Environmental Sustainability of Large Scale Cricket Farmers

By:

Ellena R Ignacio

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Abstract

In 2013, the Food and Agriculture Organization of the United Nations published a 200-page report about the future prospects of edible insects for food and feed security. Advocating for the introduction of insects as an alternative protein source. Crickets were one of the edible insects identified as having significant nutritional value for human consumption and having less environmental impact than current livestock production. As we face increasing population, global climate change and continuous degradation of natural resources the development of sustainable alternative agricultural systems like cricket production is very important. Currently there are no federal regulations or guidelines for cricket farming to ensure environmental sustainable practices. Analysis of current cricket farming methods is necessary in order to provide appropriate environmental recommendations for potential cricket farming guidelines that will improve cricket yield. This study aimed to compare the first life cycle assessment conducted on cricket farming to a life cycle assessment of cattle production and found that large scale cricket farming is environmentally sustainable as an alternative protein source.

Introduction

One major environmental issue we face today is overpopulation. As the human population continues to grow the population is expected to reach 9.5 billion by 2050 ("Carrying Capacity," 2016). Scientist are concerned about the carrying capacity for human life on Earth as natural resources are diminishing as a result of human impact. So, great is the impact on the earth that Geologist have declared a new geological epoch, the Anthropocene. We depend heavily on agricultural and livestock production to continue to meet food security and the demands of consumer needs. However, our excessive agricultural and livestock production increases greenhouse gas emissions, causes deforestations and environmental degradation. According to Edward Wilson, a Harvard University socio-biologist, the carrying capacity of Earth is a little over 10 billion people. His estimate is based on food availability (Wolchover, 2011). There are many other scientists that have also concluded the same estimated maximum carrying capacity (Wolcho ver, 2011). As the population grows food production will need to increase. Knowing this sustainable agriculture offers a solution to food scarcity and resource depletion.

One underappreciated food source is insects' production. Insects have nutritious value that many neglect to see due to stigmas associated with insects in various cultures (Food and Agriculture Organization of the United Nations, 2014). The Food and Agriculture Organization of the United Nations, recognizing the benefits of insects as a sustainable food source, has made efforts to popularize and quell misunderstanding about edible insects.

Today crickets are one of the most popularized sources of insect protein today and there has been a number of startup companies specializing in the farming of crickets (Rodriguez, 2013; Gould, 2013). They are becoming a suitable replacement for protein for human consumption, livestock feed, and aquaculture feed. As the cricket industry begins to rise and expand it is important to continue to ensure that the process of cricket farming remains environmentally sustainable among large farms. Therefore, an analysis and comparison of a life cycle assessment of cricket farming and cattle production is necessary to determine whether large scale commercial cricket farming is environmentally sustainable.
If cricket farming is sustainable than they have the potential to be a reliable alternative protein source.

Literature Review

Life Cycle of a Cricket

The term Cricket is generally used when referring to "true crickets", insects in the family Gryllidae. Crickets are omnivores. They consume almost anything. Some feed on plant matter, dead decaying matter, or other insects. They can be found almost anywhere. Many crickets are nocturnal. Distinguishing characteristics of true crickets are their cylindrical bodies, round heads and three segmented tarsi. The tarsi are the segmented parts of the insect leg that is attached to the end of the tibia. The number of tarsi present is a useful identification tool among insects. Crickets are variations of brown or black. They are similar to grasshoppers however; their antennae are very long and their wings are held flat over the body. The abdomen ends in a pair of long cerci, ------Female crickets have a long, cylindrical ovipositor that very noticeable protrudes from the back end. The ovipositor is a tubular organ through which the female cricket deposits eggs into soil or plant matter. Crickets undergo an incomplete metamorphosis. Once the nymphs hatch from the eggs their appearance is similar to adult crickets. They are not fully developed; lacking wings and females do not have ovipositors. Nymphs undergo the process of molting, the shedding of its exoskeleton many times until it becomes an adult. The adult cricket reaches maturity when its wings are fully developed. The number of molting may vary among cricket species.

