frontiers in Sustainable Food Systems

PERSPECTIVE
published: 13 January 2022
doi: 10.3389/fsufs.2021.721985

Farm to Institution to Farm: Circular Food Systems With Native Entomoculture

Patrick J. Shafer[1]*, Yolanda H. Chen[1,2,3], Travis Reynolds[1,3,4] and Eric J. B. von Wettberg[1,3,4,5]

[1] Food Systems Graduate Program, University of Vermont, Burlington, VT, United States, [2] Gund Institute for the Environment, University of Vermont, Burlington, VT, United States, [3] Plant and Soil Science, University of Vermont, Burlington, VT, United States, [4] Community Development and Applied Economics, University of Vermont, Burlington, VT, United States, [5] Department of Applied Mathematics, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia

Edible insects recycle food waste, which can help feed a hungrier planet by making food systems more circular and diversifying protein production. The potential for entomophagy (i.e., insect cuisine) to contribute to waste recycling and lower input food production is only beginning to be explored in the U.S., although insects have been consumed by people for millennia in a wide range of cultures. In this perspective piece, we consider as a case study the potential for university foodservice programs in New England to serve as incubators for circular entomophagous food systems. Students are likely early adopters of entomophagy because they increasingly demand sustainable non-meat protein options. University foodservices meanwhile purchase large amounts of food wholesale from local producers, utilize standardized pre-processing, and generate consistent waste streams which may be valuable feed for local insect farmers. Current Farm to Institution approaches strengthen regional food systems by connecting small farmers with university foodservices; we argue that a similar model (Farm to Institution to Farm) could support establishment of local insect farms, introduce edible insects to a relatively receptive base of university student customers, and provide a more sustainable mechanism for repurposing university food waste as insect feed. But to enable this type of food system, additional requirements include: (1) research on domestication of native insect species; (2) investment in processing capacity, ensuring new insect farmers have reliable markets for raw insect products; (3) infrastructure to recirculate waste streams within existing food systems; and (4) creation of recipes that entice new insect consumers.

Keywords: entomophagy, entomoculture, domestication, farm to institution, edible insects, circular food systems, waste reduction, sustainable food

OPEN ACCESS

Edited by:
Tamar Makov, Ben-Gurion University of the Negev, Israel

Reviewed by:
Clare Gupta, University of California, Davis, United States
Krishna Singh, Dr. Rajendra Prasad Central Agricultural University, India

****Correspondence:***
Patrick J. Shafer
patrick.shafer@uvm.edu

Specialty section:
This article was submitted to Nutrition and Sustainable Diets, a section of the journal Frontiers in Sustainable Food Systems

Received: *08 June 2021*
Accepted: *07 December 2021*
Published: *13 January 2022*

Citation:
Shafer PJ, Chen YH, Reynolds T and von Wettberg EJB (2022) Farm to Institution to Farm: Circular Food Systems With Native Entomoculture. Front. Sustain. Food Syst. 5:721985. doi: 10.3389/fsufs.2021.721985

INTRODUCTION

The 2020–2021 COVID-19 pandemic has shed light on modern food systems that are fragile, inefficient, and unsustainable (e.g., Niles et al., 2020). Supermarket shelves were often bare, while food rotted in farmers' fields and in restaurant refrigerators. The world continues to face widespread food insecurity, in both caloric shortfalls and nutritional deficiencies, particularly for protein, despite more than adequate production of calories from global agricultural systems (Vandermeer et al., 2018; Makov et al., 2020; Huizar et al., 2021). Dietary shifts to protein sources requiring fewer inputs are necessary to meet the expected 75% increase in protein production needed to feed the expanding global population (Alexander et al., 2017b; van Huis and Oonincx, 2017). Simply improving existing agricultural technologies will not be enough to meet this demand–innovative solutions are necessary (Shepon et al., 2018).

Circular food systems are one proposed solution for sustainable agriculture. These systems can potentially help create more food with fewer resources by recycling waste streams as inputs (Cadinu et al., 2020; Derler et al., 2021). Circular systems might help a region be more resilient to global supply chain disruption because inputs can be sourced locally. Emissions may be further reduced due to the decrease in long-distance transportation of resources (Ojha et al., 2020; Phan et al., 2020). Circularity may therefore support both the sovereignty and the sustainability of regional food systems.

Farm to Institution mechanisms also support regional food systems resilience, by increasing the amount of food that producers can sell to education and healthcare institutions. Food hubs–facilities that aggregate, store, and process harvests of local farmers, then wholesale to institutional foodservice providers (e.g., universities and hospitals)–are examples of effective Farm to Institution mechanisms in New England (Conner et al., 2014). Producers benefit from a reliable, hungry market without barriers to distribution. Foodservice providers benefit from local produce without excessive processing labor. In the case of university foodservice in particular, students may also benefit, because they increasingly demand food that is local, sustainable, fair, and humane (Townson, 2019).

Edible insects have potential applications in circular food systems (Surendra et al., 2016). They can eat food waste, and can be eaten by humans (Mancini et al., 2019a, 2020b). The practice of entomophagy has deep historical roots (Lesnik, 2017). Pliny the Elder tells us that ancient Romans reared bark beetles on flour and wine and enjoyed the larvae as a culinary delicacy (DeFoliart, 2002; Pliny the Elder. (77 CE), 2019). Currently, entomophagy is practiced in a wide range of cultures in over 119 countries, where over 2000 species of insects are eaten (Alexander et al., 2017a). Nutritional analyses of certain edible insect species have shown them to be high in fiber and low in fat; and contain up to 70% protein, a complete amino acid profile, and micronutrients such as zinc, iron, magnesium, calcium, vitamin B12, and omega 3 and 6 (Siemianowska et al., 2013; Gere et al., 2019; Oonincx and Finke, 2020; FAO, 2021). Insects are potentially more sustainable than traditional livestock and may help meet the growing demand from university students–as well as the rest of the planet–for environmentally-friendly protein (Oonincx and de Boer, 2012; Smetana et al., 2016; Cappellozza et al., 2019; Jones, 2019; Derler et al., 2021).

