Article

Insects on our Plates? Potential, Challenges and Opportunities in the Edible Insect Market

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Abstract
Our food system is a major polluter and perpetrator of climate change and biodiversity loss. Animal-based protein sources are the most energy-intensive and polluting food products. Edible insects have been touted as an alternative to traditional meat sources. This paper quantifies the sustainability of the edible insect production process. Then, it will explore the challenges edible insect companies are facing to change consumer behavior. Insects as food are still met with disgust, neophobia and are not considered as a viable food option. Through stakeholder interviews, I will be looking at how these companies are attempting to change that, notably through indirect entomophagy, increasing familiarity and building communities. I also recommend other potential strategies such as increasing familiarity by selling insect by-products, targeting a younger audience and establishing edible insects as a unique food category. Finally, I look at the government's perspective on this novel food, whether or not it should support its development and how supply side policies could be implemented to do so.

Keywords: Consumer behaviour, Microeconomics, Environmental economics, Innovation, Entomophagy, Marketing, Government intervention, Entrepreneurship, Market entry

1. Introduction

The first evidence of entomophagy, or the practice of eating insects, is found in the tools of the Australopithecus (2-4 million years ago). (Derrico, 2001) Since then, there are countless writings of different human cultures consuming insects. From Aristotle in Ancient Greece treating himself to cicada, to John the Baptist eating a diet of locusts and wild honey and silkworm pupae eaten in Ancient China. (Bodenheimer, 1951) Today, entomophagy is most popular in tropical regions because the warmer and more humid temperatures are ideal for insects to grow. Some cultures view it as a delicacy, others as food for the poor or as a last resort when there are droughts. (FAO, 2013) Over the past millennia, hundreds of insect species have been recorded as having been eaten by humans. Today, however, most Western countries do not eat insects and developing countries are slowly steering away from entomophagy.

Yet, during COP26 in 2021 in Glasgow, political leaders, activists and international organisations called for a rethink of our food production system and supply chain. There is a good reason why our food system is under fire. Agriculture occupies half of our global habitable land, uses 70% of our freshwater withdrawals and is responsible for nearly four fifths of the global ocean and freshwater pollution (eutrophication). (Poore & Nemecek, 2018) Livestock represents 94% of the mammal biomass on our planet today. What is even more striking is that meat, eggs and dairy are responsible for 83% of the food emissions of a European diet. (Sandstrom et al, 2018)

Nearly 80% of agricultural land is used to produce feed for livestock or their grazing, yet, they produce only 18% of global calories supply and 37% of global protein supply. Too much land is being used for non-protein dense foods, and that is a problem. (UN FAO, 2020) Protein is crucial to humans as it enables our bodies to repair cells and create new ones. (Arentson-Lantz et al, 2015)

This trend of environmental damage is expected to worsen if nothing is done about it. Meat, which is the most environmentally damaging source of protein, will see its consumption rise in the coming decades. As we've seen across history and more recently with China, as lower income countries become more prosperous, they will consume more protein and especially more animal-based protein. The world's population is predicted to peak at close to 10 bn by 2050, with this growth coming from sub-Saharan Africa, India, and Indonesia, among others. Lower income countries currently get between 12% to 30% of their protein from animals, while the number for higher income countries is around 60 to 70%. (UN FAO, 2020) Meat is seen as a luxury due to its higher price and presumed health benefits. (Berenicka & Pawlonka, 2018) We can see how this will put immense pressure on our food system and, by consequence, our environment.

Edible insects is a protein alternative that has been consumed for millennia, and is part of the traditional diet of 2 bn people. However, they are still neither eaten regularly nor on a large scale. In the past decade, edible insects have been on the rise in the novel food space, without having seriously taken off yet. Nevertheless, the market for edible insects continues to grow as consumers, governments and businesses are looking for more sustainable, ethical and novel food alternatives.

First, I will quantify the sustainability and efficiency of edible insects and compare them with traditional meat sources. I argue that this is one of the reasons why entrepreneurs are entering the edible insect industry. Edible insects are able to create value, opening up a business opportunity.

Then, I will explore what are the challenges that edible insect businesses face regarding consumer behavior and acceptance. Through stakeholder interviews, we will understand what strategies these start-ups are using to solve these challenges and link those with current microeconomic research. I will also offer recommendations based on an up-to date literary review.

Finally, I will discuss why governments might want to encourage the edible insect industry, the risks that government should mitigate and potential policies it could implement.

This paper makes novel calculations to compare traditional meats with edible insects and assess the sustainability and profitability of insects. It also summarises the micro-economic literature on consumer behavior, product adoption and food consumption and links them with current strategies being used in the industry. This is done through

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interviews with edible insect businesses. I then explore other potential strategies that are not and could be used by edible insect companies.

2. Motivations for Edible Insect Businesses

Entrepreneurs and environmentalists have long been enthusiastic about edible insects as a protein alternative. In 2013, after the publishing of a landmark report by the UN's Food and Agricultural Organisation (FAO) outlining the opportunities of edible insects, they started becoming very popular. (FAO, 2013) Millions of dollars were invested by venture capitalists and angel investors in edible insect startups. After a few years, however, the majority of them had disappeared and the money had dried up. Various reasons accounted for this failure, such as regulatory issues, scalability and commercial viability. The last few years have seen a resurgence of edible insect startups. What are the motivations behind those entrepreneurs taking on the challenge of convincing consumers to eat bugs?

There are thousands of insect species that are consumed around the world; however, this paper will focus on commercially produced insects for human consumption. There are currently three insect species that are being developed for large scale production: the mealworm, the black soldier fly (BSF) and the cricket. I will be focusing on the cricket as it is the most popular insect sold directly to consumers. The appendix has a more thorough description of each species. The following analysis will also be based on the production process of Instar Farming, the largest cricket farm in the UK, for which the production process is also explained in the appendix.

2.1. Sustainability

Proponents of edible insects claim that insects have a low environmental footprint. (FAO, 2013) Here, I will be testing this claim.

I used different studies estimating the inputs needed to produce 1 kg of protein for different animal-based protein-dense foods. I then make calculations to convert them to have a consistent comparison, which will be 1 kg of protein. I need to take into account whether the product's weight was for live weight or edible weight, if it included bones/inedible parts and take into account protein content.

Input per 1kg of protein	Land use (m2)	Water use (L)	GHG Emissions (kg CO2 equiv.)
Beef	1,636	11,200	128
Pig	107	5,700	38
Lamb	1,848	6,300	401
Chicken	71	3,400	20
Crickets	0	1	7

Table 1: Inputs needed to grow various meat sources. (Poore & Nemecek, 2018; FAO, 2013; Mekonnen & Hoekstra, 2012)

Firstly, it is noticeable that edible crickets only need a minute amount of land to grow. Lamb and beef (depending on the type of cattle farming method) need more than 10 times the area of land needed to farm pigs and chickens. (Poore & Nemecek, 2018) Insects barely need any land to grow even compared to chickens. (Instar Farming, 2022) That is because they are grown in boxes and can be stacked up high. In addition, the processing facility only requires one large tub where the crickets are fried or grounded into flour.