Nutritional Compositions

In a study conducted by Rumpold and Schluter (2013) after compiling nutritional compositions of 236 edible insects, results showed that many of these insects provided satisfactory amounts of energy and protein necessary for human amino acid requirements. Amino acids are required for the breakdown and synthesis of proteins in the body including nitrogen composed compounds that form creatine and some neurotransmitters (Trumbo, 2002). They are also “high in monounsaturated and/or polyunsaturated fatty acids, and are rich in micronutrients such as copper, iron, magnesium, manganese, phosphorous, selenium, zinc, as well as riboflavin, pantothenic acid, biotin and in some cases, folic acid” (Food & Agriculture Organization, 2014). A 200-calorie serving of crickets contained more grams of protein than

90% lean beef (Figure 1). Further evaluation of protein content of 100 species of insects by Xiaomin et al. (2010) revealed that Orthopteran, the order of crickets, have a high crude protein range from 23% to 65% (Figure 1). The crude protein range accounts for the stages of the insect life cycle in which the size and protein content may vary.

200-CALORIE SERVING	PROTEIN	FAT	SATURATED FAT	OMEGA-3	FIBER
Crickets	31g	8.1g	2.6g	1.8g	7.2g
Mealworms	16.2g	14.8g	4.9g	3.3g	2.5g
Salmon, farmed	20.4g	13.4g	3g	2.5g	0g
Whole eggs	19.2g	15.2g	4.8g	0.1g	0g
Beef (90% lean)	22.4g	11.2g	4.4g	0.04g	0g
Tofu	24.6g	12.6g	2.7g	0.5g	2.7g

Sources: USDA SR-25 and Nutritional composition and safety aspects of edible insects, Birgit A. Rumpold and Oliver K. Schluter Mol. Nutr. Food Res. 2013, 57, 802–823.

The results from an analysis of energy content of 78 insect species by Ramos Elorduy et al. (1997). Energy content is expressed in kilocalories per 100 g of fresh weight, dried insects, of farmed and wild insects worldwide. According to Ramos Eldordys et al. (1997), raw field crickets have an energy content of 120 kcal/100 g. The energy contents may change depending on the diet of the insects (Food & Agriculture Organization, 2014). Nutritional value could be enhanced using different feeds during farming of crickets. The minimal required energy content could be managed by altering the diet of the crickets. Manufacturers and companies could then market crickets based on energy content.

Research conducted by Rikkyo University on the healthiness of edible insects in comparison to commonly consumed meats using the Nutrient Value Score profiling model further supports the reliability of crickets as a form of protein. The model is “based on quantities of energy, protein, fat and eight micronutrients measured per 100 g (or relevant, food basket-specific quantity) of food to evaluate the relative nutritional quality of foods" (Payne et al. 2015). Figure 2 displays the median values and interquartile range of Nutrient Value Scores for insects, beef, chicken, pork and offal. Offal consists of internal organs and entrails of butchered animals. Food with a higher Nutrient Value Score is associated with being overall healthier. Crickets had a significantly higher nutrient value than livestock meat. Their nutritional significance over other protein source elevates its potential to be an alternative protein source. Its usefulness is why it is important to evaluate upscale cricket productions environmental sustainability before reliance on cricket protein becomes accepted worldwide.

