (weakly) significant differences between companies were found for the moisture content (ranging between 61.6 and 66.9 %, $p = 0.051$) and the number of bacterial endospores (mean values between 2.3 and 3.9 log cfu/g, $p = 0.059$). Nevertheless, water activity has more impact on microbial growth in foods than moisture content and those values were highly comparable between companies ($p = 0.861$). The moisture content and the water activity of insects are a result of the relative air humidity in the rearing environment, the presence or absence of water supply and the moisture content of the feed. Mealworm larvae are typically provided with water by offering a moist food product, such as carrots or apples. The varying bacterial endospore load may be reflected by differing endospore numbers in the feed, but this remains to be investigated. Notably, microbial parameters for the two companies rearing mealworm larvae for pet food (company 3 and 4; Table 2) did not differ significantly from those for the companies rearing for human consumption

(company 1 and 2). However, psychrotrophs and yeasts and moulds show slightly higher counts for the former.

For crickets (Table 3; Fig. 1), similar trends were observed. More specifically, our data indicate a weakly significant difference ($p = 0.061$) between different companies in bacterial endospore counts (ranging from 2.8 to 4.1 log cfu/g). Soil, used as a substrate for crickets to lay their eggs, can be a major source of contamination for bacterial endospores (Klunder et al., 2012; Madigan et al., 2009). In contrast to the moisture content of mealworm larvae, the moisture content of crickets was similar among the different companies. Crickets are supplied with pure water instead of a moist food product and that may result in lower variations in moisture content. The cricket moisture content obtained in our study is comparable with findings in literature (Finke, 2002). Altogether, no significant differences in mean intrinsic properties or microbial counts were observed between the two cricket species *Acheta domesticus* (company 5 and 6) and *Grylloides sigillatus* (company 7).

Although the exact rearing history of the insect samples studied is unknown, some explanations for the observed differences can be formulated. Influencing factors are likely to be situated in the feed, the rearing environment and an (optional) starvation procedure (Jones et al., 2013; Yun et al., 2014). It is also plausible that rearing practices and hygiene measures may result in a company-specific “house flora”, which can also affect the insect microbiota (Li et al. 2016).

3.4 Variation between different insect types

When comparing data from mealworm larvae and crickets (Table 4; Fig. 1), pH, moisture content, psychrotrophic count and the amount of yeasts and moulds were

significantly different. The difference in pH was statistically significant ($p = 0.000$) but numerically rather small. In line with Finke (2002), crickets contained significantly ($p = 0.001$) more moisture (total mean value of 69.9 %) than mealworm larvae (64.4 %). The significant difference ($p = 0.001$) found for psychrotrophic counts might be due to a difference in starvation temperature. Furthermore, crickets show significantly higher results for the overall fungal counts than mealworm larvae ($p = 0.004$). Interestingly, mealworm larvae were dominated by moulds, whereas for crickets yeasts dominated the fungal biota. Correspondingly, mealworm larvae are generally fed with cereal products, while crickets are reared on very diverse substrates such as chicken or pig feed, organic vegetables and brewer's spent grain.

Altogether, our results show that crickets and mealworms should be considered as different food matrices in terms of intrinsic properties and microbial quality. Therefore, when reporting on the microbial quality of edible insects, it is important to distinguish between distinct insect types and not to report average values over several types or to pool samples of different types, as was done in the past (e.g. Giaccone, 2005; Grabowski et al., 2014).

3.5 Compliance with microbial criteria for foodstuffs

Many authors mention the possibility for insects to contain pathogenic micro-organisms such as *Bacillus cereus*, *Campylobacter* spp., *Clostridium* spp., *Salmonella* spp. and *Staphylococcus aureus* (Crippen et al., 2012; EFSA Scientific Committee, 2015; Giaccone, 2005; Mpuchane et al., 2006; Rumpold and Schlüter, 2013b; Rumpold et al., 2014; Stoops et al., 2016; Templeton et al., 2006; Zheng et al., 2012). Furthermore, edible insects harbour a large amount of Enterobacteriaceae, a bacterial

