Animal Welfare

www.cambridge.org/awf

Opinion Paper

Cite this article: Barrett M and Fischer B (2023). Challenges in farmed insect welfare: Beyond the question of sentience. *Animal Welfare*, **32**, e4, 1–5
https://doi.org/10.1017/awf.2022.5

Received: 24 June 2022
Revised: 08 August 2022
Accepted: 19 August 2022

Keywords:
animal welfare; black soldier flies; crickets; farmed insects; insect sentience; mealworms

Author for correspondence:
Meghan Barrett,
Email: meghan.barrett21@gmail.com

Author contributions:
Conceptualisation: BF, MB; Writing – original draft: MB; Writing – review and editing: MB, BF.

Challenges in farmed insect welfare: Beyond the question of sentience

Meghan Barrett[1] and Bob Fischer[2]

[1]Department of Biology, California State University Dominguez Hills, Carson, CA 90747, USA
[2]Department of Philosophy, Texas State University, 601 University Dr, San Marcos, TX 78666, USA

Abstract

The global Insects as Food and Feed (IAFF) industry currently farms over a trillion individual insects a year and is growing rapidly. Intensive animal production systems are known to cause a range of negative affective states in livestock; given the potential scale of the IAFF industry, it is urgent to consider the welfare of the industry's insect livestock. The majority of the literature on farmed insect welfare has focused on: (i) establishing that insect welfare ought to be of concern; or (ii) extending vertebrate welfare frameworks to insects. However, there are many overlooked challenges to studying insect welfare and applying that knowledge in IAFF industry contexts. Here, we briefly review five of these challenges. We end with practical recommendations for the future study of insect welfare.

Introduction

By 2100, there will be 10.9 billion people to feed (United Nations 2013). Insects, a high-protein source often with a small environmental footprint (van Huis & Tomberlin 2017), can help meet protein demands. The insects as food and feed (IAFF) industry currently farms over 1 trillion insects per year; by 2030, > 8 trillion individuals per year may be farmed (Rowe 2020; de Jong & Nikolik 2021; for scale: ~79 billion birds and land mammals are slaughtered for meat each year; FAOSTAT in Šimčikas 2020).

Given the growth of the IAFF industry, it is vital to consider the welfare of its insect livestock, especially if insects are sentient — i.e, they have the capacity to experience negative affective states (Bentham 1948; Singer 2002; Birch 2017; Broom 2019). Intensive production systems cause a range of negative affective states in vertebrate livestock; from many moral perspectives, those welfare impacts are of serious concern (De Grazia 1996; Singer 2002; Thompson 2020; Fischer 2021). Comparable impacts upon farmed insects, then, would raise comparable moral issues.

Are insects sentient? At present, the empirical evidence does not readily provide a conclusive answer (Adamo 2016; Barron & Klein 2016; Klein & Barron 2016; Baracchi *et al.* 2017; Birch 2020; Lambert *et al.* 2021; van Huis 2021). Moreover, most work on insect welfare acknowledges that definitive data on insect sentience will come too slowly for industry decision-makers (and trillions of insects). Additionally, there may be reasons to question the emphasis on sentience (Monsò 2018; Pali-Schöll *et al.* 2019; van Loon & Bovenkerk 2021).

A reasonable response to current uncertainty is to employ a precautionary principle. The strongest such principle would require that humans should treat insects as though they are sentient, though weaker principles could be formulated (Fischer 2016, 2019; Birch 2017; Knutsson & Munthe 2017; Röcklinsberg *et al.* 2017; van Huis 2021). Since the welfare of insects has generally been overlooked (Horvath *et al.* 2013; Smith & Pryor 2013; International Platform for Insects as Food and Feed [IPIFF] 2019), even weak principles could significantly impact our assessment of industry practices.