This Perspective piece is an exercise in figuring the possible role of entomoculture for increasing sustainability across environmental, economic, and social dimensions. We limit the scope of our exercise to New England as a starting point for larger action, and because we believe that this particular region is well-poised to support a nascent entomoculture industry across all three dimensions. For environmental sustainability, farming insects native to New England ensures that entomoculture aligns with the regional biodiversity of ecosystems. And for economic and social sustainability, current successful farm to institution mechanisms across New England can serve as models for circular food systems that are profitable for insect farmers, accessible to institutional buyers, and meet the demands of a growing cohort of environmentally- and socially-conscious consumers. We develop a model for incorporating edible insects into a New England university system where circular farm to institution connections might be established and potential early adopters of entomophagy might be reached (**Figure 1**). We discuss one of the key environmental constraints to this initiative (ecosystem biosecurity risks), address some of the regional context about farm livelihoods in New England, and discuss some consumer preference/taste issues and how those could be addressed, particularly in a university setting. Overall, we explore the potential viability of a regional entomoculture industry that distributes university food waste to insect farms and supplies insect-based foods to university dining.

DOMESTICATING EDIBLE INSECTS FOR CIRCULAR FOOD SYSTEMS

Our first question in developing an entomophagy-based waste cycling system is the decision on what species should be used to increase the sustainability of the system and reduce the environmental impact of entomoculture (Ramos-Elorduy, 2009). The commercial growth of entomoculture has largely focused on a very small number of species (e.g., mealworms and crickets), the majority of which are non-native. Of course, there are risks to promoting new technologies without considering potential threats to native ecosystems. Expansion of insect farming will increase the possibility of insects escaping from farms into the wild, where they may establish high-fecundity founder populations that have been selected for rapid reproduction (Jansson and Berggren, 2015; Bang and Courchamp, 2020; FAO, 2021). Some of the traits of farmed insects are similar to traits of invasive pests–fast-growing farmed insects in the wild might consume native plants, compete with or predate native insects, spread pathogens, or otherwise alter the dynamics of native ecosystems (van Huis et al., 2013; Mancini, 2020a). However, it is possible that insects raised in entomoculture may be less tolerant of stress in the wild (Jensen et al., 2017).

In order to mitigate the biosecurity risk of introducing non-native insect species, we suggest domesticating native species that have interacted with endemic arthropod communities (Sun-Waterhouse et al., 2016; Berggren et al., 2019). While our proposal to domesticate native insects for entomoculture is novel for waste closed-loop systems, it is based upon historical examples of successful animal domestication, including livestock (Larson and Fuller, 2014; Lecocq, 2019). Candidate wild species for domestication can be identified by their shared traits with existing domesticated species (Lecocq, 2019; Melgar-Lalanne et al., 2019; Rumbos and Athanassiou, 2021). For example, mealworms have social populations that respond well to captivity and can consume organic and inorganic wastes; a native species with similar physiology would fit the criteria of pre-adaptation

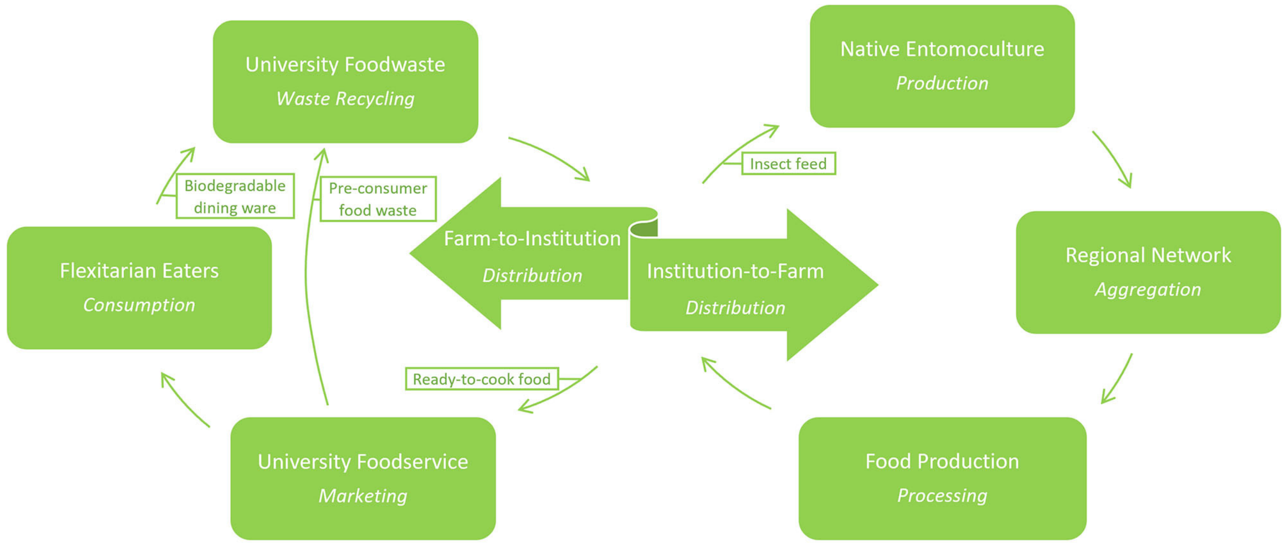

FIGURE 1 | Our conceptual food system starts with insect feed, consisting of food waste (e.g., coffee grounds, stale bread, produce scraps) from university foodservice. Feed is consumed by native insects, which are farmed by producers of varying size throughout New England. Harvested whole insects from a regional network of farms are aggregated and processed into foods that are delicious, visually appealing, and familiar to consumers. Insect-based foods are distributed wholesale to university foodservice, where they are then accessible to university students in dining halls. The same distribution channel collects institutional waste streams and directs them back into the system as feed, completing the cycle.

to human rearing (Tomberlin et al., 2015; Yang et al., 2015). An additional key step toward domestication is captive cultivation, in which wild individuals of suitable species are collected and reared extensively in controlled conditions which may or may not be similar to their native environment (Larson and Fuller, 2014). Over numerous generations, intensive selective breeding should cause individuals to display improvement for traits beneficial to captive rearing such as: feed efficiency, growth performance, and decreased aggression (Morales-Ramos et al., 2019; van Huis, 2020). If native species can be reared on regional waste streams, it may be possible to reduce emissions while increasing food security and supporting local industry, with potentially reduced threats to native ecosystems than other agricultural approaches (Wegier et al., 2018). Although this needs further research to measure emissions, environmental impacts, and market potential, we propose this as a starting point.