family containing foodborne pathogens. The Belgian Superior Health Council and the Federal Agency for the Safety of the Food Chain (SHC and FASFC, 2014) and the Dutch Food and Consumer Product Safety Authority (NVWA, 2014) both composed an opinion on food safety aspects of edible insects. The microbiological criteria referred to in those opinions are based on culture-dependent microbial counting, as is also the case for other food products described in Regulation (EC) N° 2073/2005 on microbiological criteria for foodstuffs. Both opinions refer to food safety criteria for *Salmonella*, *Listeria monocytogenes* and *Escherichia coli* for ready-to-eat meals, minced meat and live bivalve molluscs. The opinions suggest to use those criteria for edible insects, since no specific criteria for insects exist yet. That led to the screening of each batch on *Salmonella* spp. and *L. monocytogenes* in this work. Both pathogens were not detected (in 25 g) in any of the samples, which corresponds to the findings from Giaccone (2005) and Grabowski et al. (2014). Nevertheless, the recently updated circular from the Belgian FASFC states that products available on the market should still be periodically tested on the presence of pathogens *Salmonella* and *Listeria monocytogenes* (FASFC, 2016).

In addition to food safety criteria, the opinions proposed process hygiene criteria based on comparable food matrices, e.g. minced meat. All total viable counts obtained in this study (8.2 – 9.3 log cfu/g) strongly exceed the value for the low criterion ($m = 5.7 \log \text{cfu/g}$) for minced meat and even that for the high criterion ($M = 6.7 \log \text{cfu/g}$). The relevance of criteria for other foodstuffs for edible insects can be questioned, however, and the development of criteria specific for insects is desirable.

4. Conclusions

Our study provides a general view on the intrinsic properties and microbial counts of three edible insect species. Large variations in microbial counts between batches originating from a single rearer resulted in the variations between companies being smaller. Especially for aerobic bacterial endospores, aerobic psychrotrophic organisms, and yeasts and moulds, counts varied remarkably. Intrinsic properties of the insects, on the other hand, varied to a smaller extent and cannot explain the differences in microbial parameters completely. While culture-dependent analyses are very useful to quantify microbial loads and to compare counts with other food matrices or with microbiological criteria, further research using culture-independent methods is needed to reveal the composition of the edible insect microbiota and variations in the composition between batches and companies. In addition, further research is needed to explore the relation between rearing conditions, including hygiene, and the insect microbiota.

Acknowledgements

The authors thank all rearing companies who kindly provided insect samples and A. Borremans for her assistance in laboratory work. Funding: this PhD research was supported by Flanders Innovation & Entrepreneurship (VLAIO) [Project 141129].

References

- Belluco, S., Losasso, C., Maggioletti, M., Alonzi, C.C., Paoletti, M.G., Ricci, A., 2013. Edible Insects in a Food Safety and Nutritional Perspective: A Critical Review. *Compr. Rev. Food Sci. Food Saf.* 12, 296–313. doi:<http://dx.doi.org/10.1111/1541-4337.12014>

- Caparros Megido, R., Sablon, L., Geuens, M., Brostaux, Y., Alabi, T., Blecker, C., Drugmand, D., Haubruge, É., Francis, F., 2014. Edible Insects Acceptance by Belgian Consumers: Promising Attitude for Entomophagy Development. *J. Sens. Stud.* 29, 14–20. doi:<http://dx.doi.org/10.1111/joss.12077>
- Crippen, T.L., Zheng, L., Sheffield, C.L., Tomberlin, J.K., Beier, R.C., Yu, Z., 2012. Transient gut retention and persistence of *Salmonella* through metamorphosis in the lesser mealworm, *Alphitobius diaperinus* (Coleoptera: Tenebrionidae). *J. Appl. Microbiol.* 112, 920–926. doi:<http://dx.doi.org/10.1111/j.1365-2672.2012.05265.x>
- Dijk, R., Beumer, R., de Boer, E., Brinkman, E., van Dijk, J., Dijkstra, A., Uyttendaele, M., Stegeman, H., Veenendaal, H., van Woerden, M., 2007. Microbiologie van voedingsmiddelen: Methoden, principes en criteria, 4th ed. Noordervliet Media, Houten.
- Dijk, R., van den Berg, D., Beumer, R., de Boer, E., Dijkstra, A., Mout, L., Stegeman, H., Uyttendaele, M., in 't Veld, S., 2015. Microbiologie van voedingsmiddelen: Methoden, principes en criteria, 5th ed. MYbusinessmedia, Capelle aan den IJssel.
- EFSA Scientific Committee, 2015. Risk profile related to production and consumption of insects as food and feed. *EFSA J.* 2015 13, 60 pp. doi:<https://doi.org/10.2903/j.efsa.2015.4257>
- FASFC, 2016. Circular concerning the breeding and marketing of insects and insect-based food for human consumption.
- Finke, M.D., 2002. Complete nutrient composition of commercially raised invertebrates used as food for insectivores. *Zoo Biol.* 21, 269–285. doi:<http://dx.doi.org/10.1002/zoo.10031>
- Giaccone, V., 2005. Hygiene and health features of “minilivestock,” in: Paoletti, M.G.