To date, much of the literature on farmed insect welfare has focused on establishing that insect welfare ought to be of concern (Gjerris *et al.* 2016; Röcklinsberg *et al.* 2017; van Huis 2021) and there is a paucity of literature on the difficulty of improving insect welfare (Pali-Schöll *et al.* 2019). Consequently, many challenges to studying insect welfare and applying that knowledge in IAFF industry contexts have been overlooked. Here, we briefly review five of these challenges and end with recommendations for the future study of insect welfare.

Challenge 1: Rapid industry growth and innovation

Eventual 'world-scale' mass production facilities are predicted to produce > 1 million tons of insect protein per year, each rearing at least 15 trillion individual insects (Kok 2017; Rowe 2020). This scale is immense but so is the potential demand: each world-scale plant would only meet 5–6% of *just aquaculture's* potential demand for insect protein (Rowe 2020; de Jong & Nikolik 2021), alongside demand for insect protein as swine/broiler feed and in pet food.

Practically, the vast majority of studies on welfare-relevant factors for farmed insects occur at small, laboratory scales. The IAFF industry must base the rearing of insects-by-the-ton on studies of insects-by-the-gram (Tomberlin & Cammack 2017). Scaling is not necessarily linear and some welfare concerns may present only in mass-rearing environments, such as the increased risk of overheating in large, high-density rearing containers (Sørensen *et al.* 2012; Scala *et al.* 2020; Barrett *et al.* 2022). Laboratory-scale studies on welfare may thus be inaccurate/incomplete when applied to mass-production environments (Myers *et al.* 2008; Miranda *et al.* 2020; Yang & Tomberlin 2020).

Scaling will require significant technological innovation (Kok 2017), likely including emerging biotechnologies, such as genetic modification (e.g. Zhan *et al.* 2019). However, new technologies can create new welfare problems (Barrett *et al.* 2022), as they have in vertebrate livestock production (Fischer 2021). Intense genetic selection in broiler chickens (*Gallus gallus domesticus*) has increased growth rates by over 300%, resulting in a variety of painful skeletal disorders (Knowles *et al.* 2008). Zhan *et al.* (2019) produced genetically modified black soldier fly (*Hermetia illucens*) larvae whose final larval weight is nearly 300% greater than normal; the welfare impacts of this increase in weight are unknown. Assessing the welfare impacts of technological advancements in each farmed insect species, before they become commonplace for trillions of individuals, may prove incredibly challenging.

Another line of innovation involves rearing new insect species; each species may raise different welfare concerns. Currently, only seven species of insects are farmed in truly significant numbers (Rumbos & Athanassiou 2021); however, there are over 2,000 species of edible insects (Jongema *et al.* 2017), many of which are poorly studied. Devising welfare assessments that accurately characterise the different welfare needs of each species, in each farmed context, will be difficult.

Challenge 2: Adoption of vertebrate welfare tools

Most entomologists gravitate toward Brambell's Five Freedoms (1965), designed for vertebrate livestock, when considering insect welfare (Erens *et al.* 2012; de Goede *et al.* 2013; van Huis 2021; Barrett *et al.* 2022). While some aspects of Brambell's framework readily apply to insects (e.g. freedom from disease), others are more challenging to apply given our limited understanding of insects' affective states (e.g. freedom from fear; van Huis 2021). Decapod welfare researchers have recently used the Five Domains model as a more practical alternative for invertebrates (Albalat *et al.* 2022), though the fundamental issue remains. As Figure 1 illustrates, the physical/functional domains matter as proxies for the mental domain. Every welfare framework available must confront the paucity of data regarding insects' mental lives.

Additionally, behavioural and physiological differences between vertebrates and insects may impact the adaption of vertebrate assessment tools for insects (Boppré & Vane-Wright 2019). As one example, the vertebrate livestock industry uses percent pre-slaughter mortality as a welfare metric in pigs (*Sus scrofa*) (Straw *et al.* 1983; Knauer & Hostetler 2013). However, dead insects can completely disappear; having no bones, farmed insects can cannibalise the entire bodies of dead conspecifics.