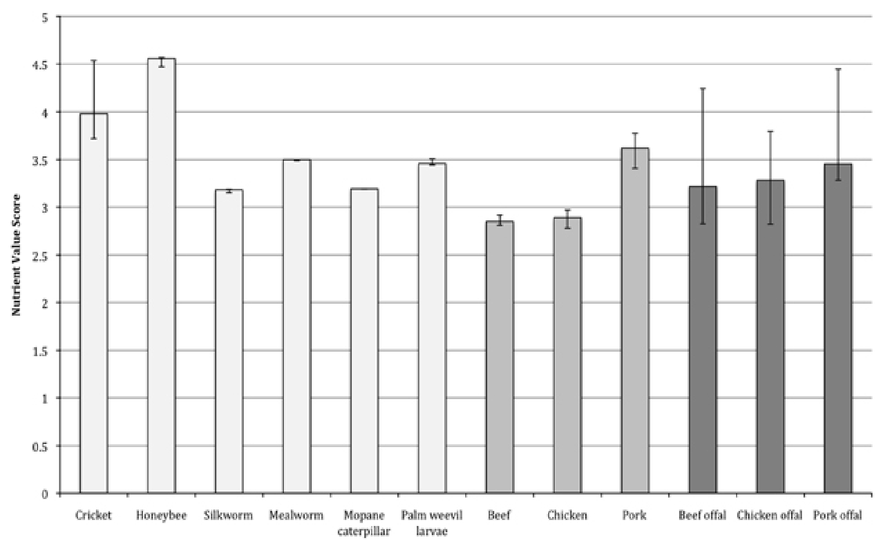

Figure 2: This figure shows the nutritional value of insects compared to traditional sources of protein.

Source: Food and Agriculture Organization of the United Nations. "Nutrition ." Insects for food and feed. Food and Agriculture Organization of the United Nations, 14 Jan. 2014. Web. 14 May 2017.

Environmental Sustainability

In 2006, the United Nations Food and Agriculture Organization released a report that projected that 18% of global Greenhouse Gas emissions were a result of agricultural livestock such as, poultry, pigs, sheep, cattle, and buffalo (Steinfeld et al., 2006). Further analysis by Robert Goodland and Jeff Anhang estimates that livestock and its byproducts are responsible for at least 32.6 billion tons of carbon dioxide annually or 50% of global GHG emissions (Goodland

and Jeff, 2009). However, insects were observed to emit less GHG and ammonia emission than commonly reported emissions of pigs and cattle. An experiment conducted by Dennis Oonincx et al. (2010) quantified the production of CO_2 and feed conversion efficiency to measure methane, nitrous oxide and ammonia. Methane and nitrous oxide are greenhouse gases that contribute to global warming while ammonia from livestock manure and urine can cause nitrification and acidification of the soil (Oonincx et al., 2010). It is estimated that 64% of the total anthropogenic ammonia emissions is a result of agricultural livestock rearing (Goodland and Jeff, 2009). Crickets produce far less GHG than traditional meats. They seem to produce the smallest amount in comparison to locust and mealworms but, it produces more ammonia. It is still significantly smaller amount of ammonia emission than pigs. Therefore, this study supports the use of crickets as an environmentally sustainable alternative for protein with respect to ammonia and GHG emissions.

Raising livestock requires more plant protein feed for an equal amount of animal protein. The conversion rate from feed to meat for livestock is far more disproportionate than that of crickets. It takes "1 kg of live animal weight in a typical United States production system requires the following amount of feed: 0.5 kg for chicken, 5.0 kg for pork, and 10.0 g for beef (Smil, 2001). While it takes at least 1.7 kg of feed for 1 kg of live animal weight in crickets (Collavo et al., 2005). Up to 80% of a cricket is consumable unlike livestock which, has a significant portion that is not consumed. This is an advantage to eating insect because only "55 percent of chicken and pig and 40 percent of cattle" is edible (Nakagaki, De Foliart, 1991). Crickets are two times more efficient at converting cattle.

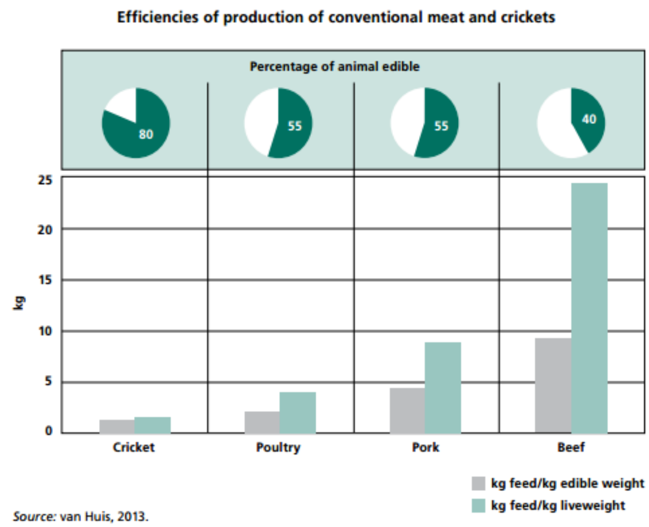

Figure 3: This chart shows the efficiencies of production of conventional meat and crickets from research conducted by Van Huis in 2013.