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Secondly, crickets need next to no water as they can efficiently extract the little water needed from the humidity in the air and the moisture in the feed. (Mekonnen & Hoekstra, 2012) This substantially reduces the environmental cost of producing edible insects as seen in Figure 1.

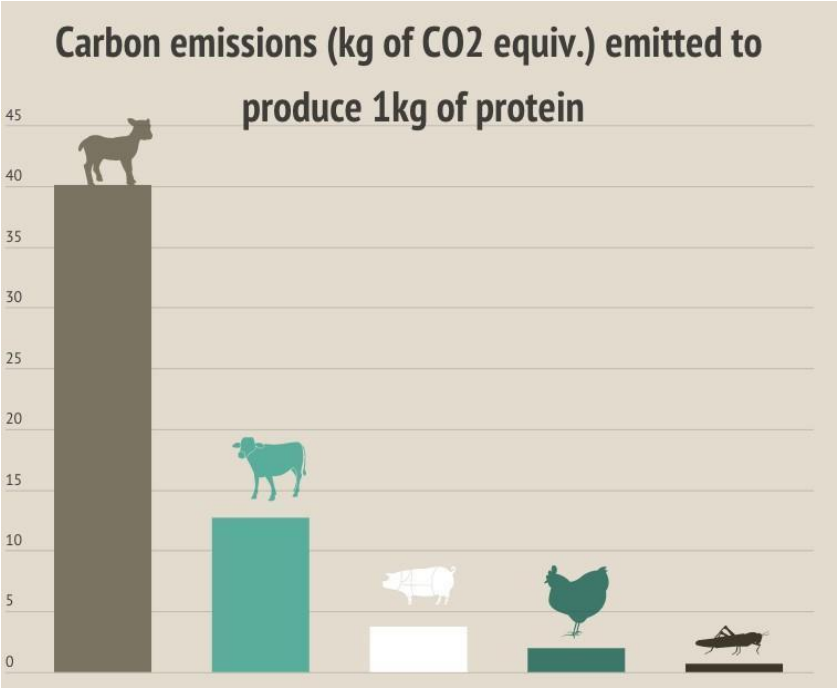

Figure 1: Crickets emit considerably less GHG compared to other animal-based protein sources

Finally, regarding greenhouse gas (GHG) emissions, lamb and beef are the least environmentally friendly meat sources. A typical kg of beef in the US emits around22 kg of CO_2-equivalent GHG. This comes from their waste (manure) and the gases they emit. (Avery & Avery, 2008) By taking into account protein content and edible weight, studies clearly demonstrate that crickets do not produce any emissions themselves nor any waste for that matter. The emissions come from the production process and transport, which is still less than 3 times that of chicken and around 18 times less than beef.

Next, these improvements can be quantified in monetary terms. I have taken price information from various sources to calculate how much monetary gain a farmer or producer would get from farming insects instead of traditional meat sources.

- Savills estimates that an acre (4,047 m^2) of agricultural land costs on average £7,000. (Savills, 2021)
- According to Agrismart, one cubic metre of water (1000 L) costs £1.75 in the UK. (Agrismart, 2013)
- The AHDB estimates that concentrate feed prices are around £0.29 per kg of feed. Note that higher protein content makes feed more expensive. (AHDB, 2022)
- The UK's Emissions Trading Scheme, which enables businesses to trade emission futures, was trading at £82.94 per tonne of CO_2-equivalent on March 17 2022. Note that the prices of ETS futures are predicted to rise in the coming years as emission quotas are reduced and governments attempt to meet their emissions target. (Ember, 2022)

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Cost of inputs per 1kg of protein	Value of land (£)	Cost of water (£)	Cost of GHG emissions (£)	Feed cost (£)
Beef	2,830	20	11	7
Pig	186	10	3	2
Lamb	3,197	11	33	4
Chicken	122	6	2	1
Crickets	1	0	1	1

Table 2: Price of Inputs. (Savills, 2021; Agrismart, 2013; AHDB, 2022; Ember, 2022)

Land needed to produce 1 kg of lamb protein is worth close to £3,200 in the UK in 2021, the value of the land insects are using is just a fraction of this. Also, feed cost for beef production is seven times that of insects. Additionally, purchasing carbon credits for 1 kg of protein of lamb and beef would cost £33 and £11 respectively, 10 and 30 times more than for the equivalent insect protein.
These calculations confirm that edible insects emit less emissions, occupy less land and use less water. Thanks to their biological efficiency, edible insects require much less inputs and raw materials to produce the same amount of protein compared to traditional meat sources. Therefore, by switching to insect protein, the environmental impact of our food can be reduced. This is one of the main reasons why more and more entrepreneurs are founding edible insect start-ups: consumers are looking for more environmentally friendly sources of food and edible insects can, in theory, meet that need.

2.2. Efficiency & Value Creation

Crickets and insects are incredibly efficient. Since they are cold-blooded animals, they do not waste any energy keeping their bodies warm. (Kim et al, 2019) This is reflected in their Feed Conversion Ratio (FCR), which shows how much kg of feed is needed to produce one kg of edible product. The lower the FCR, the more efficient an animal is in converting feed into meat. Crickets have an FCR of 2, compared to 25 for beef and 6 for pig. (Alexander et al, 2016) The protein conversion ratio is a similar metric but looks at the protein conversion efficiency. Protein conversion numbers for all protein sources are very similar to their FCR. FCR and protein conversion values across animal protein sources are depicted in the table below. In addition, humans can usually eat 80% of a cricket, compared to around half for other meats. (FAO, 2013) This means that less feed and energy are needed to grow and harvest insects for consumption.

Efficiency per 1kg of protein	Feed Conversion Ratio	% of animal edible	Protein Conversion Ratio
Beef	25	40	26
Pig	6	55	12
Lamb	15	N/A	16
Chicken	3	55	5
Crickets	2	80	2

Table 3: Crickets are incredibly efficient creatures. (Alexander et al, 2016; FAO, 2013)

The output of crickets and other animal-based products are compared below. This analysis is novel in that it helps us compare the current market value of insects versus traditional meat sources. I took typical products from Tesco and from Bugvita, one of the most popular edible cricket sellers in the UK. Figure 2 visualises how the most caloric and protein-dense products are the crickets, sold as whole or as a powder.

