



Research article

Insects' contribution to the bioeconomy and the reduction of food waste

Eili Skrivervik*

Centre for Technology, Innovation and Culture, University of Oslo, Moltke Moes vei 31, 0851 Oslo, Norway



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ABSTRACT

The growing global population and awareness of the unsustainability of livestock production have led consumers, companies, organizations, and governments to consider entomophagy (eating insects) as a more sustainable option. Minilivestock offers advantages over traditional livestock production: with greater diversity, higher nutritional levels, higher energy efficiency, higher reproductive rates, lower environmental footprint, and lower costs. This article aims to demonstrate how the successful implementation of entomophagy in the West can positively contribute to the bioeconomy. The article does this by exploring entomophagy, presenting novel research on entrepreneurs in insect farming, and introducing food waste as a free, plentiful, and sustainable feed resource for insect farms. Although none of the insect farms included in this research showed any links between insect farms and food waste reduction, this is expected to change as the industry matures.

1. Introduction

While demand for food is increasing the available resources for food production are declining (Premalatha et al., 2011): by 2050 food production will need to increase with 60%, compared to 2005/2007 numbers, to meet the demand from the growing global population (FAO, 2013). Production of livestock reportedly occupies 30 percent of all land area and 70 percent of the agricultural land on the planet, using 77 million tons of protein (from plants and animals) to produce 58 million tons of protein for human consumption yearly (Premalatha et al., 2011). A reported one-third of the food produced is thrown away, with direct environmental consequences; including wasted energy and resources, and correlated greenhouse emissions (FAO, 2013; Salomone et al., 2017; Surendra et al., 2016).

In recent years the bioeconomy has received increased attention (see graph 1 on page 9) for being considered an essential part of the solution to fix the broken food system. In the current economy, organic waste represents the loss and waste of the valuable resource that is food, and efforts are made to reduce the loss. The bioeconomy is one of such efforts. In the bioeconomy, organic waste represents a valuable resource in itself, through the full exploitation of organic waste. Discarded food is turned into valuable products such as biomaterials, biochemicals, and biopharmaceuticals (Klitkou et al., 2019). This contributes to a circular economy where food waste is not wasted but reused.

Insects are considered a potential solution to the challenges the current food system is facing (Verbeke, 2015; Hartmann et al., 2015) and has

in recent years received increased attention worldwide (FAO, 2013; EFSA Scientific Committee, 2015). Contrary to regions in Africa, Latin America, and Asia, where eating insects is rooted in tradition, entomophagy has no roots in Western society today (Van Huis and Oonincx, 2017). In the latter, insects are more closely associated with disgust than potential food; labels such as “unclean” and “dangerous” presents challenges in terms of successful implementation and acceptance (Tan et al., 2016b; Gere et al., 2017; Hartmann and Siegrist, 2016).

Growing food waste levels in the West is considered a serious environmental, political, and social issue. Using food waste as feed on insect farms holds the possibility to reduce food waste levels while offering free, nutritious, and plentiful feed for the growing number of insect farms. Reducing food waste levels is good for the environment, and so it can be deduced that using food waste as feed for insects on insect farms could benefit the environment. The research question guiding the research is: Can insect farming make a significant contribution to food waste reduction? This research is intended to contribute to a broader discussion about the bioeconomy and food waste reduction, through looking at entomophagy in Western society, and some of the pioneers in insect farming. In this study, these pioneers work as representatives for the industry in Western culture. This article will investigate the link between using food waste as feed on insect farms, introducing insects as human food in the West, and the relationship between insect farms and the bioeconomy.

Studies that look at how insects can reduce food waste include Salomone et al. (2017), Surendra et al. (2016), Pleissner and Rumpold

* Corresponding author.

E-mail address: eili.skrivervik@tik.uio.no.

(2018), and Cicková et al. (2015). The focus in this article is on entrepreneurs in the industry and on insect farms, which none of the mentioned articles look at. As well as lacking information on the entrepreneurs and how the farms are run, information on innovations, technologies, and methods used to ensure efficiency and low costs are absent from literature in the field. Minimal data exist on how insect farms influence their local environment and the environment in general. In the existing literature in the field there is also very little knowledge on food safety issues such as pathogens, toxins, and metals. This insight is considered necessary to ensure that insect farms are operating safely and sustainably. Salomone et al. (2017) reported having found only two studies looking at emissions from insects (that were published in an international scientific journal, written in English). Other texts on the topic of edible insects investigate insects as feed for livestock and aquaculture.

To observe innovation and innovators is necessary if one wishes to understand any sector: what they are producing, how they are working, which technologies are implemented and invented, and which considerations and priorities are made. This article is starting that process looking into which products and insect species a few of the entrepreneurs on the market today are focusing on. Innovators are the frontrunners for the rest of the industry, creating data, systems, and a new market for others to follow. In the case of insect farms, it is crucial to observe the entrepreneurs not only because this is a new sector but due to the industry's desperate need for data - on trials and errors, new technologies, products, and ecosystems. Gathering, assessing, and understanding data about the current state of this industry will set the tone for future development.