For a physiological example, consider that terrestrial vertebrate livestock are typically endotherms (having self-regulated, stable body temperatures across a range of ambient conditions; Clark & Pörtner 2010). Moderate changes in environmental temperature are thus insignificant from the perspective of terrestrial vertebrate welfare. Insects, however, are typically ectotherms (having body temperatures much closer to ambient conditions; Régnière *et al.* 2012). As a result, moderate changes in environmental temperature can quickly impact insects' body temperatures with, presumably, some associated effects on welfare. Welfare tools developed for vertebrates may not be sufficiently attuned to the physiological and behavioural needs of insects.

Challenge 3: Inter-population and inter-individual variation

Neutral evolutionary processes, such as genetic drift, can cause populations of initially similar individuals to differentiate genetically over time if they become isolated. Genetic differentiation can occur very quickly when animals with short generation times, such as farmed insects, are reproductively isolated by being housed in different production facilities (Ohta 1993; Thomas *et al.* 2010). This differentiation can be magnified by selective effects if local conditions on farms vary in fitness-relevant ways (Darwin 1859). In aggregate: evolutionary processes will produce phenotypically variable populations. These 'strain' effects are already known to impact farmed insect responses to environmental conditions and these differences may be welfare-relevant (Zhao *et al.* 2013; Ståhls *et al.* 2020; Rumbos *et al.* 2021). High degrees of inter-population variation will make it more difficult to design standardised assessment metrics that produce high welfare for insects across strains/facilities.

However, *intra*population (e.g. inter-individual) variation may also present an overlooked challenge to insect welfare. Inter-individual variation is widespread, involves specialised diets, behavioural strategies, etc, within a common environment, and is generally an underappreciated phenomenon in shaping ecological/evolutionary dynamics; it has been documented in numerous insect orders (Bolnick *et al.* 2003; Dall *et al.* 2012). Farmed and wild contexts differ, potentially affecting the degree of inter-individual variation. Still, inter-individual variation could have welfare-relevant dimensions for farmed insects.

Fundamentally, treating all populations, or all individuals within a population, as identical in their welfare needs may compromise the welfare of some populations or individuals.

Challenge 4: Welfare needs across insect development

Developing juvenile insects molt progressively as they grow until undergoing metamorphosis and emerging in their terminal, adult form. In hemimetabolous insects, such as crickets, nymphs are (mostly) miniature versions of adults and often occupy similar ecological niches (Mito *et al.* 2010). Holometabolous insects, such as butterflies, undergo complete metamorphosis, e.g. pupation: larvae are morphologically distinct from their adult form and may utilise very different ecological niches (Rolff *et al.* 2019).

Given dramatic differences in anatomy, physiology, or behaviour across life stages in some insect species, there will be differences in their welfare needs (e.g. life stage-dependent nutritional needs for black soldier fly larvae vs adults; Barrett *et al.* 2022). These cognitive and welfare differences are likely to be most apparent in holometabolous insects, as pupation involves significant remodelling of almost their entire anatomy, including integrative regions of the nervous system (e.g. Fahrbach 2006), to an extent not generally seen in hemimetabolous taxa (Malaterre *et al.* 2002). Holometabolous species will form the majority of farmed insects (Rowe 2020); it

https://doi.org/10.1017/awf.2022.5 Published online by Cambridge University Press