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Output per 1kg edible	Product	Calories (kcal)	Protein (g)	Retail Price (£)	Price (£)/1k calories	Price (£)/100g protein
Beef	Diced Beef	1,840	350	9	5	2
Pig	Fresh Diced Pork Topside	1,950	400	7	4	2
Lamb	Lamb Diced Leg	2,310	250	19	8	8
Chicken	British Diced Chicken Breast	1,410	330	10	7	3
Crickets	Whole Roasted Crickets	4,450	610	104	23	17
Crickets	Cricket Powder	4,450	690	43	10	6

Table 4: Comparison of output by meat source (As of February 2022). (Bugvita, 2022)

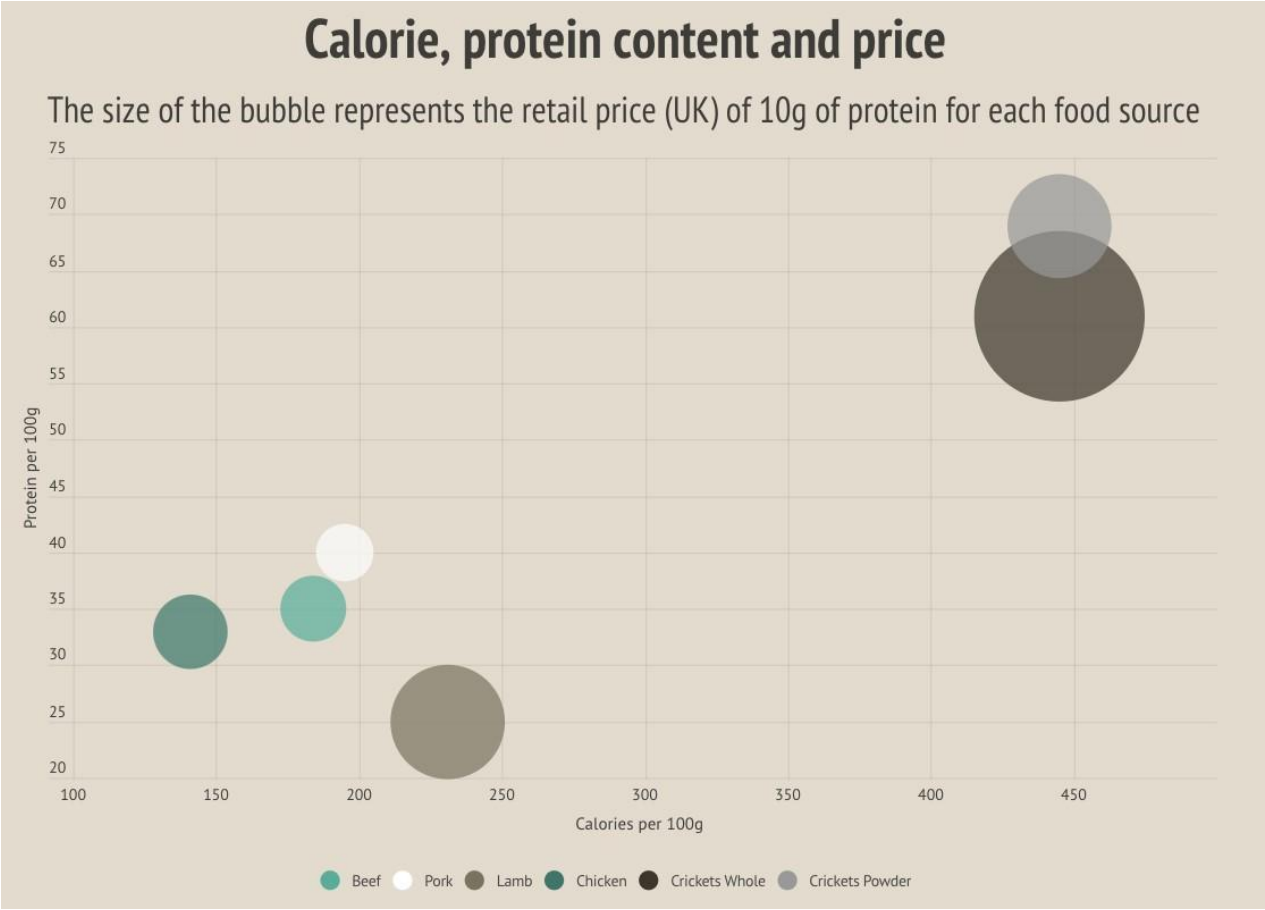

Figure 2: Crickets are the most caloric and protein-dense but also the most expensive

The least protein-dense product is lamb, which, incidentally, is one of the least environmentally friendly meat sources. Beef, chicken, and pork all have a higher ratio of protein to calorie than lamb. However, they have substantially lower protein content than the insect products. Whole crickets and cricket powder both have nearly double the protein content of chicken and triple its calories. Crickets sold as whole, as the size of the bubble indicates in Figure 2, are the most expensive of the food products compared, while pork is the least expensive. Insects' efficiency is shown by the fact they are very dense in calories and protein. They need minimal output to produce valuable output.

In conclusion, these calculations confirm research made by van. Huis (2013) that insects actually create value through their biological process. They require less input and produce more valuable output. This is the second reason why entrepreneurs are looking at edible insects. They are efficient and produce valuable and sustainable output. They can be sold at a premium to consumers (for the time being) and input costs are relatively low.

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2.3. Business Opportunity

On the demand side, consumers want environmentally friendly foods. On the supply side, producers can sell edible insects at a profit. Research by Niyonsaba et al (2021). has shown that the energy, feed and labour margins for BSF farms can range from £-661 to £12,901, mealworm farms from £6,311 to £11,405 and cricket farms from £10,161 to £65,163. These potential margins are much larger than for any other traditional meat source. Another example are the products from Bugvita, where whole crickets are the most profitable. Bugvita sells 100g of cricket powder for £5.22, but is able to sell 50g of whole crickets at the same price. The margins are thus much higher for whole crickets. (Bugvita, 2022) As a result, entrepreneurs see edible insects as a potentially profitable business opportunity. As any business looking to maximise their profits, several start-ups are trying to enter this market early and gain market share.

The advantages of entering a new market, or even creating one, are immense. Companies can essentially set monopolistic prices and maximise their profits, since they do not have any competitors. Yet, as more competitors enter the market to satisfy demand, the market becomes more mature and profits decrease. This is why companies try to enter markets as early as possible. (Saviotti & Pyka, 2004) Apart from entering a niche market early, firms also want to gain as much market share as possible. It has been shown that the size of a firm's market share is positively correlated with firm profitability. If you have more customers, you can sell more, benefit from economies of scale and better control prices, resulting in higher profits. (Buzzel et al, 1975).

I should note that the retail price for edible crickets is still relatively high in the UK and in Western countries since the production processes are not yet fully optimised. This is due to production still operating on a relatively small scale and the difficulty of reaching customers. (Instar Farming, 2022) It has been shown across studies that brand equity, marketing investment and product differentiation are associated with price levels. In this case, a substantial amount of marketing and signalling to customers is needed to convince them to try insects. (Davcik & Sharma, 2015) Naturally, these marketing costs and outreach efforts increase the cost of goods sold and are reflected in a higher price point. Also, companies are currently able to charge a premium for their insect products as they are still quite novel, often considered a gimmick. As they become more accepted, this premium might have to be reduced as competitors enter the market and the novelty of edible insects wears off.

Having recognised this business opportunity, edible insect companies are now trying to convince consumers to try and stick to eating insects. What are the main challenges that the industry and these companies are facing and what strategies are they using to solve those?