2. Methods

2.1. Terminology

When looking at edible insects, it is necessary to explain the intended meaning behind the term "edible." The word is often used when referring to something that is not hazardous to eat. It is also used to describe something that does not look or smell appealing. The term is used loosely about foodstuffs that are both toxic and safe to consume, which is both confusing and sensible since toxicity varies depending on amount (most plants and animals are deadly in high doses) and processing (many plants and animals are hazardous in one form while safe in another) (Evans, 2014). In this article, the term "edible" is used about insects that are safe to consume in one stage or another, and in one form or another (after it has gone through a preparation process). "Insects" is another word that needs depicting. In this case, the term is used about any small invertebrate animal (many which have six legs and some with wings); such as ants, caterpillars, bees, worms, and flies. The term "minilivestock" refers to insects that can be farmed and safely consumed by humans. In the same tone, "macrolivestock" refers to conventional livestock (Abbasi et al., 2016). Here, "Western society" refers to first world countries in Europe, and well as in North America, where entomophagy is not part of cultural heritage and is therefore considered new foodstuff.

Multiple definitions of the "bioeconomy" exist. In this paper, the understanding of the bioeconomy is the same as in the recently published book *From Waste to Value* (Klitkou et al., 2019) on the subject: economic activities connected to the "sustainable production and use of renewable biological feedstock and processes, to generate economic outputs in the form of bio-based food, feed, energy, materials or chemicals". FAO (2013) defines "food waste" as food produced for human consumption that has been discarded; whether the food product was left to spoil or if it passed its expiration date. Here the definition of food waste excludes food products produced for animals, food waste that occurs on the farms where the food is grown, food damaged in transport, and waste products from meat production (such as carcasses, blood, organs and other part of the animal that is not consumed by humans, such as tale and hooves).

2.2. Selection of relevant studies

Text analysis played an essential role in the research for this article. The plentitude of existing studies on entomophagy set a useful framework for understanding the field. The majority of data gathered from existing studies and articles were based on laboratory work, focus groups, and surveys. The data on the different insect farms was collected from the homepage of each of the farms. Studies and academic articles on the topic were collected from JSTOR and Elsevier between February and May 2018. The following search words were used to generate relevant searches: entomophagy/insect farming/edible insects/eating insects/insects as food/minilivestock/insects and food waste reduction. The search words were chosen to broadly yet accurately encompass the topic of entomophagy and food waste (similar search words have been reported used in other entomophagy studies). The searches generated altogether 120,337 search results spanning across academic articles, books, and academic journals. The largest amount of relevant journal articles was found in *Food Quality and Preference*, but studies in *Food Chemistry*, *Food Research International*, *Waste Management* and *Annual Review of Entomology* were also found to be highly relevant. In total, 25 different journals are included in the reference section of this paper.

With bioeconomy as the starting point, the focus of this research was narrowed down to food waste, and on ways to reduce it. As there is no existing research done on food waste reduction through insect farms, coming from the perspective of the bioeconomy (to the author's knowledge), the decision was made to target this. This is not a traditional direction to pursue when looking at food waste, and it was chosen for its novelty, possible future impact, and its potential contribution to the bioeconomy. The paper focuses on entomophagy in Western societies, rather than globally or on one continent or country, due to the growing interest in and the growing number of insect farms in the West. The research was conducted using only English written papers, as this is the primary language used in this field of study. Studies concentrating on animal welfare, meat substitutes, and dietary studies were considered off-topic and was therefore avoided. Studies focusing on wild insects, animal manure as insect feed, and breeding insects for animal feed were also excluded, as were studies older than from 1997 – as they were considered outdated. These decisions were made to focus on the topic of the paper. In the end, 43 of the articles uncovered through the JSTOR and Elsevier searches met the inclusion criteria outlined below (see Table 1) and were included in the paper.

2.3. Selection of insect farming case

In this section, the insect farms included in this research are presented. The selection represents companies that sell insect products for human consumption in the US and Europe. The choice was made to focus on Europe and the US as the majority of insect farms discovered during the research stage of this article was from this geographical area. Some of the farms that were discovered in the initial research stage did not sell

Table 1. Inclusion and exclusion criteria used for article selection.

Inclusion criteria
<ul style="list-style-type: none"> • Full-text paper published in a peer-reviewed journal in the English language • Focus on entomophagy • Focus on food waste reduction • Focus on using food waste as insects feed
Exclusion criteria
<ul style="list-style-type: none"> • Studies on breeding insects for animal feed • Studies on meat substitutes • Studies on animal manure as insect feed • Opinion papers • Animal welfare, wild insects • Dietary studies • Insect products produced for animal feed • Studies older than 1997

their products online, some were in the very first stage of production and had not started sales yet, and others bred insects for animal feed. Many farms did, however, appear to have some shared features; such as being business-to-consumer (B2C), making cricket-based products, and breeding insects for human consumption solely. The decision was made to focus the research on this group of firms that shared several similarities, i.e. this research does not include a complete guide to all insect farms in Europe and North America. The intention was never to deliver a comprehensive list of all insect farms but to gain insight into a portion of them. This study only includes B2C companies, not business-to-business (B2B). This decision was made after the discovery in the early research stage that most insect farms in the West today sell their product directly to consumers via webshops on their company's homepage (in a 2015 study, a systematic review of companies selling insects online came up with around 50 results) (Dunkel and Payne, 2016). Another reason for this choice is that there currently are no supermarkets, shops, or retailers that only sell insect products, or that sells insect products that they themselves produce.

The complete list of inclusion and exclusion criteria used for determining which companies to include are outlined below (Table 2). Table 3 shows which actors fit the inclusion criteria and thus, were included in the research. This table also gives an overview of who the actors included in this research are, what species of insects they use, which type of product they produce, what country they are based in, and what feed is used at their farm. In the cases where it was impossible to find any information about which feed the insects are bred on from the companies' webpage the feed column in Table 3 says "Unknown". When the insect feed was described as either "USDA certified organic feed" or "non-GMO" but did not specify what feed, the assumption was made that their feed was not based on food waste.