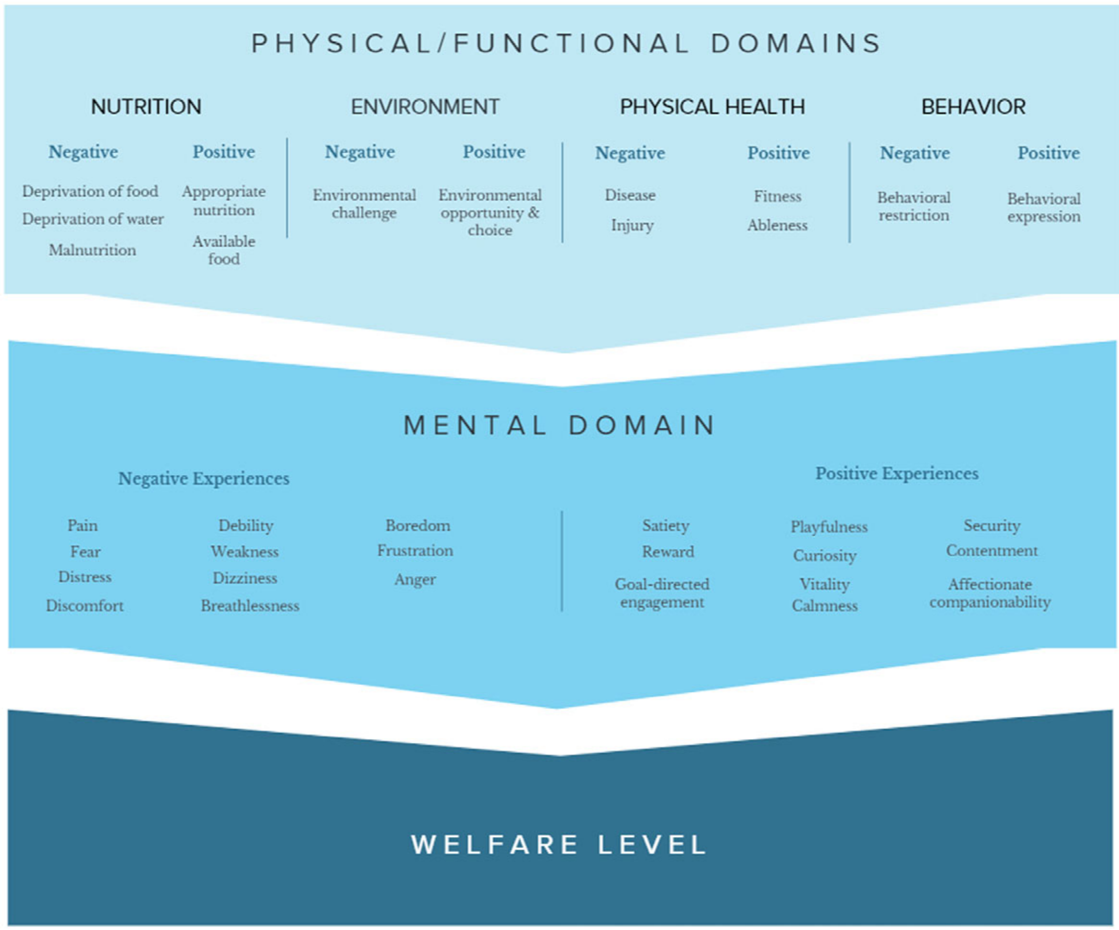

Figure 1. The Five Domains Model of animal welfare. Adapted from Mellor DJ, Hunt S and Gusset M 2015 Caring for Wildlife: The World Zoo and Aquarium Animal Welfare Strategy. WAZA Executive Office: Gland, Switzerland.

is therefore important to understand differences in their species-specific welfare needs across development.

Challenge 5: Inter-specific trade-offs

The availability of insect protein raises questions about how to make trade-offs involving different species, with different probabilities of sentience, and radically different numbers of farmed individuals (Fischer 2019; Pali-Schöll *et al.* 2019). One such inter-specific trade-off concerns a standard use case for insect protein: aquaculture. There, insect protein may replace fishmeal. If the goal is to minimise negative welfare impacts, we now need to compare the welfare impacts associated with IAFF facilities rearing a much larger number of insects to commercial fishing operations capturing a much smaller number of fish.

The growth of the IAFF industry means there will be many variations of the inter-specific welfare impacts challenge (e.g. in assessing the sustainability benefits of insect farming, which may generate trade-offs when considering human and wildlife welfare; Gamborg *et al.* 2018; Hampton *et al.* 2021). It is important, therefore, to develop decision-making frameworks for such trade-offs that allow stakeholders to consider the importance of several factors: the number and kinds of individuals affected, the size and severity of the welfare impacts, and indirect effects on other goals (e.g. sustainability).