3. Challenges, Strategies, and Potential Solutions for Consumer Acceptance in the Edible Insect Market

Insects have never been part of the diet of Western countries. This is because domestication meant they could find larger and richer sources of meat. Also, insects were associated with pests and ruining harvests. Finally, Western countries are mostly in the Northern hemisphere, where a milder, less humid climate meant that insects were not very large in these regions. (Kim et al, 2019)

Despite the recent interest in edible insects, they are still not widely consumed in Western countries. I will link the challenges that the industry is facing with microeconomic research on consumer behavior and their willingness to consume food products. Interviews with edible insect start-ups have given me additional insights about the strategies they are using to overcome those challenges, leading me to suggest potential solutions. A more thorough introduction of each of the companies interviewed can be found in the appendix.

3.1. Challenges in Reaching Consumers

Insects are often associated with dirt, disease and filth. (FAO, 2013) Across history, they were responsible for pests and carried diseases. (Bodenheimer, 1951) This consumer attitude towards insects is found in many studies

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including in Brazil and the UK. (Bisconsin-Jnior et al., 2022; Ayla & Jarchlo, 2022) This feeling of disgust is a natural reaction to a product that someone deems unsafe. As a result, insects have often been considered as a poor man's food and as a last resort when there is no other option.

Extending this idea of disgust, uninformed and unfamiliar consumers consider insects to be unsafe and a risk to one's health. When consumers perceive insects to pose a threat to their health, they are very reluctant to try them. (Castro & Chambers, 2019) Work from Tversky & Kahneman (1974) in behavioral economics explained how consumers perceived risk and made decisions based on their judgements. They showed how humans' cognitive limitations result in them making imperfect decisions. Oftentimes, when assessing a situation and the risks associated with it, we rely on heuristics (rules of thumb) to make decisions quickly. However, these can be very misleading, as humans are often risk-averse and assign higher probabilities to dangerous events than what is realistic. In the context of edible insects, it is assumed that consumers often overestimate the risk of getting sick from insects, as the true probability of it is relatively low.

Neophobia, or the fear of the "new", is often associated with novel foods such as insects. Humans like what they know and what they are used to. This makes their lives easier and safer, as they do not need to ask themselves every time whether a specific food is safe or a product is useful. Since most Western consumers have never been in contact with edible insects, they are very reluctant to try them due to their unfamiliarity with them. (Wendin & Nyberg, 2021) A survey by the Food Standards Agency (FSA) in the UK showed that three quarters of respondents were not willing to try edible insects and two thirds of those said that nothing would make them taste it. (Ayla & Jarchlo, 2022) Note that these are only answers to questions (intent) and were not actually given the choice to eat them.

Edible insects are currently still stuck in the "gimmick" phase. (Yumbug, 2022) People buy them as a gift, a dare or a one-time purchase: such purchases are driven by curiosity and context (festivals, food markets). The real challenge for entrepreneurs is to make them a regular, staple food product for households. The latter behavior is driven more by practical constraints. (La Barbera et al, 2021) Rogers (2003) identified five factors in the consumers' decision-making process when faced with an innovation:

- **Relative Advantage**: How much better is the new product compared to the current offering?
- **Compatibility**: Does the product align with the values and needs of consumers?
- **Complexity**: How hard or easy is it to use the product?
- **Trialability**: Can consumers experiment with the product?
- **Observability**: Are the effects of the innovation visible to others?

These questions can be adapted for edible insects, for example:

- **Relative Advantage**: Are edible insects cheaper and tastier than other protein alternatives?
- **Compatibility**: Are edible insects produced in a sustainable and ethical manner?
- **Complexity**: Can consumers easily cook insects, are there readily available recipes and guides?
- **Trialability**: How easy is it to get hold of edible insects, can consumers get them at the local supermarket?
- **Observability**: Can consumers see the positive environmental impact they are making?

I will use some of these factors later on when recommending strategies for edible insect companies.

3.2. Strategies to Convince Consumers

The most popular and successful way to avoid disgust in consumers is through indirect entomophagy. Several surveys have shown that reluctant consumers are much more willing to try an insect product when they cannot see parts of or the whole insect. (La Barbera et al., 2021) An example would be an insect burger where ground cricket flour is mixed with onions and spices. Usually, consumers are more suspicious of raw insects rather than processed

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ones. (Verneau et al, 2021) Indirect entomophagy can help solve the problem of **compatibility** - aligning with the needs of consumers to have insect parts disguised - and **complexity** - can consumers consume the product without needing to spend time and mental effort to convince themselves?

For instance, Hargol, a commercial grasshopper farm out of Israel, does not show any images of the insect on its products or in its communication. (Hargol, 2021) They are aware that consumers, today, prefer not to eat whole insects and do not want to be reminded they are eating one. Their marketing focuses on the grass that crickets feed on in their farm, the cleanliness of their facility and the modernity of their technology. Their main products are grasshopper protein powder and gummy bears, which are both very removed from the whole insect.

An interesting parallel to draw here is with fungi protein products. Certain fungal species with higher than average protein content have been explored to provide an alternative protein source since the 1960s. However, initially, consumers did not want to eat those: the texture, flavor and thought of fungi growing spores were met with similar feelings of disgust and neophobia as insects are nowadays. As a result, producers decided to mix mycoproducts (fungal products) with other ingredients to mask the taste and flavor. (Barzee et al, 2021) One prominent success story of this approach is Quorn, a UK-based producer of vegan protein products, where the company does not formally classify its products as fungi but instead as a protected trademark, "Quorn©".

As seen in the input/output analysis, producing edible insects is far more sustainable than other animal meat sources. They are able to produce more protein and calories per unit of input than other traditional meat sources. This meets Rogers' **relative advantage** factor - edible insects are more sustainable than other protein sources - and **compatibility** - consumers want to consume sustainable food products. Researchers have shown consumers are more attracted to and likely to consume sustainable food products. Paavola (2001) first used a standard microeconomic approach to rational consumer choice, assuming it was an individualistic phenomenon, and found that consumers would consume more of a product if it was environmentally friendly. However, when Paavola analysed interdependent consumer choices informed by self- and welfare-centered values in a simple game-theoretic model, consumers were much more likely than in the first model to consume environmentally friendly products. It suggests that the influence of society and other consumers can have an impact on an individual's consumption choice, especially regarding sustainable products.

Many edible insect companies put sustainability at the forefront of their marketing. The majority of their websites' homepages tout insects as the new, sustainable super-food. For example, "Producing one of the world's most sustainable sources of complete protein" , "(...) results in negative emissions and very low water usage" or even "Unbelievable yet true, the locust is one of the most efficient sources of protein God and nature have ever produced". (Flyfarm, 2021; Instar Farming, 2022; Biblical Protein, 2021) Yumbug also has a flyer in every one of their products, explaining how sustainable their products are. (Yumbug, 2022)

However, a survey in Poland showed that consumers were aware of the environmental challenges that our food system was facing and that edible insects had certain environmental benefits. However, the majority were still not willing to eat insects. (Kostecka, 2017) Indeed, other research on whether sustainability is the main motivation for consumers' choice shows that it is not the most important concern. There are much stronger predictors of the willingness to consume such as price and availability. As a result, it is unclear whether sustainability-focused marketing is the most effective. (Krger, 2022) The results from this study demonstrate that the sole argument of sustainability is not enough to get people to consume insects, as they have much deeper conscious and unconscious biases that influence their decisions.
Consumers perceive insects to be risky and have trouble trusting the product is tasty, healthy and safe. The key for companies is finding ways to convince them and make them trust that their product is as such. This is especially done through their communication channels. These issues address **relative advantage** - edible insects being tastier and healthier than alternatives - and **compatibility** - is the product safe enough?