2.3.1. Europe

In Norway, *Acheta* sells cricket flour produced in Thailand (Acheta, 2018). Insekt KBH, a Danish company, makes natural juice enriched with crickets: "FEMTEN Fårekylinger" (or FIFTEEN Crickets) is an apple-ginger shot based on four ingredients; apple, ginger, lemon, and crickets (Insekt KBH, 2020). Since insect farming is not yet legal in Denmark, the company grows its crickets in Holland.

Insekt KBH works together with the company Beyond Coffee on upcycling used coffee grounds from cafes. They grow mushrooms that feed on the nutrients in the coffee grounds, leaving used ground that is degraded and full of fungus, which the crickets thrive on (Madsen, 2017). Contributing even further to a scalable ecosystem the cricket droppings are upcycled, used as fertilizer for the urban garden and vegetable producer TagTomat. Although coffee grounds are not considered food waste (as it isn't meant for human consumption but for production of coffee; although the coffee is intended for human consumption), it is nevertheless a byproduct of food production and thus represents a part of the green movement, contributing to the circular economy (Michail, 2017).

Bugging Denmark was Denmark's first urban cricket farm. Their crickets are fed with leftover produce from other companies; including

Table 2. Inclusion and exclusion criteria used for actor selection.

Inclusion criteria

- Company homepage written in the English language
- Sell insect products directly to consumers (B2C)
- Located in Europe or the US
- Has a webshop
- Makes products for human consumption
- Factory must be in production
- Insect products mainly based on crickets

Exclusion criteria

- Breeding insects for animal feed
- Companies that do not sell their own products

leftovers from Couch Brewing's beer production, apple pulp from Syngjas' juice, and, like Insekt KBH, they get coffee grounds from Beyond Coffee and give any residue from production to TagTomat (Bugging Denmark, 2020).

Proti-Farm has been in business since 1981 and is the world's first fully automated high-tech buffalo worm production facility. Their producing of insects for the food and pharmaceutical industry includes whole dried larvae, protein powder, protein isolate, purified oil, chitin powder, and proti-fertilizer (Proti-Farm, 2018). Although Proti-Farm does not base their products on crickets, they are included in this study as they comply with the other criteria in this study. *Kreca*, in the Netherlands, is a part of the Proti-Farm group of companies. It has been producing and selling edible insects for more than a decade and is considered a world leader in edible insect production. They offer buffalo worms, grasshoppers, crickets, and mealworms; in powder form as well as whole, freeze-dried (Kreca, 2018). Another actor from the Netherlands is *DelüBugs*. They sell freeze-dried worms, crickets and grasshoppers, as well as peanut butter, lollipops, granola, chocolate bars, and insect powder made from the same three species (Delübugs, 2020).

2.3.2. North America

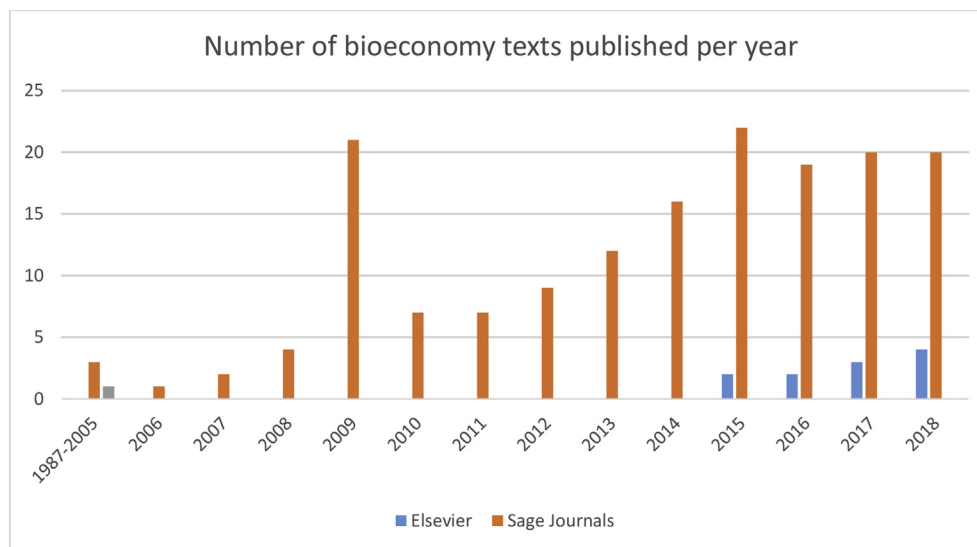
In the US several actors are in the business of producing and selling edible insect products: *Chirps Chips* get the crickets for their cricket chips from farms in North America. Aside from the cricket flour, the chips contain corn, beans, and chia seeds; creating a chip that is packed with protein and fiber, that is gluten-free, soy-free, non-GMO, 100 percent natural, with 30 percent less fat than regular chips (Chirps Chips, 2018). *All Things Bugs* manufacture and sell cricket powder (All Things Bugs, 2016), *Chapul* makes cricket protein bars additionally to their cricket powder (Chapul, 2018), and *Sens* makes both cricket protein bars and cricket flour (Sens Foods Operations, 2018). *Hotlix* produces and sell insect-based candy and snacks from ants, scorpions, crickets, and worms; including chocolate-covered crickets and scorpion lollipops (Hotlix, 2015).

After a successful crowdfunding campaign on Kickstarter, *Exo* (short for exoskeleton) was sure there was a demand for their cricket-based protein bars before starting production (IFTF, 2017). A three-Michelin starred chef makes the cricket bars they sell with premium ingredients; only those everyone knows how to pronounce (no syrups, no stabilizers, no fillers) (Aspire Food Group, 2018).