ENTOMOCULTURE, FOOD SYSTEM RESILIENCE, AND FARM LIVELIHOODS IN NEW ENGLAND

Entomoculture has the potential to provide an extra income stream for small producers (Patel et al., 2019). New England, the six states in the extreme northeastern US, has approximately 26,000 farms of varying size, but the majority of which are classified as small and medium (United States Department of Agriculture National Agricultural Statistics Service, 2019). Byproducts of some farms can be fed to insects, while insects themselves may offer a high-protein feed source for livestock (Sun-Waterhouse et al., 2016; Van Raamsdonk et al., 2017; Madau et al., 2020). It has been noted de Souza-Vilela et al. (2019) that other sources for animal nutrition including soybeans, peas, and fishmeal, are becoming more expensive–in addition to entailing serious environmental impacts. In regions like New England, which are marginal for soybean production and far from producing regions like the midwestern US, local insect farming has more potential for immediate payoffs from reduced purchases of livestock feed, and profit opportunities if insects can be sold as feed to other farmers. Paired with growing markets at the national and international scale for insects as high value inputs into pet food and specialty animal feed markets (Aridi, 2020), entomoculture may represent a production opportunity for farms to diversify. In addition, insect waste (frass) is a valuable plant fertilizer that can elicit an immune response from crops to resist fungal infections and can also be beneficial in soil amendment (Cadinu et al., 2020).

These benefits may be encouraging, but entomoculture must be profitable at the farm scale to be popular among farmers. And although profit opportunities may emerge through marketing insects for human consumption, in many cases the extra steps required to secure a market may be difficult for individual producers, and thus may be a barrier to entomoculture adoption. Although the number of potential commercial applications of insect-derived ingredients in food and feed sectors is large and growing (Villaseñor et al., 2021), some earlier efforts to develop entomoculture-based systems in New England have faced challenges, particularly surrounding low consumer acceptance of new insect-based food products and hence weak market demand (Allen, 2019). However, other regional efforts have

BOX 1 | Nascent entomoculture in New England.

Vermont Mealworm Farm *Braintree, VT 2017-Present*	Maintains a herd of roughly 2.4 million mealworms in a former dairy barn using local wheat bran and potatoes. Most orders are for livestock and pets, but owners plan to market products for human consumption as well. Frass is a valuable component of the business and is sold to local vegetable and hemp producers (Barry 2021, personal communication, https://vermontmealwormfarm.com/).
Entosense *Lewiston, ME 2015-Present*	Produces and distributes a variety of edible insect products. Sells direct to consumer using eCommerce, wholesale to retail and food service industries worldwide, and as a vendor to Sysco. Actively supports edible insect industry with extensive public communications and educational materials. Partners with producers such as Entomo Farms in Toronto, CA—the largest insect farm in North America, and Brooklyn Bugs in New York City—a gourmet insect chef (https://www.entosense.com/).
Flourish Farms *Middlesex, VT 2014–2019*	Formerly farmed crickets, processed them into powder, and marketed the product as competitive to whey and soy. Sold direct-to-consumer through eCommerce. Crickets proved difficult to keep alive, requiring specific diets and quarantined colonies. Costs of scaling to reach an acceptable profit margin were insurmountable. Former operators recommend: • Build rearing facilities that are modular to allow quarantining of colonies and scaling of production capacity. • First market whole, unprocessed insects as livestock feed to support scaling infrastructure. • Invest profits in food processing, then market a ready-to-eat insect-based food such as a meat substitute or baked goods (personal communication).
LAROUA Foods *Burlington, VT 2017–2018*	Formerly produced "bee butter"–a spread made from honeybee larvae blended with spices. Supported entomophagy and sustainable beekeeping with a unique mechanism: paying beekeepers for culled drone brood to incentivize organic methods of Varroa mite control. Notable as a student-led pilot program in response to perceived student demand at the University of Vermont (https://www.beeculture.com/save-the-bees/; https://learn.uvm.edu/foodsystemsblog/2017/11/29/edible-insects/).

been successful (**Box 1**). A regional network of insect farmers with shared infrastructure to aggregate, process, and market harvests could significantly reduce roadblocks to profit–so long as sufficient and reliable markets for insect-based products can be secured.

INVESTING IN FOOD PROCESSING INFRASTRUCTURE: FAMILIAR AND DELICIOUS

Much of the potential for any insect-based food system hinges on consumer tastes. First, insects require processing to enhance visual appeal as well as texture and flavor (Deroy et al., 2015). Processing insects into something non-reminiscent of their animal form is akin to butchering any other livestock and is helpful for acceptance among many U.S. audiences (Baiano, 2020; Rozin and Ruby, 2020; Reverberi, 2021). Insects can be dried or roasted; milled finely and mixed with glutinous flour to make bread, or milled coarsely to make falafel, tempeh, or imitation meat (Sun-Waterhouse et al., 2016; Seekings, 2020). Contextualizing insects within familiar foods also improves acceptance and ease of preparation, since audiences may not know how to cook whole insects (Caparros Megido et al., 2014; Shelomi, 2015; Higa et al., 2021).

Taste is perhaps the most important factor for long-term consumer acceptance (Mancini et al., 2019c; Woolf et al., 2019). Taste could be further improved by researching the taste profiles of insects fed different food wastes and processed by different means. For example, using mealworms reared on spent brewer grain in sourdough bread, or milling bee drone larvae with roasted nuts for honey-flavored, protein-packed nut butter; as well as recipes combining insect products with current common food products (e.g., grain flour, ground meats) in different ratios. Some recipes could also be developed drawing upon the knowledge and cultures of the hundreds of societies around the globe who currently consume insects in various forms, including Indigenous North Americans, who have consumed a multitude of insect species in a variety of preparations (Belluco et al., 2015; Schrader et al., 2016; Lesnik, 2019; Ruby and Rozin, 2019).

MARKETING AND CONSUMPTION: UNIVERSITY FOODSERVICE AND FLEXITARIAN EATERS

Innovators and early adopters of entomophagy are likely young, progressive, "flexitarian" eaters that are environment and health-conscious; and interested in reducing their consumption (Schösler et al., 2012; Verbeke, 2015; Derbyshire, 2017; Dobermann et al., 2017; Hicks et al., 2018; Mancini et al., 2019b). University students in New England match this profile, and their demand for sustainable protein has increased wholesale purchases of plant-based foods (Baxley, 2020). However, a "protein struggle" may develop when flexitarian eaters want food to be healthy, delicious, and sustainable, but are dissatisfied with available protein options (Derbyshire, 2017; Spencer et al., 2018). Insects may provide an alternate source of tasty, sustainable, and nutritionally complete non-vertebrate protein. Vegetarian and vegan students may also be interested as some may feel that insects meet their standards for sustainability, or may see the harvesting of insects (refrigeration to induce dormancy, then freezing to cease life processes) as acceptable because of the more humane treatment of these animals (Fischer, 2016). Insect-based foods may appeal to students with varied diets as they help them be environmental stewards while still eating healthy and delicious food (Naranjo-Guevara et al., 2021).