- (Ed.), Ecological Implications of Minilivestock: Potential of Insects, Rodents, Frogs and Snails. Science Publishers, Inc., Enfield (NH), USA, pp. 579–598.
- Grabowski, N.T., Jansen, W., Klein, G., 2014. Microbiological status of edible insects sold as pet feed in Germany, in: Conference “Insects to Feed the World.” Wageningen University and Research Centre, Wageningen, The Netherlands.
- Hwang, C.-A., Tamplin, M.L., 2005. The influence of mayonnaise pH and storage temperature on the growth of *Listeria monocytogenes* in seafood salad. Int. J. Food Microbiol. 102, 277–85. doi:<http://dx.doi.org/10.1016/j.ijfoodmicro.2004.11.019>
- Jones, R.T., Sanchez, L.G., Fierer, N., 2013. A cross-taxon analysis of insect-associated bacterial diversity. PLoS One 8, e61218. doi:<http://dx.doi.org/10.1371/journal.pone.0061218>
- Klunder, H.C., Wolkers-Rooijackers, J., Korpela, J.M., Nout, M.J.R., 2012. Microbiological aspects of processing and storage of edible insects. Food Control 26, 628–631. doi:<http://dx.doi.org/10.1016/j.foodcont.2012.02.013>
- Li, L., Xie, B., Dong, C., Wang, M., Liu, H., 2016. Can closed artificial ecosystem have an impact on insect microbial community? A case study of yellow mealworm (*Tenebrio molitor* L.). Ecol. Eng. 86, 183–189. doi:<http://dx.doi.org/10.1016/j.ecoleng.2015.09.015>
- Madigan, M.T., Martinko, J.M., Dunlap, P. V, Clark, D.P., 2009. Brock Biology of microorganisms, 12th ed. Pearson/Benjamin Cummings, San Francisco, CA.
- Martínez, S., Borrajo, R., Franco, I., Carballo, J., 2007. Effect of environmental parameters on growth kinetics of *Bacillus cereus* (ATCC 7004) after mild heat treatment. Int. J. Food Microbiol. 117, 223–7. doi:<http://dx.doi.org/10.1016/j.ijfoodmicro.2006.08.002>

- Mlcek, J., Rop, O., Borkovcova, M., Bednarova, M., 2014. A Comprehensive Look at the Possibilities of Edible Insects as Food in Europe – a Review. *Polish J. Food Nutr. Sci.* 64, 147–157. doi:<http://dx.doi.org/10.2478/v10222-012-0099-8>
- Mpuchane, S., Allotey, J., Matsheka, I., Simpanya, M., Coetzee, S., Jordaan, A., Mrema, N., Gashe, B.A., 2006. Carriage of micro-organisms by domestic cockroaches and implications on food safety. *Int. J. Trop. Insect Sci.* 26, 166–175. doi:<http://dx.doi.org/10.1079/IJT20063141>
- Nowak, V., Persijn, D., Rittenschober, D., Charrondiere, U.R., 2016. Review of food composition data for edible insects. *Food Chem.* 193, 39–46. doi:<http://dx.doi.org/10.1016/j.foodchem.2014.10.114>
- NVWA, 2014. Advisory report on the risks associated with the consumption of mass-reared insects.
- Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Wagner, H., 2012. *Vegan: Community Ecology*, in: *R Package Ver. 2.0–5*. R Foundation for Statistical Computing, Vienna, Austria.
- Oonincx, D.G.A.B., de Boer, I.J.M., 2012. Environmental impact of the production of mealworms as a protein source for humans - a life cycle assessment. *PLoS One* 7, e51145. doi:<http://dx.doi.org/10.1371/journal.pone.0051145>
- Oonincx, D.G.A.B., van Itterbeeck, J., Heetkamp, M.J.W., van den Brand, H., van Loon, J.J.A., van Huis, A., 2010. An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *PLoS One* 5, e14445. doi:<http://dx.doi.org/10.1371/journal.pone.0014445>
- Premalatha, M., Abbasi, T., Abbasi, T., Abbasi, S.A., 2011. Energy-efficient food