Aspire Food Group is a social enterprise specializing in farming edible insects, with some of the most advanced technology for insect farming in the world. While the company's old facility required staff to walk around to feed the crickets, the new system uses a robotic module feeding the insects the ideal amount of food (sensors use machine learning and AI to learn how the insects eat). Their fully automated, patent-pending, modular technology scales up quickly and can be implemented anywhere. Thanks to the analytics, they managed to modify the cricket's diet to grow more nutritious crickets and have increased production tenfold since implementing the system. As manual labor previously represented the majority (75 percent) of the cost, the system has dramatically reduced the price of running the insect farm, as well as reduced the prices for the final product. As well as selling cricket flour to other manufacturers, *Aspire* has its own line of products called *Aketta*. *Aketta* sells cricket products to the consumer market; including granola, whole roasted crickets, and cricket powder (Peters, 2017).

2.4. Bioeconomy publications

There has been a growing awareness and focus on the bioeconomy in recent years, demonstrated by the increasing number of scientific publications on the field (as seen on graph 1). To show this increase, two scientific publication outlets were chosen: Elsevier and Sage Journals. The choice fell on these two as they were the main publications outlets used during the research for the rest of this paper.



Graph 1. Total number of bioeconomy texts published per year.

Table 3. Overview of actors included in the study.

Actor	Species	Product(s)	Country	Feed
Acheta	crickets	powder, bread	Norway	unknown
Aketta	crickets	granola, whole roasted insects, powder	US	USDA certified organic feed
All Things Bugs	crickets	powder	US	unknown
Bugging Denmark	crickets	juice, whole roasted insects, powder	Denmark	leftover produce from other companies including apple pulp, coffee grounds and leftovers from beer production
Chapul	crickets	protein bars, powder	US	unknown
Chirps Chips	crickets	chips	US	non-GMO and gluten free diet
Delibugs	worms, crickets, grasshoppers	freeze dried insects, peanut butter, lollipops, granola, chocolate bars, powder	Netherlands	unknown
Exo	crickets	protein bars	US	certified-organic grain-based diet
Hotlix	ants, crickets, worms	candy, snacks	US	unknown
Insekt KBH	crickets	juice	Denmark	use mushrooms residue developed on used coffee ground from cafes. Unknown if this is the only feed
Kreca	buffalo worms, crickets, mealworms, grasshoppers	powder, whole insects	Netherlands	unknown
Proti-Farm	buffalo worms	whole dried larvae, protein powder, protein isolate, purified oil, chitin powder, proti-fertilizer	Netherlands	vegetable streams and GMP + certified feed
Sens	crickets	protein bars, powder	England	unknown

After entering the webpage, for each of the two the word “bioeconomy” was typed into the search field. The searches were narrowed down to texts published between 1987 and 2018 (only Sage Journals had texts dating further back than 2006, albeit only three). The searches included articles, books, book chapters, and reports written in the English language. Data, conference papers, thesis, posters, presentations, and preprints were excluded.

The search word “bioeconomy” led to 24 results on Elsevier. Of those 24, 11 fit the criteria above. The search on Sage Journals resulted in 178 texts. After excluding the ones that did not fit the criteria 163 remained. The texts were then sorted according to the year of publication.

Graph 1 display that the number of scientific publications about the bioeconomy has risen in the last 10 years, from only four across the two publication outlets in 2008 to 24 in total in 2018. Although this sample does not include every publication outlet nor every scientific publication, I have reason to believe that the trend visible here is the same across the border.

In graph 1 the two publishing outlets have been given distinct colors: Elsevier is blue and Sage Journals is orange. The y-axis represents the number of publications, while the x-axis is the year the paper was published. Despite the peak in Sage Journals in 2009, the graph shows a more or less steady incline from one year to the next in the number of published papers. The most significant amount of texts were published in 2018.

3. Literature review

The academic literature on entomophagy covers a range of angles: there are articles investigating the negative reputation entomophagy has in Western societies (Tan et al., 2016a; Hartmann and Siegrist, 2018), and research exploring consumers' willingness to eat insects (Hartmann et al., 2015; Schlup and Brunner, 2018). There are studies that look at insect farming from an environmental perspective (Alexander et al., 2017; Prather and Laws, 2018; Abbasi et al., 2016; Premalatha et al., 2011), and on food neophobia (the rejection of unfamiliar or novel foods)

(La Barbera et al., 2018). Sun-Waterhouse et al. (2016) point out that there are only a small number of studies looking at consumers' perception, demand, and acceptance to eat insects and insect-based foods. Since it has been an uncommon practice to eat insects in Western societies, there are few empirical studies on this (House, 2016).

Edible Insects by van Huis et al. (2013) and *Profiling Consumers Who Are Ready to Adopt Insect as a Meat Substitute in a Western Society* by Verbeke (2015) are considered the central academic literature on the topic. Rumpold and Schlüter published two texts in 2013, named *Nutritional Composition and Safety Aspects of Edible Insects* and *Potential and Challenges of Insects as an Innovative Source for Food and Feed Production*. Both of these texts are heavily cited in the field. As is Belluco et al. (2013), van Huis (2013), and DeFoliart (1999).

3.1. Benefit of insects as human food

Entomophagy has many benefits, a selection of which will be presented in this section.