Recommendations for early studies of insect welfare

The scale of the IAFF industry, and the welfare challenges it thus poses, can be hard to appreciate. Even if negative welfare impacts were extremely uncommon — let us assume 0.0001% of individuals per facility have low welfare under conditions that serve the average individual — 15 million insects *per world-scale facility* would be affected each year.

However, the IAFF industry is not at this scale yet; it is just beginning to grow. Accordingly, there is time to prioritise addressing these and other challenges to guide the industry in averting serious welfare impacts on invertebrate livestock. We thus make the following recommendations for early forays into insect welfare:

- Transparent, inter-disciplinary collaborations are essential to guide the industry down a cautious, welfare-respecting, and economical path (e.g. Thompson 2020). IAFF producers and entomologists lack the training and regulatory guideposts to address ethical concerns alone; similarly, animal ethicists and welfare biologists lack the necessary knowledge of insect biology and industry practices needed to devise useful welfare tools.
- The vertebrate livestock welfare literature is a valuable resource but has clear limitations in applicability. It is probably safer to borrow more theoretical frameworks (e.g. the Five Domains; Albalat *et al.* 2022) than applied ones, but all borrowing should be done while considering insect-specific modifications.

https://doi.org/10.1017/awf.2022.5 Published online by Cambridge University Press

- Initial insect welfare tools that originate in labs, rather than production-scale facilities, need to be used cautiously as scale may affect their implementation. It is important that researchers and producers collaborate to identify best practices.
- As the industry grows, there will be technological innovations, as well as changes in the species, populations, and life stages that are farmed. All these factors are welfare-relevant. So, frequent iteration in welfare assessment tools will be necessary.

Acknowledgments. MB is an NSF post-doctoral fellow at the time of publication: any opinions, findings, conclusions, or recommendations expressed in this manuscript are the authors, and do not necessarily reflect the views of the NSF.

Competing interest. MB and BF report a relationship with Rethink Priorities that includes employment or consulting. No funding was provided to MB or BF for this work (by Rethink Priorities or other sources).

References

Adamo SA 2016 Do insects feel pain? A question at the intersection of animal behaviour, philosophy and robotics. *Animal Behaviour* **118**: 75–79.

Albalat A, **Zacarias S**, **Coates CJ**, **Neil DM**, **Planellas SR** 2022 Welfare in farmed decapod crustaceans, with particular reference to *Penaeus vannamei*. *Frontiers in Marine Science* **677**.

Baracchi D, **Lihoreau M**, **Giurfa M** 2017 Do insects have emotions? Some insights from bumble bees. *Frontiers in Behavioral Neuroscience* **11**: 157.

Barrett M, **Chia SY**, **Fischer B**, **Tomberlin JK** 2022 Welfare considerations for farming black soldier flies, *Hermetia illucens* (Diptera: Stratiomyidae): a model for the insects as food and feed industry. *Journal of Insects as Food and Feed* **0**: 1–30. DOI: 10.3920/JIFF2022.0041

Barron A and Klein C 2016 What insects can tell us about the origins of consciousness. *Proceedings of the National Academy of Science* **113**: 4900–4908.

Bentham J 1948 *An introduction to the principles of morals and legislation (reprint)*. Hafner Publishing: New York, NY, USA.

Birch J 2017 Animal sentience and the precautionary principle. *Animal Sentience: An* Interdisciplinary Journal on Animal Feeling **2**: 1–15.

Birch J 2020 The search for invertebrate consciousness. *Noûs*. https://doi.org/10.1111/nous.12351

Bolnick DI, **Svanbäck R**, **Fordyce JA**, **Yang LH**, **Davis JM**, **Hulsey CD and Forister ML** 2003 The ecology of individuals: Incidence and implications of individual specialization. *The American Naturalist* **161**: 1–28.

Boppré M and Vane-Wright RI 2019 Welfare dilemmas created by keeping insects in captivity. In Carere, C., and Mather, J., (Eds.) *The Welfare of Invertebrate Animals* pp 23–67. Springer: Switzerland.