- production to reduce global warming and ecodegradation: The use of edible insects. *Renew. Sustain. Energy Rev.* 15, 4357–4360.
doi:<http://dx.doi.org/10.1016/j.rser.2011.07.115>
- R Development Core Team, 2006. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
- Rumpold, B.A., Fröhling, A., Reineke, K., Knorr, D., Boguslawski, S., Ehlbeck, J., Schlüter, O.K., 2014. Comparison of volumetric and surface decontamination techniques for innovative processing of mealworm larvae (*Tenebrio molitor*). *Innov. Food Sci. Emerg. Technol.* 26, 232–241.
doi:<http://dx.doi.org/10.1016/j.ifset.2014.09.002>
- Rumpold, B.A., Schlüter, O.K., 2013a. Nutritional composition and safety aspects of edible insects. *Mol Nutr Food Res* 57, 802–823.
doi:<http://dx.doi.org/10.1002/mnfr.201200735>
- Rumpold, B.A., Schlüter, O.K., 2013b. Potential and challenges of insects as an innovative source for food and feed production. *Innov. Food Sci. Emerg. Technol.* 17, 1–11. doi:<http://dx.doi.org/10.1016/j.ifset.2012.11.005>
- Sánchez-Muros, M.-J., Barroso, F.G., Manzano-Agugliaro, F., 2014. Insect meal as renewable source of food for animal feeding: a review. *J. Clean. Prod.* 65, 16–27.
doi:<http://dx.doi.org/10.1016/j.jclepro.2013.11.068>
- SHC, FASFC, 2014. Food safety aspects of insects intended for human consumption (Sci Com dossier 2014/04; SHC dossier n° 9160).
- Siemianowska, E., Kosewska, A., Aljewicz, M., Skibniewska, K.A., Polak-Juszczak, L., Jarocki, A., Jędras, M., 2013. Larvae of mealworm (*Tenebrio molitor* L.) as European novel food. *Agric. Sci.* 04, 287–291.

doi:<http://dx.doi.org/10.4236/as.2013.46041>

Stoops, J., Crauwels, S., Waud, M., Claes, J., Lievens, B., Van Campenhout, L., 2016.

Microbial community assessment of mealworm larvae (*Tenebrio molitor*) and grasshoppers (*Locusta migratoria migratorioides*) sold for human consumption.

Food Microbiol. 53, Part B, 122–127.

doi:<http://dx.doi.org/10.1016/j.fm.2015.09.010>

Templeton, J.M., De Jong, A.J., Blackall, P.J., Mifflin, J.K., 2006. Survival of

Campylobacter spp. in Darkling Beetles (*Alphitobius diaperinus*) and Their Larvae in Australia. Appl. Environ. Microbiol. 72, 7909–7911.

doi:<http://dx.doi.org/10.1128/AEM.01471-06>

van Huis, A., 2013. Potential of insects as food and feed in assuring food security. Annu

Rev Entomol 58, 563–583. doi:<http://dx.doi.org/10.1146/annurev-ento-120811-153704>

van Huis, A., Van Itterbeeck, J., Klunder, H.C., Mertens, E., Halloran, A., Muir, G.,

Vantomme, P., 2013. Edible insects: Future prospects for food and feed security.

FAO (Food and Agricultural Organization of the United Nations), Rome.

Yen, A.L., 2015. Insects as food and feed in the Asia Pacific region: current

perspectives and future directions. J. Insects as Food Feed 1, 33–55.

doi:<http://dx.doi.org/10.3920/JIFF2014.0017>

Yun, J.-H., Roh, S.W., Whon, T.W., Jung, M.-J., Kim, M.-S., Park, D.-S., Yoon, C.,

Nam, Y.-D., Kim, Y.-J., Choi, J.-H., Kim, J.-Y., Shin, N.-R., Kim, S.-H., Lee, W.-

J., Bae, J.-W., 2014. Insect gut bacterial diversity determined by environmental

habitat, diet, developmental stage, and phylogeny of host. Appl. Environ.