3.1.1. Protein

Today the global demand for animal protein is higher than the supply. As developing countries are becoming more prosperous, they are adapting a Western diet, eating more meat than before. With two of the most populous countries in the world (India and China) growing in population, with complimentary rising standards of living, the demand is predicted to continue to rise (Abbasi et al., 2016).

Protein levels in insects are a topic that splits experts: Protein levels are reported to vary with more than 50 percent within the same species, depending on the development stage, feed and other variable conditions. Across different species, protein levels are reported to vary from 7-91 percent (Nongonierma and FitzGerald, 2017). Some say insects require up to 10 times less feed than cattle to produce the same amount of protein (Schlup and Brunner, 2018; Premalatha et al., 2011). In a study investigating 94 insect species, 87 percent of the insect species had a higher caloric value than maize, 70 percent were superior to fish, lentils, and beans, 63 percent to beef, and 50 percent to soybeans. In the same study, only nine percent of the species contained less than 30 percent protein (Premalatha et al., 2011). The average protein level in chicken is calculated to around 54 percent, beef is 40 percent, and the general percentage in insects is 80, according to Abbasi et al. (2016). While developed countries are calculated to have a protein consumption of 95g per person per day (60 percent animal protein), developing countries only have 45g per person per day (15 percent animal protein) (Premalatha et al., 2011). Another thing worth mentioning in relation to measuring protein is that the Kjeldahl analysis, commonly used to measure protein levels, tends to overestimate the protein content of insects as it cannot separate between easily-digested proteins, inaccessible proteins, chitin, and other N-containing molecules (Jonas-Levi and Martinez, 2017).

3.1.2. Comparison to livestock

To get a better understanding of the positive sides of insect farming, it is interesting to compare them to traditional livestock. Meat production has received critique for the negative impact it has on the ecosystem: macrolivestock take up a significant portion of agricultural area and is a major emitter of the greenhouse gas nitrous oxide, making livestock production highly eco-degrading and a clear contributor to global warming. Insects have a higher feed conversion rate than cattle, they can be farmed in urban settings, they use fewer resources, and a larger percentage of the insect is consumed, compared to conventional meat; in most cases it is 100 percent, compared to 40 percent of cattle (Alexander et al., 2017). Insects are also poikilothermic (cold-blooded), which means that they adapt their body temperature to their surroundings, spending less energy on maintaining body temperature (Abbasi et al., 2016; Dossey, 2013). The feed conversion ratio for the house cricket (*Acheta domesticus*) is estimated to be two times more efficient than chickens, four times more efficient than pigs, and more than 12 times more efficient

than cattle (Yi et al., 2013). In research conducted by Payne et al. (2016), studying if insects are nutritionally preferable to meat, it was concluded that insects are higher in nutritional diversity compared to commonly consumed meats. It also concluded that insects are neither less nor "healthier" than meat.

3.2. Plant protein

Although meat is considered one of the most high-status foodstuffs both in high and low-income countries (Smil, 2002), plant protein foods are increasing in popularity. Plant protein foods include products such as soy, wheat, nuts, and vegetables (van del Spiegel et al., 2013), and can be bought as whole products, in powder form, or in processed foods such as bars and burgers. Specialty stores that cater to the customers of plant protein typically cater to a specific customer segment, including vegetarians and people with other dietary restrictions, such as allergies. The products in these stores are not geared towards the masses but towards the consumer who is looking for a more environmentally friendly source of (plant) protein. Plant protein foodstuffs also appeal to consumers with an adventurous taste -the same group that would be interested in trying insects (Schösler et al., 2011).

3.3. Entomophagy

With more than one million species, insects are the largest and most diverse group of organisms on the planet (Dossey, 2013). There are over 1900 known edible insect species; beetles, caterpillars, bees, wasps and ants being the most popular ones (Kourimska and Adámková, 2016; Yi et al., 2013; Sogari et al., 2017). A number of them are predicted to do well in a farming environment, although the mapping of safe and nutritious insect species is still in its infancy. There are many plus sides to entomophagy: insects have a high conversion efficiency, insects require fewer resources (water, land, labor) than traditional livestock, there are cost advantages attached to insects' short life cycle and the high reproduction rates, animal welfare is high, and nutrition levels are high. Insects have high levels of protein, minerals, vitamins (A, B, C, D, E), as well as amino acids (Megido et al., 2016; Rumpold and Schlüter, 2013b; Bukkens, 1997; Shelomi, 2015; EFSA Scientific Committee, 2015; Yi et al., 2013; Nongonierma and FitzGerald, 2017; Bublér et al., 2016; Gere et al., 2017; Klunder et al., 2012; Hartmann et al., 2015; Zielinska et al., 2015; Kourimska and Adámková, 2016; Schlup and Brunner, 2018; Nowak et al., 2016). However, the nutritional level does vary greatly between species and is dependent on life stage, feed, and season (Kourimska and Adámková, 2016).

3.3.1. History of entomophagy

Although most insects are still collected in the wild, insect farming is nothing new (Klunder et al., 2012). While the domestic silkworm (*Bombyx mori*) has been farmed for more than 5000 years, European honeybees are thought to have been domesticated for 7000 years (Payne et al., 2016). Human consumption of insects has been traced back to prehistoric times (Abbasi et al., 2016); both the Bible and ancient texts from Greece and Rome mention entomophagy (Anthes, 2014). Today insect eating is practiced in 113 countries worldwide, with the majority in Africa, Asia, and Latin America (Hartmann et al., 2015; Deroy et al., 2015).