Consumers prefer when their food has minimal ingredients and is minimally processed. (Grant et al, 2021) For instance, Hargol focuses on "clean labels", with as few additives and processing ingredients as possible. Other companies also try to be completely transparent about where and how their products are made. Flyfarm, for example,

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sells live insects, dried ones, insect fishmeal, oil and fertilisers but clearly explains how these products are made from BSF. (Flyfarm, 2022)
Economists have recognised that consumption is not only a process of meeting one's needs, but also a way to create an identity and communicate beliefs. (Dolfsma, 2013) Consumption patterns are a way for an individual to be unique and project an image of themselves onto others. This links to **compatibility** - whether a product is in line with consumers' values.

Religion is a very strong influence on one's consumption. Food choices are a way for religious people to signal to their peers their faith. (Dolfsma, 2013) As Jews eat kosher and Muslim eat halal, they show that they act in line with the teachings of their religion. This is a powerful tool as entire industries have been created from these religious guidelines. Hindus have been shown to turn down insects due to their religious beliefs (vegetarianism), showing that religion can influence the consumption of novel foods. (Krger, 2022)

A peculiar but interesting example employing a religious identity strategy is the insect start-up Biblical Protein. They target orthodox Jews and Christians with edible insect products in the shape of protein bars and shakes. Their inspiration comes from the prophet John the Baptist, for whom the New Testament mentions that he ate "locusts and wild honey". (Holy Bible, 1974) Believers want to get as close to their prophet and the teachings of God as possible and, therefore, want to live like one. Their faith is an important part of their identity, and start-ups like Biblical Protein target consumer products that match it.

However, as a caveat, other studies such as one in Finland, contradict the idea that consumption is only an "identity constructing quest". (Wilska, 2002) It has been found that there are much more important considerations for consumers such as low prices, accessibility, and ease-of-use. In addition, consumers are not always consciously aware of the identity they are constructing, even if they are doing so. Hence, targeting identity may constitute a smart strategy for a niche group of dedicated consumers but perhaps not for reaching the mass market.

Motoki (2020) showed that people were more willing to consume insects with friends and families as well as in more social settings (pubs, restaurants, festivals). This shows the importance of community and connection. Experiences are usually more enjoyable when they are shared with others. For example, this is what the start-up Yumbug attempts to achieve, (Yumbug, 2022) creating a "Bug Community", consisting of a relatively small, but passionate group of bug enthusiasts. They specifically cater to their needs and organise regular "Bug Clubs" where they can meet each other. By offering Yumbug crickets and being part of a tight-knit community, the company encourages a strong sense of connection towards their product, which is invaluable for customer retention. Particularly powerful is the influence of friends and family on the consumption patterns of an individual. Although television and celebrities can have an impact, friends and family have a much bigger influence. (Motoki, 2020; Wilska, 2002) Having a passionate and loyal customer base will help a company spread its products to families and friends of the individuals in that group.

"Early adopters" are especially important for innovation. Early adopters are consumers who intensively like a product, because of the values a product/company has or because it is solving an immediate need that they have. They are even content with an unfinished and sub-par version of the product, usually have a strong relationship with the product, and are very loyal. The benefit of starting with early adopters is that they can give feedback and information on how to improve the product. The company can innovate and change the product without risking this consumer base. These early adopters will enable the company to iterate and grow so that, at some point, it will be ready for a much wider audience. (Palm, 2020) They will also help diffuse and spread the product to the mainstream. (Rogers, 2003) Drawing from the example of Yumbug, their group of bug enthusiasts helps edible insects be more accepted as they talk about it with many people, and spread positive ideas about insects as food.

3.3. Potential Solutions

I have investigated the challenges the edible insect market faces regarding consumer acceptance as well as some solutions current companies are developing. I will now suggest alternative strategies and recommendations companies could use to appeal to a more mainstream audience.

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Consumers, especially in Western countries have not been exposed to eating insects, they are unfamiliar with them and are very reluctant to eat them. How can companies change this consumer behavior? One way is that companies could focus on increasing the visibility of insects as a product and normalising entomophagy. An intermediate step to insects as food is having insect by-products.

One of these by-products is organic fertiliser. BSF produce frass as waste, and this excrement can be used as an organic fertiliser. (Barragn-Fonseca et al, 2022) Current synthetic fertilisers use by-products from the petroleum industry. As countries look to reduce their emissions, this insect-based organic fertiliser could mitigate the reduction in the supply of synthetic ones. Experiments have shown that frass-based fertilisers do improve productivity and improve the soil's health and sustainability. (Menino, 2021) Flyfarm produces and sells this organic, insect-derived, fertiliser. (Flyfarm, 2022)

BSF oil can be used for biodiesel. BSF larvae grown on 1kg of cattle, swine, and poultry manure can produce 36, 58, and 91g of biodiesel, respectively. (van Huis, 2013) BSFs could produce 2, 1.9 and 0.01kg of bio-diesel per animal, respectively. (Leip, 2019; Chastain et al, 1998; Williams, 2018) In the US, 4kg (a gallon) of biodiesel cost £4.3 (£1.075 per kg of biodiesel). (IndexBox, 2022) This means that a single cow, pig, and chicken could produce, through the BSF conversion process, £2.15, £2.04, and £0.01 worth of biodiesel through their manure each day, respectively. Flyfarm also uses oil from BSF for livestock feed, replacing poultry fat, fish oil and oilseeds for example. (Flyfarm, 2022) The price of oilseeds has doubled in the past 10 years, opening the door for BSF oils to be used more widely. (Defra, 2022)

Insects as feed is also a great way to normalise having insects on our plates, even if not in a direct manner. A huge issue with the current agricultural system is that a large part of agricultural land and cropland is used to feed livestock: 70% of agricultural land is used for grazing and 34% of cropland is used for feed production. This is taking land away from direct human consumption of crops, fruits, vegetables, and pulses. (Stehfest, 2013) Mealworms and other insects do not need to feed on outputs of cropland as they can feed on produce scraps. Huge amounts of waste from produce is discarded and can be repurposed for feeding mealworms. The UN estimates that around 17% of the world's food production is wasted, creating a huge source of feed for certain types of edible insects. (van Huis, 2013)