Microbiol. 80, 5254–64. doi:<http://dx.doi.org/10.1128/AEM.01226-14>

Zheng, L., Crippen, T.L., Sheffield, C.L., Poole, T.L., Yu, Z., Tomberlin, J.K., 2012.

Evaluation of *Salmonella* Movement Through the Gut of the Lesser Mealworm,
Alphitobius diaperinus (Coleoptera: Tenebrionidae). Vector-Borne Zoonotic Dis.
12, 287–292. doi:<http://dx.doi.org/10.1089/vbz.2011.0613>

List of figure captions

Fig. 1. Non-metric multidimensional scaling (NMDS) of the samples analysed in this study. Batches MW 4.1, MW 4.2, CR 1.1 and CR 2.2 were excluded from this analysis because of lacking parameters or data lower than the detection limit. All intrinsic and microbial parameters (mean values) were included in the analysis for the other batches. Batches from the same rearing company are represented by the same colour. The distance between samples on the plot reflects their similarity level: the more similar two samples are, the smaller their distance is. Sample IDs correspond with those in Table 1.

Tables

Table 1. Sample information.

Sample ID	Rearing company	Batch	Sampling month (2015)	Insect type	Species	Purpose (human/pet food)
MW 1.1	1	1	March	Mealworm	<i>T. molitor</i> ¹	Human food
MW 1.2	1	2	May	Mealworm	<i>T. molitor</i>	Human food
MW 1.3	1	3	September	Mealworm	<i>T. molitor</i>	Human food
MW 2.1	2	1	March	Mealworm	<i>T. molitor</i>	Human food
MW 2.2	2	2	June	Mealworm	<i>T. molitor</i>	Human food
MW 2.3	2	3	October	Mealworm	<i>T. molitor</i>	Human food
MW 3.1	3	1	May	Mealworm	<i>T. molitor</i>	Pet food
MW 3.2	3	2	July	Mealworm	<i>T. molitor</i>	Pet food
MW 3.3	3	3	November	Mealworm	<i>T. molitor</i>	Pet food
MW 4.1	4	1	July	Mealworm	<i>T. molitor</i>	Pet food
MW 4.2	4	2	August	Mealworm	<i>T. molitor</i>	Pet food
MW 4.3	4	3	September	Mealworm	<i>T. molitor</i>	Pet food
CR 1.1	5	1	March	Cricket	<i>A. domesticus</i> ²	Human food
CR 1.2	5	2	June	Cricket	<i>A. domesticus</i>	Human food
CR 1.3	5	3	September	Cricket	<i>A. domesticus</i>	Human food
CR 2.1	6	1	April	Cricket	<i>A. domesticus</i>	Human food
CR 2.2	6	2	July	Cricket	<i>A. domesticus</i>	Human food
CR 2.3	6	3	October	Cricket	<i>A. domesticus</i>	Human food
CR 3.1	7	1	August	Cricket	<i>G. sigillatus</i> ³	Human food
CR 3.2	7	2	October	Cricket	<i>G. sigillatus</i>	Human food
CR 3.3	7	3	December	Cricket	<i>G. sigillatus</i>	Human food

¹*T.*: *Tenebrio*; ²*A.*: *Acheta*; ³*G.*: *Gryllos*.

Table 2. Intrinsic properties and microbial counts of fresh mealworm larvae (*T. molitor*) from different rearing companies and batches¹.

Rearin g compa ny	Sam ple ID	Intrinsic properties			Microbial counts (log cfu/g)					
		pH	a _w	Moist ure conten t (%)	Total viabl e aero bic coun t	Lacti c acid bacte ria	Entero- bacteriac eae	Aerobic bacteria l endospo res	Psych ro- trophi c aerobi c count	Yeas ts and moul ds
1	MW 1.1	6.7 3 ±	0.97 ±	61.4 ± 0.4 ^{a,b}	8.3 ± 0.0 ^a	7.4 ± 0.0 ^a	6.8 ± 0.1 ^a	4.2 ± 0.1 ^{a,b}	5.8 ± 0.0 ^{a,b*}	4.8 ± 0.1 ^a