In 1978 Professor Gene DeFoliart began to investigate the feed potential of insects for chickens. It was his pioneering work, followed by a small, group of researchers, advocating the tremendous potential of edible insects, that laid the brick for the industry that is emerging today. The Forestry paper 171 published by the Food and Agricultural Organization of the United Nations (van Huis et al., 2013) is credited for serving as a catalyst for new companies, researchers and academics entering the industry. After the publication of the paper, the use of insects as food ingredients accelerated considerably (it is the most downloaded FAO

report to date numbering 6 million downloads) (Dunkel and Payne, 2016).

3.3.2. Acceptance

Considering acceptance is necessary when looking at insects as a possible way of reducing food waste for one simple reason: if insects as food are not socially accepted insects are not likely to be farmed with the intention of reducing food waste or for human consumption. Cultural attitudes, perceived risk, sensory properties (such as taste, smell, texture), and social appeal matter in the consumers' decision-making process around food, and in the acceptance of new foods (Hartmann et al., 2015). Negative socio-culturally defined public bias towards insects is one of the main barriers to adopting insects into the Western diet (Hartmann et al., 2015; Verbeke, 2015). Piha et al. (2017) argue that these factors can be impacted and changed by regulators and scientists if they provide reliable information. Media is another known factor in shaping public opinion. With the increase in the amount of media coverage on entomophagy in recent years, it is likely that media has contributed to increasing acceptance of eating insects in Western societies.

A study by Hartmann and Siegrist (2016) pointed out that the willingness to eat insects is generally low among Europeans. Overall, young males were found to be the most likely early adopters of insects as food (Verbeke, 2015). While some studies indicate that low visibility of insects has a positive influence on the social acceptance of entomophagy (Tan et al., 2016a), others argue the opposite. Shelomi (2015), Gere et al. (2017) and Hartmann et al. (2015) agree that the implementation of entomophagy to the Western pallet is more likely to be successful if insects are incorporated into familiar dishes. Factors that have been found to increase willingness to consume insects include: familiarity, recommendations from friends and family, curiosity, convenience, visibility of insects, a personal desire to decrease meat consumption, the belief that entomophagy is healthy, and a personal interest in the environment, and in healthy food (Verbeke, 2015; House, 2016; Schlup and Brunner, 2018; Alemu et al., 2017).

3.3.3. Obstacles

Implementing insects into the Western diet brings many challenges. At the present time, there are significant knowledge gaps regarding which species are safe and which are not (Bubler et al., 2016): insects have viruses, bacteria, and fungi that could be potentially harmful to humans (Anthes, 2014). Insects produce toxins at specific stages of their development (egg, larvae, pupae, adult) and mapping which is safe and not will be crucial. Allergic reactions are a largely unexplored field (Kourimska and Adámková, 2016). Entomophagy struggles with bad associations in the West. As many species are found in and around waste, insects are, by many, associated with dirt, decay, and disease (Anthes, 2014; Deroy et al., 2015). The taste, smell, sight, and texture of different insects is something that Western consumers need to be familiarized with before entomophagy will be adapted by the mainstream. Sustainability is another issue. Today the insects in insect farms are raised in heated rooms before they are freeze-dried, which is massively energy consuming. Finding sustainable solutions to keep energy usage to a bare minimum will be essential. Another hurdle is the price point. In the West, the price is currently higher for insect protein than for the same amount of animal protein (mostly due to high dependency of manual labor, and small production size) (Shelomi, 2015; Rumpold and Schlüter, 2013a).

Something rarely mentioned in the literature on entomophagy is convenience. It is difficult to buy insects meant for human consumption, i.e. the consumers that are interested in buying edible insects have few supermarkets to choose from, and many are forced to buy it from pet or bait shops (the conditions these insects are bred in is not intended for human consumption and is not considered sanitary). Although the number of supermarkets carrying insects is increasing, and despite the possibility of ordering online, the inconvenience creates an extra barrier for new consumers (Shelomi, 2015). In order for insect-based foods to be successful in

the marketplace safety, price, associations, sustainability, tastiness, and availability needs to be comparable to existing Western foods.

3.4. Insect farming and food waste

Through history and many places where insects are still consumed, insects are harvested in the wild (FAO, 2010). In the West today, insects are increasingly bred on insect farms, kept isolated from the natural population with controlled living conditions and diets. There are six known characteristics that allow a species to be domesticated: appropriate diet, high growth rate, breeding capabilities in captivity, a domesticable disposition, relatively calm behavior, and a clear hierarchical social structure (van Huis et al., 2013). To this day, little is known about the life cycles, population dynamics, and management potential of most edible insects (FAO, 2010). Uncovering the appropriate conditions (optimal harvest time, humidity levels, light, feed, how to scale-up production, how to make the farms less labor-intensive, and so forth) will take time (Ortiz et al., 2016; Rumpold and Schlüter, 2013a). What is considered state of the art in insect farms today is primitive compared with production technology for other farmed animals (Ortiz et al., 2016). What is known is that a number of species can successfully be grown on food waste, converting the low-value products into high-value protein for human consumption (Surendra et al., 2016; Van Huis and Oonincx, 2017).

The ways in which the use of food waste as feed on insect farms presents environmental benefits are twofold. First, several insects (such as grasshoppers, flies, and crickets) thrive on food waste that humans and traditional livestock cannot eat. The insects eat the food waste, and as a result, landfilling and incineration are avoided. Second, through adding insects to the Western diet, insects are contributing to the bioeconomy; food that otherwise would be thrown away is used to feed insects, and consumers then (ideally) eat the insects. Insects also do not compete with humans for the same foods - as livestock do (grain and corn)-, i.e. insect farming does not take from the already limited resources on the planet but helps reduce an abundant one (food waste).