Research has shown that consumer acceptance for animals fed with insects is much higher than eating edible insects, suggesting it might be a more viable alternative for insect farming in the near future. (Sogari et al, 2019) Insects are especially useful because of their high protein content, providing a high-quality source of feed for animals. Currently, they are predominantly used for aquaculture feed, especially for salmon. (Agriprotein, 2022) Salmon feed accounts for half of the production costs of a salmon farm (£1.3/kg of feed), so farmers are looking for cheaper feed alternatives, while keeping the protein content and feed quality high. (McCullough, 2019)

The main barrier to using insects as livestock feed, as embodied by Ynsect, the largest edible insect startup in the world, is the fact that current livestock feed is very cheap. Ynsect, having received nearly half a billion USD in funding, has decided in 2021 to shift its focus away from livestock feed to human consumption as it could not compete with current feed prices. However, the cost of livestock feed (including cattle, poultry, pig and sheep) has more than doubled in the past 15 years, suggesting that if this trend continues, insects might become a commercially viable option for farmers in the near to mid-term future. (Defra, 2022)

Surveys currently show that age is not a good predictor of current insect-consuming patterns. Yet, they do demonstrate that children are more "willing" to eat insects than older individuals. (Krger, 2022) Children have less life experience, and thus less time to develop certain biases, influenced by parents, society, or experience. They are more naive and thus more open to insects. In addition, past familiarity with insects makes an individual much more willing to consume them again. The idea of several researchers is that if young children are exposed to and eat insects early on, they will not have the usual disgust and reluctance towards edible insects as their elders had. (Dupont & Fiebelkorn, 2020)

Companies could target younger audiences with specific products and offerings. They might be able to gain a receptive and hopefully loyal customer base. This could include children's birthday parties, products sold in the children section or collaboration with cartoon and animated characters. Collins et al (2019) found that the age where

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the attitude shifts from a positive to a negative perception of insects as food is around 11 years old, so companies should focus their efforts on children under that age limit. Alternatively, Collins suggests introducing them in school canteens, but that might be more often the remit of public institutions.

An important but abstract goal that edible insect companies should aim for is to provide a positive experience to consumers. (Gmuer et al, 2016) As one would expect, a positive product experience makes a customer return and spread the benefits of the product to friends, family and social media.

A certain segment of consumers is curious about and interested in edible insects, likely a similar customer segment that currently engages in Yumbug's "Bug Club". (Stone et al 2022) These individuals want to experience a less-processed, slightly abnormal food product. In this case, direct entomophagy might actually be a good solution. This is different from the strategy of using indirect entomophagy to reduce the disgust factor, as it caters to the curiosity of a different consumer type. (La Barbera et al, 2021) It might be a good alternative for companies to target both types of customer segments with their products.

Sensory attributes are also crucial to consumers' experience with eating insects.
(Wendin & Nyberg, 2021) These include:

- **Visual:** Not seeing the insect, the insect being small.
- **Auditory:** Crunchy, sharp sounds are preferable.
- **Olfactory:** Insects usually do not smell strong, but it might be better to cover the smell in favor of more known and appreciated ones.
- **Gustatory:** Insects have a mild taste and spices can make the taste more enjoyable.
- **Tactile:** Touching the insect, cooking with it.

Some research by Chow et al (2021) suggests, however, that tactile stimuli do not have a positive impact on consumers' experiences and perceptions. Rather, they just increased the disgust factor of the study participants. Hence, this stimulus should be treated with caution.

Finally, Motoki (2020) showed that positive arousing emotions (fun, excitement) are preferable to positive calming emotions (romance, tranquility) when convincing consumers to try insects. Practically speaking, the context and atmosphere companies should attempt to create when selling insects (packaging, advertisement, stall at a food market) should be one of excitement and novelty.
The final recommendation for edible insect start-ups is to market and present their products as a unique and separate food category. They should not attempt to market edible insects as a meat alternative or substitute. By competing against animal-based protein sources, it would be competing against a well-established food source. The price of meat today is relatively cheap, thanks to years of innovation and scaling, and it will take a long time for edible insects to achieve that price competitiveness. Consumers for the past thousand years have been born and bred eating meat. Culturally it is an accepted food and preference-wise, the majority of people find it a natural food source. Studies have shown that plant-based alternatives cannot compete with meat in terms of flavor, texture and taste. (Zhao et al, 2022) Consumers often buy both animal-based products and plant-based ones at the same time, to compare. Then, they usually revert back to the animal-based product, unsatisfied with the plant alternative.

Therefore, edible insect companies should attempt to create a novel food category, where they can charge a premium and not compete with meat in terms of price and flavor. For example, tofu is by now considered a food category on its own, and is not marketed as a meat-alternative. This way, consumers do not compare tofu and meat on an equal footing.

Lobsters are a further good example of how a food that was once considered to be for the poor was catapulted in the mainstream and eventually the (very) high end, at the start of the 20th century. At some point, lobster used to be banned from US prisons, as it was considered unworthy food for inmates. The lobster industry tried to change that perception. Companies got Hollywood movies to include lobsters, got pictures of celebrities eating it and introduced them to high end restaurants. Slowly, attitudes towards lobsters changed and started to be seen as

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expensive food for the rich. (Spanier et al, 2015) Edible insects can learn from this success (and many others such as shrimp and sushi), and target higher-end customers to change the public perception of insects.
All these strategies attempt to increase the value that consumers have for edible insects, to ultimately increase demand. However, food history shows that the way that food becomes accepted is usually the other way: through increased supply.

The lobster example mentioned above, was only enabled by a new kind of boat (the lobster smack) that enabled fishermen to transport lobsters alive across distances, so they could fish further out and in higher quantities. Supply was first ramped up, and then demand followed. (Spanier et al, 2015)

By increasing the supply, insects will be more accessible for consumers to trial: (**trialability**) and knowledge about how to consume them will be more widespread: (**complexity**). Also, seeing insects in many different shops and contexts will help the normalisation of insects as food and will encourage and facilitate the diffusion by early adopters and other consumers of the product. Finally, large-scale production will drive costs and prices down for producers and consumers, respectively. This can make insects a much more competitive food product. (Shelomi, 2015)

The issue is that each company, on its own, cannot massively increase the supply without incurring large costs. It can only produce to meet the current demand, otherwise it will be operating at a loss. On the quest to maximise its profits, the company might operate at a loss to acquire new customers, but it still needs to break even at some point. This is where the government and the public sector can come and steer the market in a certain direction, that is in the interest of the wider population.
Next, I will explain why policymakers might want to encourage the edible insect industry, what risks it should aim to mitigate and what policies it could implement to do so.

4. The Role of the Government

Governments can have a role in helping certain industries and products over others, if they deem it beneficial for their population. With important challenges in the coming decades such as climate change, international competition, the race for innovation and the reformation of our food system, governments must find new policies to solve these problems. Do edible insects solve certain problems and what risks do edible insects, themselves, bring to the table?

4.1. Why Should Governments Care About Edible Insects?

Firstly, governments must make sure their population has enough food to sustain itself and has a robust supply chain that can withstand shocks. Food security is defined by the UN as “when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet dietary needs”. (FAO, 1996) Thanks to its efficient transformation of inputs, potential for scale and nutritious content, edible insects can help countries achieve food security. They can also fortify foods by adding protein to nutritionally lacking foods. Food security is a crucial component of a country’s sovereignty, independence and stability.