		0.0 2 ^a	0.00 a							
	MW	6.7 5 ±	0.97 ±	60.8 ± 0.1 ^a	8.4 ± 0.0 ^a	7.4 ± 0.0 ^a	7.2 ± 0.1 ^{a,b}	5.0 ± 0.6 ^a	4.8 ± 0.6 ^a	4.5 ± 0.1 ^{a,b} *
	1.2	0.0 1 ^a	0.00 a							
	MW	6.7 6 ±	0.95 ±	62.7 ± 0.1 ^b	8.3 ± 0.0 ^a	7.7 ± 0.0 ^{b*}	7.6 ± 0.1 ^b	2.6 ± 0.1 ^b	7.0 ± 0.0 ^{b*}	4.2 ± 0.1 ^{b*}
	1.3	0.0 1 ^a	0.00 b							
	Mea n	6.7 5 ± 0.0 1 ^A	0.96 ± 0.00 A	61.6 ± 0.5 ^A	8.3 ± 0.0 ^A	7.5 ± 0.1 ^A	7.2 ± 0.2 ^A	3.9 ± 0.7 ^A	5.9 ± 0.6 ^A	4.5 ± 0.2 ^A
	MW	6.7 3 ±	0.97 ±	64.8 ± 0.0 ^a	8.5 ± 0.2 ^{2,a}	8.2 ± 0.0 ^{2,a}	6.9 ± 0.2 ^{2,a}	2.3 ± 0.1 ^{a,b*}	6.5 ± 0.0 ^{2,a}	5.3 ± 0.0 ^{2,a}
	2.1	0.0 2 ^a	0.00 a							
	MW	6.6 8 ±	0.97 ±	65.3 ± 0.1 ^b	8.2 ± 0.0 ^b	7.6 ± 0.0 ^{b*}	7.4 ± 0.1 ^a	2.0 ± 0.1 ^a	6.6 ± 0.0 ^a	5.3 ± 0.1 ^a
	2.2	0.0 1 ^b	0.00 a,b							
2	MW	6.7 5 ±	0.95 ±	70.7 ± 0.3 ^b	8.2 ± 0.0 ^{a,b}	8.1 ± 0.0 ^{a,b*}	7.5 ± 0.1 ^a	2.5 ± 0.2 ^{b*}	6.7 ± 0.1 ^a	5.3 ± 0.1 ^a
	2.3	0.0 1 ^a	0.00 b							
	Mea n	6.7 2 ± 0.0 2 ^A	0.96 ± 0.01 A	66.9 ± 1.9 ^{B*}	8.3 ± 0.1 ^A	8.0 ± 0.2 ^A	7.3 ± 0.2 ^A	2.3 ± 0.1 ^{B*}	6.6 ± 0.1 ^A	5.3 ± 0.0 ^A
	MW	6.6 8 ±	0.96 ±	64.3 ± 0.1 ^{a,b}	8.0 ± 0.0 ^a	7.4 ± 0.0 ^{a,b*}	7.1 ± 0.0 ^a	4.2 ± 0.1 ^a	5.3 ± 0.4 ^a	5.6 ± 0.1 ^{a,b}
	3.1	0.0 1 ^a	0.00 a							
	MW	6.6 1 ±	0.97 ±	64.8 ± 0.1 ^a	8.2 ± 0.1 ^{a,b}	7.3 ± 0.0 ^a	7.5 ± 0.1 ^{a,b}	3.5 ± 0.7 ^a	7.0 ± 0.1 ^{a,b}	4.6 ± 0.1 ^a
	3.2	0.0 0 ^b	0.00 a							
3	MW	6.7 1 ±	0.96 ±	63.4 ± 0.1 ^b	9.3 ± 0.1 ^b	8.1 ± 0.1 ^{b*}	8.3 ± 0.0 ^b	4.1 ± 0.1 ^a	9.1 ± 0.0 ^b	7.5 ± 0.0 ^b
	3.3	0.0 1 ^a	0.00 a							
	Mea n	6.6 7 ± 0.0 3 ^A	0.96 ± 0.00 A	64.2 ± 0.4 ^{A,B*}	8.5 ± 0.4 ^A	7.6 ± 0.3 ^A	7.6 ± 0.4 ^A	3.9 ± 0.2 ^A	7.1 ± 1.1 ^A	5.9 ± 1.5 ^A
4	MW	N.D. 3	N.D. .	N.D.	8.3 ± 0.1 ^a	N.D.	7.8 ± 0.1 ^a	2.2 ± 0.2 ^{a,b}	N.D.	N.D.
	MW	N.D.	N.D.	N.D.	8.3 ±	N.D.	7.8 ±	1.7 ±	N.D.	N.D.