The need for improved feeds and raw materials for insects will surely increase with production levels. Although most insect species farmed today are omnivores, that display a high level of nutritional flexibility, their nutritional requirements are hard to determine; in the wild, they consume food from a variety of origins with different nutritional characteristics. Balancing the nutrient requirements of the farmed insects with the food waste will require research, and trial and error. Different species will thrive on different food waste, and different feed presentation forms -size, shape, and texture (liquid, powders, mash, dried, or semi-moist). Research has shown that mealworms, for example, can be raised on dried organic waste materials from fruit and vegetables (Van Huis and Oonincx, 2017). At present, this represents a knowledge gap in regard to insect feed (Ortiz et al., 2016).

4. Results

In the farms researched here, it is evident that crickets are the most popular species by far: 12 out of 13 are growing crickets, and the remaining one is only growing buffalo worms. Nine of the 12 that sell crickets only grow crickets, while two also grow grasshoppers, and three grow worms. The most significant number of farms in this study (six out of 13) are located in the US. This is not very surprising since this article considers North America as one large entity, and Europe as many smaller entities; the number of farms is expected to be larger in a bigger entity than in smaller ones. The second biggest location is the Netherlands (three of 13), while Denmark has two, and Norway and England have one each. The location of the farms is not random but a result of the level of leniency in policies and laws in each of the countries. While the US is more lenient than Europe (a probable assumption considering the higher number of farms), the Netherlands is the most lenient of the European countries. The Netherlands is a leader in the field of entomophagy due to

its expertise in climate control, farming, and logistics. Businesses, researchers, and the government in the Netherlands continue to support and pursue innovation in the field despite restricting European Commission (EU) regulations affecting the production and processing of insects for food (Marberg et al., 2017).

The majority of the actors make more than one insect-based product (eight of 13), with five focusing on just one product. The most popular product is powder, with nine of 13 producing powdered insect products. Four of the farms sell whole insects, three sell protein bars, and snacks, juice, candy, and granola have two each. This is closely linked to the section about *acceptance* (see 3.3.2). When the product (insects) is concealed in powder form, or in already familiar food products like tortilla chips or candy, the bar for trying that product is lowered (at least this is the assumed reasoning for the farms choosing this presentation form). That four of the 13 sell whole insects resonated with the opposite way of reasoning; that the sight of insects on a plate will increase the normality and acceptance of insect-eating.

All of the farms included in this research sell their product through the farms' webshop. This tells us that the customers of insect-based products do not buy them by chance, but that they are looking to buy insect products and make an active choice to enter that website to make that purchase. It is unknown whether they are first time buyers or regulars and their reasons for buying insect-based products. Probable reasons include customers who are environmentally conscious, those looking for other sources for protein than traditional meat, consumers who are curious or who like to experiment with food, and people who have received personal recommendations from friends or family, or who has been intrigued by media coverage.

Research showed that none of the insect farms use food waste as feed (although two - Bugging Denmark and Insekt KBH- use coffee grounds, apple pulp, and leftovers from beer production). This shows that at the moment there is either no interest in combining food waste reduction and insect farming or that the current policies make it too hard, if not impossible, resulting in scaring off the interested actors. It could also be the case that the actors sampled in this study misrepresent the industry and that other actors in the marketplace are using food waste as feed. What is evident from the amount of literature on entomophagy is that there is academic interest in the field.

5. Discussion

Crickets appear to be the favored species in insect farming, both through the findings in this study and from the number of texts and studies dedicated to them in the field. This is likely linked to their sustainability and nutrition levels: crickets produce virtually no methane and only one percent of the greenhouse gases that cattle produce, and they are also a complete protein source, containing all the essential amino acids, and has twice as much iron as spinach (Aspire Food Group, 2018). The further mapping of edible species and familiarizing of entomophagy in the US and Europe will most likely increase the diversity of species, and the number of farms.

Part of the limitations of this study lies in the number of entrepreneurs included. It is not clear whether the chosen actors are good representations for insect farming or good examples to show a link between the bioeconomy and insect farming. Further research is encouraged to include the farms that were excluded in this research.

In this research, none of the insect farms used food waste as feed. There are several potential explanations as to why this is: 1) Regulations and a regulatory framework, and the lack thereof, are currently making insect farming a problematic process. When appropriate regulations and legal frameworks are in place, it will make it much easier for the existing and the emerging farms to establish themselves in the market successfully, and to use food waste as feed. 2) The market is in its infancy. The entrepreneurs in the field might be focused on establishing themselves in the market, and on creating successful products, not focusing on the sustainability of the feed for the insects. It could also be a strategic and conscious choice; to

concentrate on getting up and running before taking on another regulatory and organizational challenge, which feeding food waste to farm animals is today. 3) The perception that consumers might not accept food waste as feed on insect farms could be reason enough for the farms to hold off with using food waste. There is no existing research on consumer acceptance in regard to using food waste as feed on insect farms. The field would benefit from research into whether this will have any effect on people's perception of insect farming and insect products. 4) The availability of food waste from suppliers might be low, irregular, or non-existent. More research into the relationship between insect farms and food waste collection companies is needed. 5) There is still much to be done in terms of collecting data on which species that thrive on which food waste, and optimization of the rearing process. Until more research has been gathered, insect farms might be consciously staying clear of using food waste altogether.