These studies have provided valuable insight and support of crickets as an environmental sustainability protein sources and a solution to current and future food crises. However, these studies do not evaluate the environmental performance of large scale cricket farming systems. They focus more on isolating variables of the cricket production. Until recently there existed no life cycle assessment of the cricket farming system. The environmental impacts of mass production of crickets on a commercial level were never quantified. The first case of a life cycle assessment on the cricket farming system was published on July 10, 2017. The assessment was performed on an existing production system of Gryllus bimaculatus (field cricket) and Acheta domesticus (house cricket) production in north-eastern Thailand and compares it with the broiler production in the same region. This study relies on the life cycle assessment conducted in Thailand to examine and compare the environmental impacts associated with cricket farming as a system for mass production.

Lack of FDA Regulations

Amidst the various research that exists and the evidence provided in support of the environmental sustainability of crickets as an alternative protein source to livestock. The sustainability of mass production of crickets on a commercial level is vague. Cricket farming has been occurring around the world for centuries but, on relatively small scale individual bases. Cricket farming in the United States has skyrocketed in the last ten years. Since the industry is relatively new there are no FDA regulations specific to insect products nor is there an established framework for insect farming. As it stands current FDA regulations can be applied to edible insects even though they are not explicitly stated because the FDA says, “the term “food” means (1) articles used for food or drink for man or other animals, (2) chewing gum, and (3) articles used for components of any such article” (Food & Drug Administration, 2007). Insects are only mentioned in regulations pertaining to the Food Defect Action Levels which, discusses the unavoidable presence of insects in some agricultural products. Although the current regulations do ensure that products are labeled, do not contain harmful substances, and “must be raised specifically for human food following Good Manufacturing Practices, these regulations are based on known food products. We do not have a full grasp of insect allergies and toxins, nor is there research on proper safety practices needed for mass production of edible insects. With a lack of guidance cricket farmers are left to their own devices in creating a system for cricket production. These cricket farmers are looking for ways to maximize their profit and may not be considering the sustainability of their farms. They may not know of any sustainable efforts. This freedom means that cricket farms around the United States may drastically differ in farming methods with varying degrees of environmental sustainability.

Cricket Farming Techniques

Field crickets, *Gryllus bimaculatus*, and house crickets, *Acheta domesticus*, along with *Teleogryllus testaceus* and *Telegryllus occipitails* are species that have been successfully farmed. These crickets are most commonly used for human consumption or animal feed and are purchased alive or dead. The farming process begins with the breeding of crickets. Crickets are bred in various containers that maybe covered with mosquito nets to keep out pests and predators. The containers can be lined with layers of rice husk or cardboard egg cartons to act as bedding, but some breeders do not use any materials for bedding. Bowls with a mixture of husk and sand are placed in breeding containers when male crickets stridulate. Stridulation is the production of sound created by male crickets. Their chirping is a way for male crickets to attract females (Ohio, 2005). Within 24 hours after mating the females stick their ovipositors into the soil like mixture and depositing their eggs into the bowls. Farmers remove the bowls and place them in a separate enclosure for incubation and after about fourteen days, it will have developed into a nymph (Cricket Care, 2017).