4.2	.	.		0.0 ^a		0.1 ^a	0.1 ^a		
	6.7	0.97	65.9 ±	8.3 ±	8.2 ±	6.9 ±	3.4 ±	7.6 ±	6.0 ±
MW	6 ±	±	0.1	0.0 ^a	0.0	0.1 ^{b*}	0.1 ^b	0.0	0.1
4.3	0.0	0.00							
	2								
Mea	6.7	0.97	65.9 ^B	8.3 ±	8.2 ^A	7.5 ±	2.4 ±	7.6 ^A	6.0 ^A
n	6 ^A	^A		0.0 ^A		0.3 ^A	0.5 ^{B*}		

¹Data are the mean values of three replicates ± standard error of the mean; ^{a,b}Means per sample with the same superscript (small letter) within the same columns from the same rearing company do not differ significantly ($p > 0.10$); ^{A,B}Means per rearing company with the same superscript (capital) within the same columns do not differ significantly ($p > 0.05$). *Superscripts with an asterisk indicate a weak significance ($0.05 < p < 0.10$).

²Mean value of two replicates ± standard error of the mean.

³N.D. not determined.

Table 3. Intrinsic properties and microbial counts of fresh crickets (*A. domesticus* or *G. sigillatus*) from different rearing companies and batches¹.

Rearin g compa ny	Sam ple ID	Intrinsic properties			Microbial counts (log cfu/g)					
		pH	a _w	Moist ure conten t (%)	Total viabl e aero bic coun t	Lacti c acid bacte ria	Entero- bacteriac eae	Aerobic bacteria l endospo res	Psych ro- trophi c aerobi c count	Yeas ts and moul ds
5	CR 1.1	6.58 2,a	0.96 2,a	N.D. ³	8.3 ± 0.1 ^{4,a} , b*	7.6 ± 0.3 ^{4,a} , b*	8.0 ± 0.0 ^{4,a,b*}	2.9 ± 0.0 ^{4,a}	5.3 ± 0.3 ^{4,a}	6.1 ± 0.0 ^{4,a} , b
	CR 1.2	6.03 ± 0.01 b	0.97 ± 0.00 a	65.3 ± 0.1 ^a	8.1 ± 0.1 ^a	7.4 ± 0.2 ^a	7.5 ± 0.2 ^a	2.8 ± 0.0 ^{a,b*}	6.4 ± 0.7 ^a	5.9 ± 0.0 ^a
	CR 1.3	6.61 ± 0.01 a	0.98 ± 0.00 b	73.3 ± 0.1 ^b	8.8 ± 0.1 ^{b*}	8.1 ± 0.0 ^{b*}	8.3 ± 0.2 ^{b*}	2.6 ± 0.0 ^{b*}	4.9 ± 0.2 ^a	7.2 ± 0.4 ^b
	Mea n	6.41 ± 0.19 A	0.97 ± 0.00 A	69.3 ± 4.0 ^A	8.4 ± 0.2 ^A	7.7 ± 0.2 ^A	7.9 ± 0.2 ^A	2.8 ± 0.1 ^A	5.5 ± 0.5 ^A	6.3 ± 0.4 ^A
	CR 2.1	6.44 ± 0.01 a	0.97 ± 0.00 a	73.0 ± 0.1 ^a	8.3 ± 0.1 ^a	7.8 ± 0.1 ^{a,b*}	7.7 ± 0.1 ^a	4.2 ± 0.9 ^a	5.2 ± 0.5 ^a	6.1 ± 0.4 ^a
6	CR 2.2	6.34 ± 0.01 b	0.99 ± 0.00 b	69.9 ± 0.1 ^b	8.2 ± 0.1 ^a	8.0 ± 0.1 ^a	7.4 ± 0.1 ^a	3.9 ± 0.1 ^a	< 3.0 ± 0.0 ^b	7.1 ± 0.2 ^a
	CR 2.3	6.69 ± 0.01 c	0.97 ± 0.00 a,b	70.8 ± 0.2 ^b	8.2 ± 0.0 ^{4,a}	7.7 ± 0.0 ^{4,b*}	7.6 ± 0.0 ^{4,a}	4.3 ± 0.0 ^a	3.7 ± 0.2 ^{4,a,b}	6.4 ± 0.0 ^{4,a}
	Mea n	6.49 ± 0.10 A	0.98 ± 0.00 A	71.3 ± 0.9 ^A	8.2 ± 0.0 ^A	7.8 ± 0.1 ^A	7.6 ± 0.1 ^A	4.1 ± 0.1 ^{B*}	< 4.0 ± 0.6 ^A	6.5 ± 0.3 ^A
	CR 3.1	6.37 ± 0.01 a	0.97 ± 0.00 a	69.0 ± 0.6 ^{a,b}	8.7 ± 0.2 ^a	8.3 ± 0.0 ^a	7.9 ± 0.2 ^a	3.8 ± 0.1 ^{a,b*}	4.5 ± 0.3 ^{4,a}	6.2 ± 0.2 ^{a,b}
7	CR 3.2	6.23 ± 0.01 b	0.96 ± 0.00 a,b	67.5 ± 0.1 ^a	8.4 ± 0.1 ^a	8.2 ± 0.1 ^a	7.2 ± 0.1 ^{b*}	3.4 ± 0.3 ^a	< 3.2 ± 0.1 ^{b*}	5.6 ± 0.1 ^a