University dining halls are promising marketing outlets due to their clientele, and for the prevalence of peer influence in a social environment. Student peer influence plays a crucial role in acceptance of new foods and food technologies (Berger et al., 2019; Lesnik, 2019). Past research suggests U.S. consumers often are averse to consuming insects primarily due to (a) a lack of exposure in context as a food source, (b) a lack of social acceptance, and (c) a lack of consumer access (Looy et al., 2014; Caparros Megido et al., 2016; Menozzi et al., 2017). Distribution in universities directly confronts these barriers as it allows for marketing (1) with continual exposure alongside more familiar foods (Gumussoy et al., 2021), (2) among environmentally conscious peers thereby encouraging normative influence (Berger and Wyss, 2020; Russell and Knott, 2021), and (3) without typical barriers to consumer purchasing such as price or preparation (Barska, 2014; Menozzi et al., 2017).

FARM TO INSTITUTION TO FARM

Given the development of a viable entomoculture-based circular food system requires (a) simultaneous investment and expansion of production, processing, distribution, marketing, and waste recovery, and (b) sufficient market scale to support financially viable systems, we argue that a farm to institution framework might be used to connect insect farmers who need reliable demand for unprocessed insects with receptive audiences at a large scale. Existing Farm to Institution organizations such as "food hubs" seek to incentivize new farmers in a range of sectors and have proven more efficient than individual producers running separate operations (Izumi et al., 2009; Berti and Mulligan, 2016). Through new insect food hubs, farmers' harvests could be aggregated, dried, milled, and processed into ready-to-cook items at centralized facilities for delivery to university foodservice buyers. Aggregation could be flexible to accept insect harvests of any size, and processing could incorporate different species of farmed insects while still meeting consumer preferences. Aggregation and standard processing therefore have upstream benefits as they support the production network, and downstream benefits as they make marketing easier.

But just as a Farm to Institution approach connects producers and institutional buyers, a parallel "Institution to Farm" approach could support aggregating, processing, and distributing institutional waste to farmers for use as insect feed (Morales-Ramos et al., 2020). University waste streams include foodservice byproducts–such as coffee grounds, vegetable peels, and stale bread; and post-consumption waste–such as biodegradable dining ware. These waste streams could be returned to the food hub that providing the university with insect-based foods. Some wastes need to be dried and sterilized before use as insect feed, which is conveniently accomplished with the same processing equipment used to dry and sterilize harvested insects (Shuliy Machinery, 2020). Some species may have improved growth performances on curated diets, and diet blends for these species can be conveniently developed and distributed by the same hub housing the industrial drying infrastructure (Van Broekhoven et al., 2015; Pinotti et al., 2019; Silva et al., 2020). Thus, Institution to Farm and Farm to Institution mechanisms might efficiently both use the same infrastructure and distribution channels, in opposite directions (**Figure 1**).

DISCUSSION

We suggest that a circular food systems model can be integrated with Farm to Institution approaches to develop local and regional food systems that are environmentally, economically, and socially sustainable (Eshel et al., 2019; Madau et al., 2020). Entomoculture and entomophagy hold some promise in supporting this model; however, their adoption is not without risks and obstacles. A food system that sustainably uses edible insects to cycle nutrients from farm to institution to farm will only be attainable with cooperative development from institutions and local industry, who are unlikely to invest without significant research to close the large knowledge gaps. There are still several areas under the umbrella of sustainability that need more investigation:

(1) The risk of farmed insects becoming invasive is clearly possible. Thus, research on domestication of native species is needed to protect ecosystems (Berggren et al., 2019; Bang and Courchamp, 2020). Furthermore, domestication of native species could increase gains in feed conversion, growth performance, and nutrition of edible insects (Berggren et al., 2019).
(2) Farmers in New England are primed with an interest in new forms of agriculture and may be interested to adopt insect farming if they are provided evidence demonstrating the viability of regional entomoculture (Houle et al., 2015). A Life Cycle Assessment (LCA) of a New England insect farm could generate *in situ* productivity estimates, as well as measures of potential ecological impacts and sustainability, including opportunities to produce case studies of the benefits, costs, and overall financial potential of a regional entomophagy-based business model (Halloran et al., 2016; Smetana et al., 2021).
(3) Institutions in New England are likewise primed with an interest to reduce costs of recycling food waste, while their students, both in dining halls and as individual consumers, are increasingly demanding diverse non-meat protein options. Both sets of actors may be encouraged to engage with edible insects–with institutions offered lower-cost options for obtaining high-protein foods and for recycling food waste, and students offered opportunities to consume more sustainable and local foods–with expanded evidence of student support for entomophagy and demand for insect-based food products.
(4) Producers, institutions, and consumers may benefit from recipe development of insect-based foods that can incorporate a variety of species from different producers, can be purchased wholesale in a ready-to-cook form, and can be enjoyed by students as products resembling familiar foods. Ultimately, consumers of insects will demand something that tastes great. Recipes can support those who want to give a potentially highly sustainable and local food source a try, as they will need guidance to prepare an unfamiliar food (van Huis, 2013; Menozzi et al., 2017).

Infrastructure for aggregation of ready-to-eat insects; processing of insects into ready-to-cook, familiar foods; and distribution to universities *via* existing farm-to-institution programs in New England could be coupled with new Institution to Farm initiatives, using similar infrastructure, to facilitate foodservice waste collection and recirculation as insect feed. The resulting circular food system could both enhance food system sustainability and increase profitability of small- and medium-sized farms in the region, in addition to providing a working model for enhancing food system circularity nationally and globally.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

PS, YC, EW, and TR contributed to the logistical design of "Farm to Institution to Farm" conceptual model. PS wrote the first draft of the manuscript with feedback and comments from YC. YC, EW, and TR wrote and revised sections of the manuscript, providing expert-level intellectual content on regional agroecosystem interactions, domestication and nutrition, and diverse agriculture and rural livelihoods, respectively. PS designed the graphic display of the model, with editing from TR. EW guided the overall development of the paper. YC shaped the form, objective, and writing style of the paper and ensured that our application of domestication theory was suitable and realistic for insects. All authors contributed equally to revising, with YC, EW, and TR critically editing/ensuring accuracy of intellectual perspectives.