Cricket farming systems in Thailand are among the most advanced in the world at present (Hanboonsong et al., 2013, Halloran, 2017). In Thailand there are four types of breeding containers used in the cricket farming process. Each container has its limitations and advantages. Concrete cylinder pens ranging from 80 cm in diameter and 50 cm high can potentially contain 2 to 4 kilograms of crickets. They are inexpensive though hard to move and need considerable space. Concrete block pens can produce 15 to 30 kilograms of crickets depending on their space availability but 1.2 by 2.4 by 0.6 meters is common. The rectangular shape maybe an efficient way of using space however, there is a risk of disease outbreak or overheating due to overcrowding inside the pen. Multiple colonies could be destroyed during a disease outbreak in the concrete block pen. Boxes made of plywood or gypsum board at 1.2 by 2.4 and 0.5 meters high can hold produce 20 to 30 kilogram of crickets. Although the boxes are less durable than the concrete pens they are easy to clean and do not lock in heat as much. Plastic drawer are around .8 by 1.8 meters and 0.3 meters high. A set of 3 to 4 drawers can produce 6 to 8 kilograms of crickets. These different types of container all have their environmental advantages and disadvantages and require resources to be made. The materials of the pens contribute to the overall sustainability of farms.

Entomo Farms is a well-known cricket company uses 60,000 square foot barns, renovated from old abandoned chicken barns. There are approximately 100 million crickets in each barn, ranging in different stages of maturation (“The Future of Food”, n.d.). The Vice President of Farming Operations at Entomo Farms, Darren, has created a more efficient way to care for the crickets. He has developed what he calls Cricket Condos. These condos allow the crickets more freedom to move and go to different feeding stations. Crickets are naturally a swarming species and like being in a dark, warm place. The condos mimic how a cricket would live in the natural world. Within the United States crickets are typically kept in plastic or cardboard bins and workers must go through every bin to feed the crickets (“The Future of Food”, n.d.).

Aspire Food Group a seller of edible crickets on a commercial scale raises crickets in large warehouses. Each month, more than 22 million crickets are raised in plastic bins in a 25,000 square foot farm. The company’s original facility required staff to walk around a vertical farm multiple times a day, feeding bins full of crickets on multiple racks. The new system uses a robotic module that travels around the farm, depositing the ideal amount of food; sensors use machine learning and AI to monitor how the insects eat and when they need more (“The Future of Food”, n.d.).

The crickets mate and lay eggs in a dedicated breeding space, and then the hatched eggs are moved to a bin where they grow until harvest. Each bin is monitored with the company's own sensor technology, and each aspect of the cricket's life, from hatching to harvest. The company has seen a tenfold increase in production with the system. Because manual labor at the farm previously accounted for 75% of the cost of goods their newly implemented technology can make cricket-based food cheaper to buy. Other companies are also using technology to farm insects. Tiny Farms, an Oregon-based startup, also uses data analysis and automation to rear crickets, and opened a pilot farm in San Leandro, California, in 2016. But while Tiny Farms creates modules that can be used on a small scale, arguing that it makes sense to raise insects in a distributed way, Aspire believes that larger farms are needed (Aspire Groups, n.d.). The size of cricket farms based on the amount of land used and the materials used to build the farm also contributes to the sustainability of the system.

Cricket Feed & Water

As stated previously crickets are omnivores. They will eat just about anything that is available to them. It is important that the crickets are not malnourished or it may lead to cannibalism. Cricket feed is commonly used by farmers. There are various types of cricket feed that contain different ingredients such as soybean meal, palm oil, salt, and fish meal. Dairy products can also be used as part of the dry or wet food sources. Dry milk is often used as an ingredient in cricket gut loading recipes. Gut loading is a term used to describe the process of stuffing your crickets with lots of nutritious foods right before you feed them to your lizards, frogs, or any other pet. Typically, a gut load consists of a mixture of all of the healthiest foods that you are already feeding to your crickets. The difference between regular feeding and gut loading is that when you gut load, you are combining multiple types of foods together to overload the nutritional value. The process of manufacturing cricket feed maybe detrimental to the environment and there is a possibility that the benefits of large scale cricket production maybe negated by the impact of feed production. Thus, examination of the cricket production system in comparison to cattle production is necessary.