If a country depends on other countries for its supply of food, it is vulnerable and dependent on these other countries. It will have to make sure it is on good terms with its suppliers and may need to accept certain trade deals or other agreements in order to protect its food supply. This is dangerous because this essentially means that a country is not fully independent.

The provision of a stable and sufficient food supply is also important for the internal stability of a country. The lack of food, famines and high food prices have been, over millennia, the source of political coups, revolutions and uprisings. The most recent example is during the Arab Spring. Riots started in Tunisia and other Arab regions when grain prices shot up. It resulted in multiple dictatorial regimes being toppled. (Dellmuth et al, 2020)

Second, governments want to make sure their economy is competitive and growing, in turn making its citizens prosperous. They can do so by encouraging innovation. Edible insects can be considered an innovation in that they are a new product and also a new way of producing protein. Innovations enable societies to improve, meet the needs of their population and better the lives of consumers.

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Third, a country wants to be integrated in the international trade network, and, thus, needs to have competitive firms. This enables the country and its companies to export and import products. Porter argues that a country's international trade competitiveness comes from the ability of its national firms to innovate. (Porter, 1990) If a country encourages innovation in a certain sector, for example the food sector, it will have a competitive advantage and can increase its exports and improve its trade balance. In addition, trade relationships and integration reduce the likelihood of war between states and promotes cooperation. (Copeland, 1996) Being a leader in a new product can also give the country a head-start in that market and benefit from the "first-mover advantage", these are the profits and advantages those that entered a market early can have. (Lieberman & Montgomery, 1988)

Fourth, edible insects seem to be a more sustainable protein source than traditional meats. As governments have pledged to reduce their greenhouse gas emissions and protect their biodiversity, insects might be part of a solution to "greening" their economy.

Finally, edible insects have been shown to have many health benefits that I will not delve deeper into in this paper. These include a very high protein content, large amounts of B12, iron and zinc. (Schmidt, 2019; Mwangi et al, 2018) The protein quality is also much higher than other protein sources. (Oibiokpa et al, 2018) These benefits can have very important positive effects on the health of humans and, by consequence, can save a considerable amount of money, time, and resources for national healthcare services.

4.2. What Risks Should They Mitigate?

Policymakers need to balance the need of the economy to grow and develop new innovations with the safety and stability of the country. Edible insects do pose some risks that governments will have to address.

The biggest risk in factory farming insects is biodiversity leakage. One can imagine that if an insect species that has been genetically engineered escapes in the wild, it may destroy local biodiversity and bring its ecosystem out of balance. Collins (2022) argues that this risk is minimal for different reasons. First, the likelihood that they escape is low because government regulators are very strict with how insect farms operate. They are required to have a three-layer approach, meaning there are three barriers for insects to get over (the cage, the room and the warehouse). In addition, the probability of a large enough escape is, again, low as thousands of boxes are separate from each other and handled one at a time. Finally, it is most probable that factory insects are not well-suited to the local environment, will therefore not survive and that the local species would have a greater chance of surviving than the factory-bred insects.

Current research on edible insects is looking at how to optimise the nutrient profile of insects to make them as healthy and nutritious as possible. This is done by genetically engineering species to get the desired nutrient profile. Collins (2022) explains that the majority of our food today is manipulated in some way. This is especially true for the meats and produce we consume. As a result, although the idea of genetically engineering insects for consumption might seem futurist, it is in fact normal and in line with current food practices.

Due to the large genetic and evolutionary difference between insects and humans, the risk of zoonotic diseases (diseases transmitted from animals to humans) present in insects is relatively low. (Collins, 2022) However, there is a non-negligible risk of allergies. It has been shown there is a link between crustacean and insect allergies. (Ribeiro, 2017) Around 0.5-2% of humans have a shellfish allergy and it is likely that the majority of them will be allergic to edible insects. Microbial risks (contamination by microorganisms found in the air, food, water, soil), will always be a threat in producing food products, but does not seem to be especially important in insects. (Cappelli et al, 2020)

Policymakers should be wary of the unintended economic consequences of edible insects. Rogers, seminal author on the diffusion of innovations, would predict that larger farms would take over smaller ones, as they scale up and take over the market. (Rogers, 2003) This is what happened when tofu became popular in Western countries but is also a wider trend in the farming industry. (Menzel & D'Aluisio, 1998) There could also be impacts on the price of

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other products: if competing with the same resources, the price of feed, meat and pet food might increase. (Shelomi, 2015)

The issue with our food system is that we have taken our production close to its maximum with factory farming and intensive monocultures. Our agriculture developed to have a highly efficient system to produce food in the short term, but is damaging our long-term ability to produce food as it is destructive to our ecosystems. More local, less intensive food production systems might be less efficient but might help restore the environmental balance and ecosystem. Consequently, is scaling up edible insects and factory-farming them really the solution? Although the inputs are minimal, producing insects on a large scale may pose some unforeseen problems. It might be better to steer our food system in a different direction, away from intensive, factory farming. This question over factory farming is a dilemma, as the world population is growing and certain regions of the world are suffering from famines. The real issue is actually how we distribute our production, and not how much we produce. Bloomberg (2010) calculated that we can feed two Earths with our current agriculture infrastructure, so innovation might be better directed in how we allocate our production in a fairer manner.

4.3. Policy Recommendations

Policymakers may benefit from encouraging edible insects as a product and as an industry. The most obvious policy would be pricing carbon emissions more heavily. Since insects emit minimal carbon emissions, this would help them reduce costs compared to other food sources. One way to price carbon is to give a certain amount of emissions quotas to companies and let them trade these emissions quotas based on their need. This is called an “Emissions Trading Scheme” and has been implemented in the UK and the EU. If a company wants to emit more, it has to pay more. The European Union emissions trading system has been shown to reduce emissions by 10% without hurting the financial performance of firms. (Dechezleprtre et al, 2018) Pricing carbon would make edible insects more competitive compared to other protein sources.

Governments could also find ways to encourage innovation, which could benefit the insect industry. Innovation enables firms to differentiate themselves, be more competitive and offer better products. Collins (2022) argues that the lack of funding is what is holding the edible insect industry back. This includes funding for researchers looking to optimise the nutrient profiles of edible insects, and those looking at the best way to domesticate insects for human consumption. It also includes grants and funding for entrepreneurs and businesses wanting to sell edible insects. Initiatives such as the “Emerging Insect Technology Hub (EIT-Hub)” (2022) between Africa and Australia are a great example of cooperation and innovation in this space. Another success story is Agriprotein, which developed its own technology to treat food waste so that it is digestible by BSF. This was protected by a patent (Intellectual Property - IP) and enabled them to differentiate themselves from other competitors. Having IP rights leads to above average returns for companies. It is also a type of intangible asset that adds value to a company and can be sold. (Greenhalgh & Dixon, 2002) For example, when Agriprotein did not find enough funding to continue operating, it managed to sell its IP rights to a larger company before being disbanded, without the need to file for bankruptcy.