FUNDING

This work was facilitated by a Sodexo Food Systems Innovation Fellowship to PS. USDA Hatch funding to YC, TR, and EW. EW is further supported by the Ministry of Science and Higher Education of the Russian Federation as part of World-class Research Center program: Advanced Digital Technologies (Contract No. 075-15-2020-934 dated 17.11.2020).

ACKNOWLEDGMENTS

We thank Clare Knowlton for helpful comments on earlier versions of our manuscript. We thank Fred Wiseman for his insights on Indigenous entomophagy.

REFERENCES

Alexander, P., Brown, C., Arneth, A., Dias, C., Finnigan, J., Moran, D., et al. (2017a). Could consumption of insects, cultured meat or imitation meat reduce global agricultural land use? *Global Food Security*. Elsevier B.V. p. 22–32. doi: 10.1016/j.gfs.2017.04.001

Alexander, P., Brown, C., Arneth, A., Finnigan, J., Moran, D., and Rounsevell, M. D. A. (2017b). Losses, inefficiencies and waste in the global food system. *Agri. Sys.* 153, 190–200. doi: 10.1016/j.agsy.2017.01.014

Allen, A. W. (2019, March 31). Middlesex cricket farmers call it quits. *VTDigger*. Available online at: https://vtdigger.org/2019/03/31/middlesex-cricket-farmers-call-quits/

Aridi, et al. (2020). Available online at: https://www.smithsonianmag.com/smart-news/fido-how-about-some-fly-larvae-dinner-180976270/

Baiano, A. (2020). Edible insects: An overview on nutritional characteristics, safety, farming, production technologies, regulatory framework, and socio-economic and ethical implications. *Trends Food Sci Technol.* 100, 35–50. doi: 10.1016/j.tifs.2020.03.040

Bang, A., and Courchamp, F. (2020). Industrial rearing of edible insects could be a major source of new biological invasions. *Ecol. Lett*. doi: 10.1111/ele.13646

Barry, J. (2021). Vermont Mealworm Farm Fuels Plants, Pets and People. Seven Days. Available online at: https://www.sevendaysvt.com/vermont/vermont-mealworm-farm-fuels-plants-pets-and-people/Content?oid=33581578and_ga=2.117365190.177658490.1634334538-1292181124.1632347763.

Barska, A. (2014). Attitudes of young consumers towards innovations on the food market. *Management*. 18, 419–431. doi: 10.2478/manment-2014-0031

Baxley, S. (2020). *A Study of Plant-based Offerings on Campus* (MSc.thesis). University of Vermont, Burlington, VT, USA.

Belluco, S., Losasso, C., Maggioletti, M., Alonzi, C., Ricci, A., and Paoletti, M. G. (2015). Edible insects: A food security solution or a food safety concern? *Animal Front.* 5, 25–30. doi: 10.2527/af.2015-0016

Berger, S., Christandl, F., Bitterlin, D., and Wyss, A. M. (2019). The social insectivore: Peer and expert influence affect consumer evaluations of insects as food. *Appetite*. 141. doi: 10.1016/j.appet.2019.104338

Berger, S., and Wyss, A. M. (2020). Consumers' Willingness to Consume Insect-Based Protein Depends on Descriptive Social Norms. *Front. Sustain. Food Syst*. 4, 144. doi: 10.3389/fsufs.2020.00144

Berggren, Å., Jansson, A., and Low, M. (2019). Approaching Ecological Sustainability in the Emerging Insects-as-Food Industry. *Trends Ecol. Evol.* 34, 132–138. doi: 10.1016/j.tree.2018.11.005

Berti, G., and Mulligan, C. (2016). Competitiveness of small farms and innovative food supply chains: The role of food hubs in creating sustainable regional and local food systems. *Sustainability*. 8, 616. doi: 10.3390/su8070616

Cadinu, L. A., Barra, P., Torre, F., Delogu, F., and Madau, F. A. (2020). Insect rearing: Potential, challenges, and circularity. *Sustainability.* 12. doi: 10.3390/su12114567

Caparros Megido, R., Gierts, C., Blecker, C., Brostaux, Y., Haubruge, É., Alabi, T., et al. (2016). Consumer acceptance of insect-based alternative meat products in Western countries. *Food Qual Prefer*. 52, 237–243. doi: 10.1016/j.foodqual.2016.05.004

Caparros Megido, R., Sablon, L., Geuens, M., Brostaux, Y., Alabi, T., Blecker, C., et al. (2014). Edible insects acceptance by belgian consumers: promising attitude for entomophagy development. *J. Sens. Stud.* 29, 14–20. doi: 10.1111/joss.12077

Cappellozza, S., Giovanna Leonardi, M., Savoldelli, S., Carminati, D., Rizzolo, A., Cortellino, G., et al. (2019). A first attempt to produce proteins from insects by means of a circular economy. *Animals*. 9, 278. doi: 10.3390/ani9050278

Conner, D. S., Sevoian, N., Heiss, S. N., Berlin, L., Conner, D. S., Heiss, Á. S. N., et al. (2014). The diverse values and motivations of vermont farm to institution supply chain actors. *J Agric Environ Ethics*. 27, 695–713. doi: 10.1007/s10806-013-9485-4

de Souza-Vilela, J., Andrew, N. R., and Ruhnke, I. (2019). Insect protein in animal nutrition. *Animal Production Sci.* 59, 2029–2036. doi: 10.1071/AN19255

DeFoliart, G. R. (2002). The human use of insects as a food resource: a bibliographic account in progress. Available online at: https://Insectsasfood.Russell.Wisc.Edu/.~https://insectsasfood.russell.wisc.edu/the-human-use-of-insects-as-a-food-resource/

Derbyshire, E. J. (2017). Flexitarian diets and health: a review of the evidence-based literature. *Frontiers in Nutrition* 3, 55. doi: 10.3389/fnut.2016.00055