Water is a crucial part of a cricket's diet. In mass production of crickets free standing water is avoid due to the risk of crickets drowning in it. Drowning is more likely occur in the breeding and mass production of crickets because there can be thousands of crickets in a container at one time. Overcrowding of the container can cause crickets to accidently fall into the water and drown. There are alternative ways in which farmers provide water to crickets. A damp sponge is sometimes used. The sponge must not be dripping with water but have just the right amount of saturation. Pieces of vegetables and fruit can also be fed to crickets. They are an indirect way to provide crickets with a water source. There are some manufactured dry gel crystals that provide nutrients in the same way water would.

With the development of cricket farming techniques continuing to expand there is a need to evaluate the different environmental impacts these methods may have. To what capacity do certain farming practices influence sustainability of the mass cricket production system? With a lack of FDA regulation and overview on the sustainability of these methods, this study hopes to create a platform for future analysis by determining if large scale cricket farming is environmentally sustainable when compared to cattle production, the primary source of protein.

Methods

This study will examine the environmental sustainability of cricket production by using life cycle assessments to compare the full range of environmental impacts that result between cricket and cattle production. Specifically, a comparison of a cricket production system in north eastern Thailand to cattle production in Denmark. Cattle production was chosen as a benchmark for comparison because beef is a significant source of protein in the United States. Cattle production is one of the largest systems of protein production that is scrutinized for its large amounts of water and feed usage. The life cycle assessment of cricket farming used within this study was the first LCA conducted on an existing production system of *Gryllus bimaculatus* (field cricket) and *Acheta domesticus* (house cricket). While data used to calculate environmental impacts of cattle production was acquired from the LCA Food Database of Denmark. A database that provides environmental data on processes in food products' product chains and on food products at different stages of their product chains (Nielsen, Nielsen, Weidema, Dalgaard, Halberg, 2003).

Cricket Farm Description

The cricket LCA conducted by Halloran et al. was based on a cricket farm located in Mahasalakam Province in north eastern Thailand. The selected cricket farm was a medium-scale production system of 2720 m^2 located in the village of Nacheung. The buildings contained a total of 78 pens of various sizes (average of 9.43 m2). The farm reared both G. bimaculatus (48% of total production by mass) and A. domesticus (52% of total production by mass). Thirty-eight of the pens were dedicated to the production of G. bimaculatus and the remaining 38 were used for A. domesticus. The average life cycles of G. bimaculatus and A. domesticus were estimated as 42 and 49 days respectively. The farm produced approximately 8.5 cycles of crickets per year.

Cattle Farm Production Data

Little descriptive information was provided on the farm in Denmark that the data was gathered from. However, it is known that the data is representative of one farm and not aggregated averages of the collective farms within Denmark. The Denmark farm uses slaughterhouse waste such as bones and intestines to be converted into bone and blood meal. The products were previously used as ingredient in animal feed but the Denmark farm incinerates waste due to fear of BSE, mad cow disease. The contributions to global warming from these processes are too small and were not included in the data for cattle production. The unprocessed data provided by the LCA Food Database was used to perform a life cycle assessment in order to compile environmental impacts from cattle production. SimaPro, a LCA software, was used to analyze the data to provide a sustainability report and calculate environmental impacts and services throughout the life cycle stages of cattle production. Environmental inputs and outputs associated with the production process of cattle farming were estimated by summarizing the inputs and outputs (Q1) from the entire production process in the production chain (p).

Equation: $Q_i = \sum Q_{i,p}$

Environmental impacts associated with specific substances (i) emitted in the production chain were determined by multiplying total emissions of substances (Q_i) with specific equivalency factors ($EF(j)_i$) for specific categories of impacts (j).

Equation: $EP(j)_i = Q_i \times EF(j)_i$

System Boundaries

The study covered the production of construction materials, energy, transportation and the feed production process at mills. Processing and transportation processes were also included. Thus, the systems boundaries did not cover farm gate to retail.