Brambell FWR 1965 *Report of the technical committee to enquire into the welfare of animals kept under intensive livestock husbandry systems*. Her Majesty's Stationery Office: London, UK.

Broom D 2019 Sentience. In J. C. Choe (ed.), *Encyclopedia of Animal Behaviour* (2nd ed., Vol. **1**). Elsevier, Academic Press**:** London, UK.

Clarke A and Pörtner H 2010 Temperature, metabolic power and the evolution of endothermy. *Biological Reviews* **85**: 703–727.

Dall SRX, **Bell AM**, **Bolnick DI and Ratnieks FLR** 2012 An evolutionary ecology of individual differences. *Ecology Letters* **15**: 1189–1198.

Darwin C 1859 *On the origin of species by means of natural selection, or preservation of favoured races in the struggle for life*. John Murray: London, UK.

de Goede DM, **Erens J**, **Kapsomenou E and Peters M** 2013 Large scale insect rearing and animal welfare. In: Röcklinsberg H and Sandin P (Eds.) *The Ethics of Consumption* pp 236–243. Wageningen Academic Publishers: Wageningen, The Netherlands.

DeGrazia D 1996 *Taking animals seriously: Mental life and moral status*. Cambridge University Press: Cambridge, UK.

de Jong B and Nikolik G 2021 No longer crawling: Insect protein to come of age in the 2020s. *Rabobank*: 1–9.

Erens J, **Es van S**, **Haverkort F**, **Kapsomenou E and Luijben A** 2012 *A bug's life: Large-scale insect rearing in relation to animal welfare* pp 57. Wageningen UR, Wageningen, The Netherlands.

Fahrbach SE 2006 Structure of the mushroom bodies of the insect brain. *Annual Review of Entomology* **51**: 209–232.

Fischer B 2016 Bugging the strict vegan. *Journal of Agricultural and Environmental Ethics* **29**: 255–263.

Fischer B 2019 How to reply to some ethical objections to entomophagy. *Annals of the Entomological Society of America* **112**: 511–517.

Fischer B 2021 *Animal ethics: A contemporary introduction*. Routledge: New York, NY, USA.

Gamborg C, **Röcklinsberg H and Gjerris M** 2018 Sustainable proteins? Values related to insects in food systems. In: Halloran A, Flore R, Vantomme P and Roos N. (Eds.) *Edible Insects in Sustainable Food Systems* pp 468. Springer: Switzerland.

Gjerris M, **Gamborg C and Röcklinsberg H** 2016 Ethical aspects of insect production for food and feed. *Journal of Insects as Food and Feed* **2**: 101–110.

Hampton JO, **Hyndman TH**, **Allen BL and Fischer B** 2021 Animal harms and food production: Informing ethical choices. *Animals* **11**: 1225.

Horvath K, **Angeletti D**, **Nascetti G and Carere C** 2013 Invertebrate welfare: An overlooked issue. *Annali dell'Istituto Superiore de Sanità* **49**: 9–17.

International Platform for Insects as Food and Feed 2019 Ensuring high standards of animal welfare in insect production. *International Platform for Insects as Food and Feed.* https://ipiff.org/wp-content/uploads/2019/02/Animal-Welfare-in-Insect-Production.pdf

Jongema Y 2017 *List of edible insects of the world*. Wageningen UR: Wageningen, The Netherlands. https://tinyurl.com/mestm6p

Klein C and Barron A 2016 Insects have the capacity for subjective experience. *Animal Sentience* **100**: 1–19.

Knauer MT and Hostetler CE 2013 US swine industry productivity analysis, 2005 to 2010. *Journal Swine Health Production* **21**: 248–252.

Knowles TG, **Kestin SC**, **Haslam SM**, **Brown SN**, **Green LE**, **Butterworth A**, **Pope SJ**, **Pfeiffer D and Nicol CJ** 2008 Leg disorders in broiler chickens: prevalence, risk factors and prevention. *PLoS ONE* **3**: e1545.