Derler, H., Lienhard, A., Berner, S., Grasser, M., Posch, A., and Rehorska, R. (2021). Use them for what they are good at: mealworms in circular food systems. *Insects*. doi: 10.3390/insects12010040

Deroy, O., Reade, B., and Spence, C. (2015). The insectivore's dilemma, and how to take the West out of it. *Food Qual Prefer*. 44, 44–55. doi: 10.1016/j.foodqual.2015.02.007

Dobermann, D., Swift, J. A., and Field, L. M. (2017). Opportunities and hurdles of edible insects for food and feed. *Nutr Bull.* 42, 293–308. doi: 10.1111/nbu.12291

Eshel, G., Stainier, P., Shepon, A., and Swaminathan, A. (2019). Environmentally optimal, nutritionally sound, protein and energy conserving plant based alternatives to U.S. *Meat. Sci. Rep.* 9, 1–11. doi: 10.1038/s41598-019-46590-1

FAO (2021). Looking at edible insects from a food safety perspective. *Challenges and Opportunities for the Sector*. doi: 10.4060/cb4094en

Fischer, B. (2016). Bugging the strict vegan. journal of agriculture, environment, and ethics. *J. Agric. Environ.* 29, 255–63. doi: 10.1007/s10806-015-9599-y

Gere, A., Radványi, D., and Héberger, K. (2019). Which insect species can best be proposed for human consumption? *Innov. Food Sci. Emerg. Technol.* 52, 358–367. doi: 10.1016/j.ifset.2019.01.016

Gumussoy, M., Macmillan, C., Bryant, S., Hunt, D. F., and Rogers, P. J. (2021). Desire to eat and intake of 'insect' containing food is increased by a written passage: The potential role of familiarity in the amelioration of novel food disgust. *Appetite*. 161. doi: 10.1016/j.appet.2020.105088

Halloran, A., Roos, N., Eilenberg, J., Cerutti, A., and Bruun, S. (2016). Life cycle assessment of edible insects for food protein: A review. *Agron. Sustain. Dev*. 36. doi: 10.1007/s13593-016-0392-8

Hicks, T. M., Knowles, S. O., and Farouk, M. M. (2018). Global Provisioning of Red Meat for Flexitarian Diets. *Front. Nutr*. 5, 50. doi: 10.3389/fnut.2018.00050

Higa, J. E., Ruby, M. B., and Rozin, P. (2021). Americans' acceptance of black soldier fly larvae as food for themselves, their dogs, and farmed animals. *Food Qual. Preference*. *90*, 104119. doi: 10.1016/J.FOODQUAL.2020.104119

Houle, D., Paquette, A., Côté, B., Logan, T., Power, H., Charron, I. et al. (2015). Impacts of climate change on the timing of the production season of maple syrup in Eastern Canada. *PLoS ONE*. 10, e0144844. doi: 10.1371/journal.pone.0144844

Huizar, M. I., Arena, R., and Laddu, D. R. (2021). The global food syndemic: the impact of food insecurity, Malnutrition and obesity on the healthspan amid the COVID-19 pandemic. *Prog. Cardiovasc. Dis.* 64, 105–107. doi: 10.1016/j.pcad.2020.07.002

Izumi, B. T., Wynne, A. D., Ae, W., and Hamm, M. W. (2009). Farm to school programs: exploring the role of regionally-based food distributors in alternative agrifood networks. *Agri. Human Values*. 27, 335–350. doi: 10.1007/s10460-009-9221-x

Jansson, A., and Berggren, Å. (2015). Insects as food-something for the future? A report from Future Agriculture. Available online at: https://www.researchgate.net/publication/299598712

Jensen, K., Kristensen, T. N., Heckmann, L.-H. L., Sørensen, J. G., Van Huis, A., and Tomberlin, J. K. (2017). Breeding and maintaining high-quality insects. Wageningen Academic Publishers, Wageningen, Netherlands. *J. Insects as Food Feed.* 9, 175–198.

Jones, V. (2019). Adapting our diets for global climate change: Could eating bugs really be the answer? *Teach. Geography*. 44, 72–74.

Larson, G., and Fuller, D. Q. (2014). The evolution of animal domestication. *Annu. Rev. Ecol. Evol.* 45, 115–136. doi: 10.1146/annurev-ecolsys-110512-135813

Lecocq, T. (2019). Insects: the disregarded domestication histories IntechOpen. *Animal Domestication* 3, 35–68. doi: 10.5772/intechopen.81834

Lesnik, J. J. (2017). Not just a fallback food: global patterns of insect consumption related to geography, not agriculture. *Am. J. Hum. Biol.* 29, 1–8. doi: 10.1002/ajhb.22976

Lesnik, J. J. (2019). The colonial/imperial history of insect food avoidance in the United States. *Ann. Entomol. Soc. Am.* 112, 560–565. doi: 10.1093/aesa/saz023

Looy, H., Dunkel, F. V., and Wood, J. R. (2014). How then shall we eat? *Insect-eating attitudes and sustainable foodways. Agric Human Values*. 31, 131–141. doi: 10.1007/s10460-013-9450-x

Madau, F. A., Arru, B., Furesi, R., and Pulina, P. (2020). Insect farming for feed and food production from a circular business model perspective. *Sustainability*. 12, 5418.

Makov, T., Shepon, A., Krones, J., Gupta, C., and Chertow, M. (2020). Social and environmental analysis of food waste abatement via the peer-to-peer sharing economy. *Nature Communications*. 11, 1–8. doi: 10.1038/s41467-020-14899-5

Mancini, S. (2020a). Insects as sustainable feed and food. *Acta Fytotechnica et Zootechnica*. 23, 214–216. doi: 10.15414/afz.2020.23.mi-fpap.214-216

Mancini, S., Fratini, F., Tuccinardi, T., Degl'Innocenti, C., and Paci, G. (2020b). Tenebrio molitor reared on different substrates: is it gluten free? *Food Control*. 110, 107014. doi: 10.1016/j.foodcont.2019.107014

Mancini, S., Fratini, F., Turchi, B., Mattioli, S., Dal Bosco, A., Tuccinardi, T., et al. (2019a). Former Foodstuff Products in Tenebrio Molitor Rearing: Effects on Growth, Chemical Composition, Microbiological Load, and Antioxidant Status. *Animals.* doi: 10.3390/ani9080484

Mancini, S., Moruzzo, R., Riccioli, F., and Paci, G. (2019b). European consumers' readiness to adopt insects as food. A review. *Food Res. Int.* 122, 661–678. doi: 10.1016/j.foodres.2019.01.041