Although there is, at the present time, no direct link between food waste and insect farming, there is an opportunity for a close link in the future. Insect farming is promoted as a more sustainable way of producing animal protein. The insect farms investigated here are contributing to the bioeconomy (through offering an environmental protein option compared to traditional livestock), just not through food waste reduction. To establish a closer link between insect farming and the bioeconomy, it is evident that further research is needed and that the industry needs more time to mature.

5.1. Normalizing entomophagy

When new foods are introduced to a culture they are often regarded as inappropriate. Commonly eaten foods in certain cultures are considered inedible in other cultures (e.g., reindeer, dog, frog), this is also true for specific body parts (such as brain, testicles, and ears). A single sight, smell, or the idea of eating these foods can evoke disgust, preventing potential consumers to even try it (Tan et al., 2016a). However, significant changes in cultural tastes are not impossible. Foods like quinoa, kombucha, and goji berries that were first rejected by consumers in the West, were later accepted; e.g. lobster that once was "poor man's food" is now considered to be a luxury food and priced accordingly. Sushi underwent a similar transition; moving from being considered peculiar and non-appealing in Western countries to being socially accepted and trendy in a mere decade, notably without scientific or political interference (Hartmann et al., 2015; Shelomi, 2015).

Hartmann et al. (2015) predict that when insects are sold in supermarkets, restaurants, and health stores, prejudice and negative attitudes might decrease. A strategy to normalize entomophagy could be to incorporate more recipes with insects into cooking shows and cookbooks, and simultaneously featuring insects less on shows that project insects as weird or dangerous (Shelomi, 2015). Considering how difficult the marketing of fruits and greens that do not fit supermarkets' product standards has been to sell to Western consumers, insects are a hard sell. The appearance of insects is not compatible with what in the West is considered "food," which adds to the level of difficulty. Shelomi (2015) mentions three ways entomophagy can become socially accepted: 1) farming insects for feed for macro livestock, 2) market edible insects to better fit the needs and desires of Western consumers, and 3) to focus more attention on supply-side innovations.

5.2. Policy

Some argue that regulation is an even bigger obstacle to entomophagy than the "yuck factor." The previous Novel Foods regulation (containing foods without a significant history of consumption in the EU before 1997) was unclear regarding insects, resulting in national governments making local laws legalizing something in one country, and making it illegal in the next (Livingstone, 2018). In many ways, insects have been subject to the same legislation as livestock (Hodson, 2014) which has not served insect farming particularly well. Marberg et al.

(2017) note that the European Novel Food regulation has prohibited the production and processing of insects for food on a commercial scale.

The legislation on new foods in the EU, Novel Food Regulation (EU) 2015/2283, has since January 2018 made it easier to bring new food into the EU. It has, among others, expanded the categories of foods to include insects. In January 2019 the European Commission proposed the introduction of new rules in relation to insects; insects for human consumption specifically. The goal of the proposal is to both ensure the safety of citizens and to harmonize the regulations across EU countries. In the proposal, three types of feed are listed as not appropriate feed for insects intended for human consumption; including manure, catering waste, and other waste. "Catering waste" includes all food leftovers from restaurants, catering facilities and kitchens, and household kitchens. "Other waste" refers to all food that the holder discards or plans to discard (European Commission, 2019). If this proposal is accepted it would mean that it would become illegal to feed farmed insects (intended for human consumption) food scraps from supermarkets, farms, and households. Both the environment and economy would suffer from this, as food waste would end up being wasted rather than being a part of the bioeconomy as a feed source for insects on insect farms.

Despite recent advances in regulations, it is still a long way to go before the full potential of insect farming has been reached. Holistic thinking where the bioeconomy is taken into account will be an essential part of moving forward in this industry. A proper regulatory framework needs to be in place; including legislation, regulatory bodies, and industry standards, to monitor and govern the production, handling, and use of insects as food for human consumption. Ensuring the conservation of biodiversity, disease control, integrated pest management, and sanitation are key issues. The Codex Standards could assist in setting international standards for food safety and trade rules (Sun-Waterhouse et al., 2016).

6. Conclusions

In much of the recent literature, insects are portrayed as a solution to world hunger, depleted resources, and overpopulation. In reality, entomophagy cannot singlehandedly create a sustainable food system. Entomophagy does, however, have the potential to contribute in creating a more sustainable food system. The perhaps biggest challenge in implementing entomophagy to the western diet is strong, socio-culturally defined public bias towards insects.

To the authors' knowledge, this is the first study to attempt to map some of the entrepreneurs in insect farming in the West. It is also the first study to do so with a food waste reduction and bioeconomy perspective. This research contributes to insight about the current landscape of insect farming and to the broader discussion about the bioeconomy and food waste reduction.

The main findings of the study show that none of the insect farms in this research use food waste as feed today. This might change when 1) appropriate legislation and regulatory frameworks are in place to support this, 2) the market has developed further, and entomophagy has become more socially accepted, and 3) more data is gathered on insect farming (both regarding species, methods, and technologies).

The following opportunities for future research have been identified: exploring insect farming's potential in contributing to reducing food waste, studying which insects can thrive on which food waste, examining the way insect farms are run (which technologies and methods are in use), and mapping the entrepreneurs. Further insight into the existing entrepreneurial businesses could give much needed understanding of the status quo and the challenges the industry face.

From the literature in the field, it seems that insect farming is not currently considered a viable option in reducing food waste. This is expected to change as legislation and industry standards catch up with the development in the industry. It is somewhat unlikely that using food waste as insect feed can significantly reduce food waste on a global level in the current landscape. There is, however, the potential for entomophagy to make a positive contribution to food waste reduction and the bioeconomy.

Declarations

Author contribution statement

Eili Skrivervik: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

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