Results

Based on the total annual resource inputs for cricket and cattle production, the cricket farm used less feed and water annually compared to cattle production. The Thailand cricket farm produced 36,741 kg of edible mass far less that the Cattle farm which produced 11.9 billion kilograms of meat. Cattle farming required 1,762 liters of water per 1 kg of protein significantly more than 1.85 liters for 1 kg of cricket protein. Cattle production also required significantly more feed per 1 kg of protein in comparison with the cricket production. The overall environmental impacts associated with cattle production were greater than cricket production. When considering 1 kg of protein as the functional unit of comparison, cattle production has a notably higher acidification potential of 0.43 Mole of H + eq compared to 0.08 Mole of H + eq from cricket farming, global warming potential of 42.4 kg CO2 eq compared to 2.57 kg CO2 eq, and 8.8 kg NMVOC photochemical ozone formation potential compared to 0.013 kg NMVOC.

Table 1. Comparison of Resource Inputs in Cattle and Cricket Production

Variable	Cricket	Cattle
Edible Mass (kg)	36741	11.9 x 10^9
Inputs Per 1 kg of Protein		
Water (L)	1.85	1,762
Feed (kg)	2.02	65.04

Table 2: Comparsion of environmental impacts of 1 kg of protein.

Impact Category	Unit	Crickets	Cattle
Global Warming	kg CO2 eq	2.57	42.4
Acidicifcation	Moles of H+ eq	0.08	0.427
Photochemical ozone formation	kg NMVOC	0.013	8.8

Discussion

Based on the data that has been processed regarding resource inputs and environmental impact, large scale cricket farming is far more environmentally sustainable than cattle production. The environmental impact categories analyzed in the cattle LCA were used as a comparison to the cricket LCA impact categories because they were the only impacts that were calculated using the same functional units. An accurate comparison of environmental impact cannot be conduct between different functional units. Although only three environmental impact categories were analyzed they are important indicator of sustainability. Global warming potential indicated the contribution of carbon dioxide to the greenhouse effect. Global warming is one of the major environmental issues the world faces today. Adopting alternative protein sources such as cricket farming that contributes less to global warming has the potential to be an environmentally sustainable move forward. A comparison of eutrophication potential between both farms was not conducted because the cricket LCA did not provided a holistic examination of eutrophication. However, a comparison of acidification of land and water was made between each farm. The photochemical ozone formation impact category was an important measure for estimating non-methane volatile organic compounds potential for forming atmospheric oxidants.

Energy use is a variable of comparison that was not used in this study but, is an important input that should be included if this study was to be conducted again. Energy usage was not used because the cricket LCA did not calculate energy input. Energy input needs to be calculated in the cricket LCA because farms have to be conscious of temperature during the developmental period of a cricket's life cycle. Farms may utilize heaters to maintain a constant temperature and cricket farms do depend on electricity for lighting so, energy usage occurs. If cricket farming becomes more industrialized it may require more energy than cattle production. Thus, an examination of energy use is necessary.

This research can aid in the development of efficient and environmentally sustainable farming methods for crickets. As mentioned previously, there are no cricket specific FDA or USDA regulations or guidelines for farming crickets. Results of this study showed that the upscale production system of crickets remains environmentally sustainable in comparison with cattle production. Therefore, serious consideration of FDA and USDA regulations are necessary because of the viability of cricket farming indicated by this study. A starting point in creating cricket farming regulations would be to establish accepted farming methods that are the most environmentally sustainable. Continued research would focus on the life cycle assessments of several cricket farms with different farming methods. All farms would be evaluated based on environmental impact. Farming methods that have the least amount of environmental impact on the farm could be used as a standard farming regulation. This study would be significantly beneficial to cricket farmers. Cricket farmers like most farmers are not all experienced environmental scientist. Analysis of multiple cricket farming methods within the United States would allow U.S. farmers to take the time to evaluate their methods. Results of the study could encourage them change their current practices to more efficient and environmentally sustainable methods. Thus, the life cycle assessment comparison between cricket and cow farming systems is a stepping stone to continued in-depth research on industrialized cricket farming systems. Future researchers could build upon this study.