Mancini, S., Sogari, G., Menozzi, D., Nuvoloni, R., Torracca, B., Moruzzo, R., et al. (2019c). Factors predicting the intention of eating an insect-based product. *Foods*. 8. doi: 10.3390/foods8070270

Melgar-Lalanne, G., Hernández-Álvarez, A. J., and Salinas-Castro, A. (2019). Edible Insects Processing: Traditional and Innovative Technologies. *Comprehensive Reviews in Food Science and Food Safety. Blackwell Publishing Inc*. doi: 10.1111/1541-4337.12463

Menozzi, D., Sogari, G., Veneziani, M., Simoni, E., and Mora, C. (2017). Eating novel foods: An application of the Theory of Planned Behaviour to predict the consumption of an insect-based product. *Food Qual. Pref.* 59, 27–34. doi: 10.1016/j.foodqual.2017.02.001

Morales-Ramos, J. A., Kelstrup, H. C., Guadalupe Rojas, M., and Emery, V. (2019). Body mass increase induced by eight years of artificial selection in the yellow mealworm (Coleoptera: Tenebrionidae) and life history trade-offs. *J. Insect Sci.* 19. doi: 10.1093/jisesa/iey110

Morales-Ramos, J. A., Rojas, M. G., Kelstrup, H. C., and Emery, V. (2020). Self-selection of agricultural by-products and food ingredients by tenebrio molitor (Coleoptera: Tenebrionidae) and impact on food utilization and nutrient intake. *Insects*. 11, 827. doi: 10.3390/insects11120827

Naranjo-Guevara, N., Fanter, M., Conconi, A. M., and Floto-Stammen, S. (2021). Consumer acceptance among Dutch and German students of insects in feed and food. *Food Sci. Nutr.* 9, 414–428. doi: 10.1002/fsn3.2006

Niles, M.T., Bertmann, F., Belarmino, E.H., Wentworth, T., Biehl, E. and Neff, R. (2020). The early food insecurity impacts of COVID-19. *Nutrients*. 12, 2096. doi: 10.3390/nu12072096

Ojha, S., Bußler, S., and Schlüter, O. K. (2020). Food waste valorisation and circular economy concepts in insect production and processing. *Waste Management*. doi: 10.1016/j.wasman.2020.09.010

Oonincx, D. G. A. B., and 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: 10.1371/journal.pone.0051145

Oonincx, D. G. A. B., and Finke, M. D. (2020). Nutritional value of insects and ways to manipulate their composition. *J. Insects Food Feed*. 1–22. doi: 10.3920/jiff2020.0050

Patel, S., Suleria, H. A. R., and Rauf, A. (2019). Edible insects as innovative foods: Nutritional and functional assessments. *Trends. Food Sci. Technol.* 86, 352–359. doi: 10.1016/j.tifs.2019.02.033

Phan, C., Phi, V., Walraven, M., Bézagu, M., Lefranc, M., and Ray, C. (2020). Industrial symbiosis in insect production-a sustainable eco-efficient and circular business model. *Sustainability*. doi: 10.3390/su122410333

Pinotti, L., Giromini, C., Ottoboni, M., Tretola, M., and Marchis, D. (2019). Review: Insects and former foodstuffs for upgrading food waste biomasses/streams to feed ingredients for farm *animals*. *Animals.* 13, 1365–1375. doi: 10.1017/S1751731118003622

Pliny the Elder. (77 CE). "*The Natural History of Pliny* (Vol. 3)" In, Bohn, Bostock, J., Riley, H., Trans, eds. (Web translation published (2019). Available online at: https://www.gutenberg.org/files/59131/59131-h/59131-h.htm#Footnote_3179_3179

Ramos-Elorduy, J. (2009). Anthropo-entomophagy: Cultures, evolution and sustainability. *Entomolog. Res.* 39, 271–288. doi: 10.1111/j.1748-5967.2009.00238.x

Reverberi, M. (2021). The new packaged food products containing insects as an ingredient. *J. Insects Food Feed*. 1–8. doi: 10.3920/JIFF2020.0111

Rozin, P., and Ruby, M. B. (2020). Bugs are blech, butterflies are beautiful, but both are bad to bite: Admired animals are disgusting to eat but are themselves neither disgusting nor contaminating. *Emotion*. *20*, 854–865. doi: 10.1037/EMO0000587

Ruby, M. B., and Rozin, P. (2019). Disgust, sushi consumption, and other predictors of acceptance of insects as food by Americans and Indians. *Food Qual Prefer*. *74*, 155–162. doi: 10.1016/J.FOODQUAL.2019.01.013

Rumbos, C. I., and Athanassiou, C. G. (2021).'Insects as Food and Feed: If You Can't Beat Them, Eat Them!'-To the Magnificent Seven and Beyond. *J. Insect Sci.* 21, 9–10. doi: 10.1093/jisesa/ieab019

Russell, P. S., and Knott, G. (2021). Encouraging sustainable insect-based diets: The role of disgust, social influence, and moral concern in insect consumption. *Food Qual Prefer*. 104187. doi: 10.1016/j.foodqual.2021.104187

Schösler, H., de Boer, J., and Boersema, J. J. (2012). Can we cut out the meat of the dish? Constructing consumer-oriented pathways toward meat substitution. *Appetite.* 58, 39–47. doi: 10.1016/j.appet.2011.09.009

Schrader, J., Oonincx, D. G. A. B., Ferreira, M. P., Schrader, J., and Oonincx, D. G. A. B. (2016). North American entomophagy. *J. Insects Food Feed*. 2, 111–120. doi: 10.3920/JIFF2016.0003

Seekings, T. (2020). The proof is in the cricket: engaging with edible insects through action research Cricket Farming View project edible insects in Taiwan View project. *J. Insects Food Feed.* 6, 2. doi: 10.3920/JIFF2019.0027

Shelomi, M. (2015). Why we still don't eat insects: Assessing entomophagy promotion through a diffusion of innovations framework. *Trends Food Sci. Technol.* 45, 311–318. doi: 10.1016/j.tifs.2015.06.008

Shepon, A., Henriksson, P. J. G., and Wu, T. (2018). Conceptualizing a sustainable food system in an automated world: toward a "eudaimonian" future. *Front. Nutr.* 5, 104. doi: 10.3389/fnut.2018.00104