Knutsson S and Munthe C 2017 A virtue of precaution regarding the moral status of animals with uncertain sentience. *Journal of Agricultural and Environmental Ethics* **30** :213–224.

Kok R 2017 Insect production and facility design. In: van Huis, A. and Tomberlin, J.K. (Eds.) *Insects as food and feed: From production to consumption*. Wageningen Academic Publishers: Wageningen, The Netherlands.

Lambert H, **Elwin A and D'Cruze N** 2021 Wouldn't hurt a fly? A review of insect cognition and sentience in relation to their use as food and feed. *Applied Animal Behaviour Science* **243**: 105432

Malaterre J, **Strambi C**, **Chiang AS**, **Aouane A**, **Strambi A and Cayre M** 2002 Development of cricket mushroom bodies. *Journal of Comparative Neurology* **452**: 215–227.

Miranda CD, **Cammack JA and Tomberlin JK** 2020 Mass production of the black soldier fly, *Hermetia illucens* (L.), (Diptera: Stratiomyidae) reared on three manure types. *Animals* **10**: 1243.

Mito T, **Nakamura T and Noji S** 2010 Evolution of insect development: To the hemimetabolous paradigm. *Current Opinion in Genetics and Development* **20**: 355–361.

Monsó S 2018 Why insect sentience might not matter very much. In: Springer S and Grimm H (Eds.) *Professionals in food chains* pp 375–380. Wageningen Academic Publishers, Wageningen, the Netherlands.

Myers HM, **Tomberlin JK**, **Lambert BD and Kattes D** 2008 Development of black soldier fly (Diptera: Stratiomyidae) larvae fed dairy manure. *Environmental Entomology* **37**: 11–15.

Ohta T 1993 An examination of the generation-time effect on molecular evolution. *Proceedings of the National Academy of Science* **90**: 10676–10680.

Pali-Schöll I, **Binder R**, **Moens Y**, **Polesny F and Monsó S** 2019 Edible insects - defining knowledge gaps in biological and ethical considerations of entomophagy. *Critical Reviews in Food Science and Nutrition* **59**: 2760–2771.

Régnière J, **Powell J**, **Bentz B and Nealis V** 2012 Effects of temperature on development, survival and reproduction of insects: Experimental design, data analysis and modeling. *Journal of Insect Physiology* **58**: 634–647.

Röcklinsberg H, **Gamborg C and Gjerris M** 2017 Ethical issues in insect production. In: van Huis A and Tomberlin JK (Eds.) *Insects as food and feed:*

From production to consumption. Wageningen Academic Publishers, Wageningen, The Netherlands.

Rolff J, **Johnston PR and Reynolds S** 2019 Complete metamorphosis of insects. *Philosophical Transaction of the Royal Society B* **14**: 20190063.

Rowe A 2020 Insects raised for food and feed - global scale, practices, and policies. *Effective Altruism Forum.* https://forum.effectivealtruism.org/posts/ruFmR5oBgqLgTcp2b/insects-raised-for-food-and-feed-global-scale-practices-and#Black_soldier_flies1

Rumbos CI and Athanassiou CG 2021 'Insects as food and feed: If you can't beat them, eat them!' - To the magnificent seven and beyond. *Journal of Insect Science* **21**: 9.

Rumbos CI, **Adamaki-Sotiraki C**, **Gourgouta M**, **Karapanagiotidis IT**, **Asimaki A**, **Mente E, and Athanassiou CG** 2021 Strain matters: Strain effect on the larval growth and performance of the yellow mealworm, *Tenebrio molitor* L. *Journal of Insects as Food and Feed* **7**: 1195–1205.

Scala A, **Cammack JA**, **Salvia R**, **Scieuzo C**, **Franco A**, **Bufo SA**, **Tomberlin JK and Falabella P** 2020 Rearing substrate impacts growth and macronutrient composition of *Hermetia illucens* (L.) (Diptera: Stratiomyidae) larvae produced at an industrial scale. *Scientific Reports* **10**: 19448.