Although environmental impact data derived from life cycle assessments of cricket farming system in the United States are difficult to find. These issues are due to the lack of research conducted on cricket farms within the United States. There are numerous studies that are accessible and show individual components of sustainability for cricket production but there has only been one environmental assessment of the entire functionality of a cricket farm. More research is needed. However, the same explanation cannot be said for the availability of life cycle assessment data on U.S. livestock production. Life cycle assessments conducted on U.S. livestock production are not as easily accessible in comparison to other countries. While searching databases such as the World Bank and the U.S. Department of Agriculture for livestock life cycle assessment data, only economic and statistical data of livestock production was discussed. The United States lacks life cycle inventory databases for livestock production. There is more available data for feed production, dairy production and crop production then livestock production. It is important that the U.S. store and collect data on assessments that focus more on livestock production and the meat portion of our food sector, ensuring environmental oversite and implementation of sustainable production methods.

There are a few databases that contain worldwide life cycle assessment inventory data however, of the databases encountered in this study, most of them required a paid subscription. Limiting accessibility of LCA inventory data prevents the inventories from being used as secondary data in LCAs. Not every material input or output of a system can be collected for an LCA. In such cases, secondary LCA data from LCA inventory databases are heavily relied upon. Having open databases that do not require any form of monetary gain is not unprecedented. There are numerous European countries that are transparent in their disclosure of LCA data on basic food products produced and consumed, providing aggregated data of emissions, waste and material usage. Due to lack of availability of U.S. livestock production data, LCA data of cattle production from Denmark was used in this study. Denmark was ranked 13th out of 180 countries on the 2016 Environmental Performance Index according to the Yale Center for Environmental Law & Policy. The EPI is a method of quantifying and numerically marking the environmental performance of a state's policies. With the United States EPI being twice that of Denmark there may be some differences in the life cycle assessment of cattle production between Denmark and the United States. The United Sates cattle production may be less environmentally sustainable then that of Demark because Denmark has stricter environmental policies and regulations.

This study relied heavily on the data from life cycle assessment of cricket farming in northeastern Thailand. The life cycle assessment depended on data and assumptions about the efficiency with which feed is converted into animal based food. Large differences can be seen in studies that use different feed sources for experiments with crickets and therefore the conclusion of the study is not without uncertainties. The life cycle assessment method for examining the cricket production also needs to be evaluated because there are some inputs and outputs as well as environmental impacts that were not able to be quantified in the first ever cricket LCA.

Similar to the findings of this study, Smetana et al. (2016) found that protein diets are responsible for high environmental impacts and high insect yields. Major improvements can be made in the sourcing of local feed ingredients. One of the advantages of insects over traditional livestock is that they are able to live on feed from other sources (van Huis et al., 2013). As other studies, have shown, these sources could come from "surplus production and perhaps even waste side streams or ingredients" that cannot be used for feeding traditional livestock species (Collavo et al., 2005; Lundyand Parrella, 2015; Oonincx et al., 2015; Smetana et al., 2016). It is importance for cricket and cattle farms to use natural resources efficiently, generating socioeconomic benefits for farmers, and generating safe, nutritional and economically-viable animal feeds. As such, this presents both an opportunity and a challenge for the expanding cricket farming.

The high cost of commercial feed is already one of the main disadvantages of rearing crickets (Hanboonsong et al., 2013; Caparros Megido et al., 2016). Another future scenario that maybe more economically viable could be the use of surpluses and waste from vegetable production as cricket feed. This may also be more desirable from an environmental perspective. This is because although high-protein feeds result in the lowest feed conversion ratios and are thus most efficient (Tongpool et al., 2012), the high impact associated with the production of the feed could mean that alternative feed sources could help decrease the environmental impacts. Future research into the economics and environmental consequences of alternative feed sources for cricket production is highly relevant. This study is the first attempt to compare the systems of cricket farming with cattle production. Although this study has found that cricket production is more sustainable then cattle production it does not suggest that cricket production is sustainable overall. Further research is still needed to accesses the cricket productions sustainability in comparison with other protein sources.

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