Shuliy Machinery (2020). *Mealworm Drying Machine | Microwave Dryer*. Mealworm Machine. Available online at: https://mealwormmachine.com/mealworm-drying-machine-microwave-dryer/

Siemianowska, E., Kosewska, A., Aljewicz, M., Skibniewska, K. A., Polak-Juszczak, L., Jarocki, A., et al. (2013). Larvae of mealworm (Tenebrio molitor) as European novel food. *Agri. Sci.* 04, 287–291. doi: 10.4236/as.2013.46041

Silva, L. B., Gomes De Souza, R., Ribeiro Da Silva, S., Da, A., Feitosa, C., Lopes, E. C., et al. (2020). Development of Tenebrio molitor (Coleoptera: Tenebrionidae) on Poultry Litter-Based Diets: Effect on Chemical Composition of Larvae. *J. Insect Sci*. doi: 10.1093/jisesa/ieaa145

Smetana, S., Palanisamy, M., Mathys, A., and Heinz, V. (2016). Sustainability of insect use for feed and food: Life Cycle Assessment perspective. *J. Cleaner Prod.* 137, 741–751. doi: 10.1016/j.jclepro.2016.07.148

Smetana, S., Spykman, R., and Heinz, V. (2021). Environmental aspects of insect mass production. *J. Insects Food Feed*. 1–20. doi: 10.3920/JIFF2020.0116

Spencer, M., Kurzer, A., Cienfuegos, C., and Guinard, J. X. (2018). Student consumer acceptance of plant-forward burrito bowls in which two-thirds of the meat has been replaced with legumes and vegetables: The Flexitarian FlipTM in university dining venues. *Appetite*. 131, 14–27. doi: 10.1016/j.appet.2018.08.030

Sun-Waterhouse, D., Waterhouse, G. I. N., You, L., Zhang, J., Liu, Y., Ma, L., et al. (2016). Transforming insect biomass into consumer wellness foods: A review. *Food Res. Int.* 89, 129–151. doi: 10.1016/j.foodres.2016.10.001

Surendra, K. C., Olivier, R., Tomberlin, J. K., Jha, R., and Khanal, S. K. (2016). Bioconversion of organic wastes into biodiesel and animal feed via insect farming. *Renew. Energy*. 98, 197–202. doi: 10.1016/j.renene.2016.03.022

Tomberlin, J. K., van Huis, A., Benbow, M. E., Jordan, H., Astuti, D. A., Azzollini, D., et al. (2015). Protecting the environment through insect farming as a means to produce protein for use as livestock, poultry, and aquaculture feed. *Journal of Insects as Food and Feed.* 1, 307–309. doi: 10.3920/JIFF2015.0098

Townson, M. L. (2019). *Changing Form for Function: Scaling Up Production of Minimally Processed Local Vegetables for Institutional Use*. University of Vermont Extension and Vermont Housing and Conservation Board, 2018

United States Department of Agriculture National Agricultural Statistics Service (2019). *New England Agricultural Statistics Annual Bulletin. USDA National Agricultural Statistics Service New England Field Office, Concord, NH, United States*. Available online at: https://www.nass.usda.gov/Statistics_by_State/New_England_includes/Publications/Annual_Statistical_Bulletin/2019/2019%20New%20England%20Annual%20Bulletin_revised.pdf

Van Broekhoven, S., Oonincx, D. G. A. B., Van Huis, A., and Van Loon, J. J. A. (2015). Growth performance and feed conversion efficiency of three edible mealworm species (Coleoptera: Tenebrionidae) on diets composed of organic by-products. *J. Insect Physiol*. 73, 1–10. doi: 10.1016/j.jinsphys.2014.12.005

van Huis, A. (2013). Potential of Insects as Food and Feed in Assuring Food Security. *Annu. Rev. Entomol.* 58, 563–583. doi: 10.1146/annurev-ento-120811-153704

van Huis, A. (2020). Insects as food and feed, a new emerging agricultural sector: A review. *J.Insects Food Feed.* 6, 27–44. doi: 10.3920/JIFF2019.0017

van Huis, A., and Oonincx, D. G. A. B. (2017) The environmental sustainability of insects as food and feed. A review. *Agron. Sustain. Dev.* 37, 43. doi: 10.1007/s13593-017-0452-8

van Huis, van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., et al. (2013). *Edible Insects - Future prospects for food and feed security*. Food and Agriculture Organization of the United Nations.

Van Raamsdonk, L. W. D., Van der Fels-Klerx, H. J., and De Jong, J. (2017). New feed ingredients: the insect opportunity. *Food Addit. Contam*. 34, 1384–1397. doi: 10.1080/19440049.2017.1306883

Vandermeer, J., Aga, A., Allgeier, J., Badgley, C., Baucom, R., Blesh, J., et al. (2018). Feeding Prometheus: An Interdisciplinary Approach for Solving the Global Food Crisis. *Front. Sustain. Food Syst*. 2, 39. doi: 10.3389/fsufs.2018.00039

Verbeke, W. (2015). Profiling consumers who are ready to adopt insects as a meat substitute in a Western society. *Food Qual. Pref.* 39, 147–155. doi: 10.1016/j.foodqual.2014.07.008

Villaseñor, V. M., Enriquez-Vara, J. N., Urías-Silva, J. E., and Mojica, L. (2021). Edible insects: techno-functional properties food and feed applications and biological potential. *Food Reviews International* 1–27. doi: 10.1080/87559129.2021.1890116

Wegier, A., Alavez, V., Pérez-López, J., Calzada, L., and Cerritos, R. (2018). Beef or grasshopper hamburgers: The ecological implications of choosing one over the other. *Basic Appl. Ecol.* 26, 89–100. doi: 10.1016/j.baae.2017.09.004

Woolf, E., Zhu, Y., Emory, K., Zhao, J., and Liu, C. (2019). Willingness to consume insect-containing foods: A survey in the United States. *LWT*, 102, 100–105. doi: 10.1016/j.lwt.2018.12.010

Yang, Y., Yang, J., Wu, W. M., Zhao, J., Song, Y., Gao, L., et al. (2015). Biodegradation and mineralization of polystyrene by plastic-eating mealworms: Part 1. *Chemical and physical characterization and isotopic tests. Environ. Sci. Technol.* 49, 12080–12086. doi: 10.1021/acs.est.5b02661

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.