CR	6.37 ±	0.92 ±	70.0 ± 0.1 ^b	8.6 ± 0.1 ^a	7.9 ± 0.1 ^{b*}	7.6 ± 0.1 ^{a,b*}	4.9 ± 0.5 ^{b*}	4.1 ± 0.5 ^a	7.2 ± 0.1 ^b
3.3	0.02 a	0.00 b							
Mea	6.32 ±	0.95 ±	68.9 ± 0.7 ^A	8.6 ± 0.1 ^A	8.1 ± 0.1 ^A	7.6 ± 0.2 ^A	4.0 ± 0.4 ^{B*}	< 3.9 ± 0.4 ^A	6.3 ± 0.5 ^A
n	0.05 A	0.02 A							

¹Data are the mean values of three replicates ± standard error of the mean; ^{a,b,c}Means per sample with the same superscript (small letter) within the same columns from the same rearing company do not differ significantly ($p > 0.05$); ^{A,B}Means per rearing company with the same superscript (capital) within the same columns do not differ significantly ($p > 0.05$). *Superscripts with an asterisk indicate a weak significance ($0.05 < p < 0.10$).

²Value of a single replicate.

³N.D. not determined.

⁴Mean value of two replicates ± standard error of the mean.

Table 4. Total mean values for intrinsic properties and microbial counts of fresh crickets and mealworm larvae¹.

Insect type	Intrinsic properties			Microbial counts (log cfu/g)					
	pH	a _w	Moisture content (%)	Total viable aerobic count	Lactic acid bacteria	Enterobacteriaceae	Aerobic bacterial endospores	Psychrotrophic aerobic count	Yeasts and moulds
Mealworm larvae	6.70	0.96							
	± 0.02 _A	± 0.00 _A	64.4 ± 0.9 ^A	8.4 ± 0.1 ^A	7.7 ± 0.1 ^A	7.4 ± 0.1 ^A	3.1 ± 0.3 ^A	6.6 ± 0.4 ^A	5.3 ± 0.3 ^A
Crickets	6.40	0.96	69.9 ± 0.9 ^B	8.4 ± 0.1 ^A	7.9 ± 0.1 ^A	7.7 ± 0.1 ^A	3.6 ± 0.3 ^A	4.5 ± 0.4 ^B	6.4 ± 0.2 ^B
	± 0.07 _B	± 0.01 _A							

¹Data are the total mean values of all investigated batches per insect ± standard error of the mean.

^{A,B}Means per insect with the same superscript do not differ significantly (p > 0.05).

Figure 1

Highlights

- A comparison between 7 rearers and 3 different batches per rearer was made.
- Intrinsic properties pH and a_w were determined on edible insects for the first time.
- There were large differences in microbial counts between batches per rearer.
- There were smaller differences in counts between different rearers.
- Differences were only partially explainable by intrinsic properties.