Šimčikas S 2020 Estimates of captive vertebrate numbers. Effective Altruism Forum. https://forum.effectivealtruism.org/posts/pT7AYJdaRp6ZdYfny/estimates-of-global-captive-vertebrate-numbers

Singer P 2002 *Animal Liberation*. HarperCollins: New York, NY, USA.

Smith R and Pryor R 2013 *Work package 5:* Pro-insect platform in Europe. Deliverable 5.1 – mapping exercise report with regard to current legislation and regulation: Europe and Africa and China. ProteInsect and Minerva: Brussels, Belgium.

Sørensen J, **Addison M and Terblanche J** 2012 Mass-rearing of insects for pest management: Challenges, synergies and advances from evolutionary physiology. *Crop Protection* **38**: 87–94.

Ståhls G, **Meier R**, **Sandrock C**, **Hauser M**, **Zoric LS**, **Laiho E**, **Aracil A**, **Doderović J**, **Badenhorst R**, **Unadirekkul P**, **Adom NABM**, **Wein L**, **Richards C**, **Tomberlin JK**, **Rojo S**, **Veselić S and Parviainen T** 2020 The puzzling mitochondrial phylogeography of the black soldier fly (Hermetia illucens), the commercially most important insect protein species. *BMC Evolutionary Biology* **20**:60.

Straw BE, **Neubauer GD and Leman AD** 1983 Factors affecting mortality in finishing pigs. *JAMVA* **183**: 452–455.

Thomas JA, **Welch JJ**, **Lanfear R, and Bromham L** 2010 A generation time effect on the rate of molecular evolution in invertebrates. *Molecular Biology and Evolution* **27**: 1173–1180.

Thompson PB 2020 Philosophical ethics and the improvement of farmed animal lives. *Animal Frontiers* **10**: 21–28.

Tomberlin JK and Cammack JA 2017 Black soldier fly: Biology and mass production. In: van Huis A and Tomberlin JK (Eds.) *Insects as food and feed: From production to consumption*. Wageningen Academic Publishers, Wageningen, The Netherlands.

United Nations 2013 World population prospects: The 2012 revision. Key findings and advance tables. *Working Paper No. ESA/P/WP.227.* United Nations, Department of Economic and Social Affairs, Population Division, New York, NY, USA.

van Huis A 2021 Welfare of farmed insects. *Journal of Insects as Food and Feed* **7**: 573–584.

van Huis A and Tomberlin JK 2017 *Insects as food and feed: From production to consumption*. Wageningen Academic Publishers, Wageningen, The Netherlands.

van Loon MS and Bovenkerk B 2021 The ethics and mindfulness of insects. In: Schübel H and Wallimann-Helmer I (Eds.) *Justice and food security in a changing climate*. Wageningen Academic Publishers: Wageningen, The Netherlands.

Yang F and Tomberlin JK 2020 Comparing selected life-history traits of black soldier fly (Diptera: Stratiomyidae) larvae produced in industrial and bench-top-sized containers. *Journal of Insect Science* **20**: 25.

Zhan S, **Fang G**, **Cai M**, **Kou Z**, **Xu J**, **Cao Y**, **Bai L**, **Zhang Y**, **Jiang Y**, **Luo X**, **Xu J**, **Xu X**, **Zheng L**, **Yu Z**, **Yang H**, **Zhang Z**, **Wang S**, **Tomberlin JK**, **Zhang J and Huang Y** 2019 Genomic landscape and genetic manipulation of the black soldier fly *Hermetia illucens,* a natural waste recycler. *Cell Research* **30**: 50–60.

Zhao F, **Tomberlin JK**, **Zheng L**, **Yu Z and Zhang J** 2013 Developmental and waste reduction plasticity of three black soldier fly strains (Diptera: Stratiomyidae) raised on different livestock manures. *Journal of Medical Entomology* **50**: 1224–1230.