However, the most basic and important piece of legislation is whether edible insects are a legal food in a country. The EU, for example, considers the mealworm and the cricket as novel foods. These are foods that are traditionally eaten outside of the EU and that the EU deems safe to consume. This gave a huge boost to the edible insect industry and enabled European companies to function within a legal framework. In the UK, however, this is not the case anymore because FSA decided not to keep the EU’s legislation regarding novel foods after Brexit. This means that all edible insect companies in the UK are currently operating in a grey area at best, or outright illegal at worst. This obviously hinders the businesses’ ability to function, receive funding, expand and market themselves. (Horizon Insects, 2021)

5. Concluding Remarks

Edible insects can be produced in a more sustainable manner than traditional animal-based protein sources. The resources used to produce edible insects is just a fraction of what is needed for traditional meat sources. In addition,

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they are dense in protein, a crucial macro-nutrient that most humans do not get enough of. Environmental and nutritional benefits are there and are pushing entrepreneurs to enter this industry. The challenge for them is in changing consumer behavior and acceptance. Edible insects are still met with disgust due to cultural norms and neophobia. Insects are still not taken seriously and are often seen as a gimmick.

Edible insect companies are trying to overcome this reluctance with indirect entomophagy and using insects as feed, to normalize the act of eating insect products. Additionally, companies are attempting to build communities, mimicking the early adopters strategy in the technology industry.

We suggest that companies could also increase familiarity by selling insect byproducts, targeting a younger audience and making edible insects a unique food category. Competing directly against traditional meat sources does not seem to work, edible insects should look to differentiate themselves in another manner.

However, the supply side of the market must also be addressed. Diets and food habits change when there is a major improvement in the supply of a certain product, as we have seen with lobsters in the 20th century. Governments might have an interest in promoting insects as food and boosting its supply. Insects could provide an answer to food security, climate change, and economic competitiveness. Legalising edible insects and encouraging innovations in that industry might do just that.

Whether consumers are ready to eat bugs is still an open question, and this is the most crucial one the industry must answer. Further research will be needed to understand the evolving acceptance of insects, the evolution of societal norms, and consumer attitudes. It will be important to identify what strategies work or not, especially those involving children and insects' long term effects on them.

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Appendix

A.1. Edible insect species

There are three species that are currently being produced on a large scale.

The **Mealworm**, which is the larvae of the *Tenebrio molitor* has a neutral taste, is easy to grow as it doesn't jump or fly and can grow on oats and produce scraps. It is usually eaten whole and mixed in dishes. It has one of the highest protein densities of edible insects at 72%.

The **Black Soldier Fly** (BSF), or *Hermetia illucens* does not have a good taste and feeds on food waste and manure. It produces some waste, frass, which makes the farming of BSFs more time consuming and less efficient. Since it is not the most clean insect product, it is usually ground up for pet food or livestock and fish feed. (Agriprotein, 2022)

Finally, we have the **House cricket**, *Acheta domesticus*, and the **Banded Cricket**, *Gryllodes sigillatus*. This is the most sold edible insect species in the UK and Europe for human consumption. It is also the only species that the three main monotheist religions (Christianity, Judaism and Islam) allow their followers to eat. The cricket has an earthy flavor and is considered more approachable. It can feed on cardboard and leaves, but the optimal feed is a type of modified chicken feed. We will be focusing on crickets in our following input-output analysis.

A.2. Instar Farming's production process

This is information taken from a phone interview with Instar Farming, the largest cricket farm in the UK. (Instar Farming, 2022) The whole production process takes around 35 days: eggs hatch after 8 days and become larvae, then become mature adults ready for harvest 26 days after.

The factory layout is simple: boxes of 0.83 cubic metres are stacked up as high as the ceiling allows. Every box outputs 7.6kg of wet weight, they are then frozen, which puts them into a state of hibernation. This enables the crickets to be killed without any suffering. They are then processed to produce around 2.3kg of dry weight (70% of a whole cricket is made up of water). This can be as whole cricket or as powder. Crickets are fed a modified chicken feed, the higher the protein content of the feed the bigger and higher quality the crickets will be.

A.3. Edible insect start-ups

A.3.1 Hargol

Hargol is the first commercial scale grasshopper farm in the world, based in Israel. A third of its sales are currently whole grasshoppers, but aim to be the leader in grasshopper protein powder. They are especially interested in selling grasshopper powder to large food multinationals.

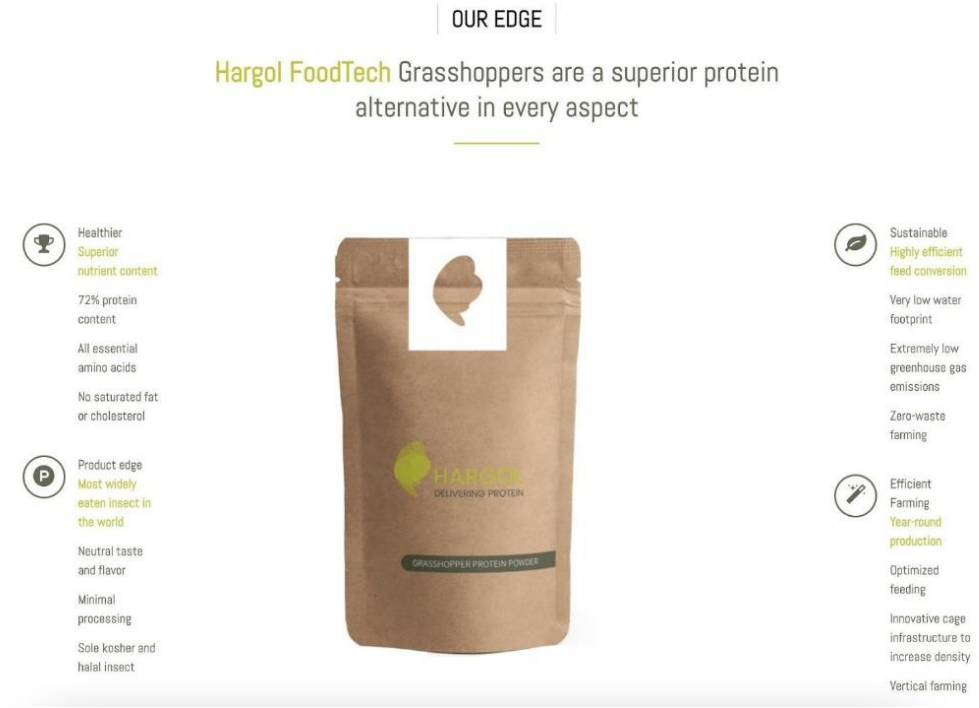

Figure 3: Hargol

https://doi.org/10.14324/111.444.2755-0877.1383

A.3.2. Biblical Protein

Biblical Protein is a spin-off brand from Hargol, catering for Orthodox Jews and Christians. They are trying to recreate the diet of John the Baptist, who ate “locusts and wild honey”, as narrated in the New Testament. (Holy Bible, 1974)

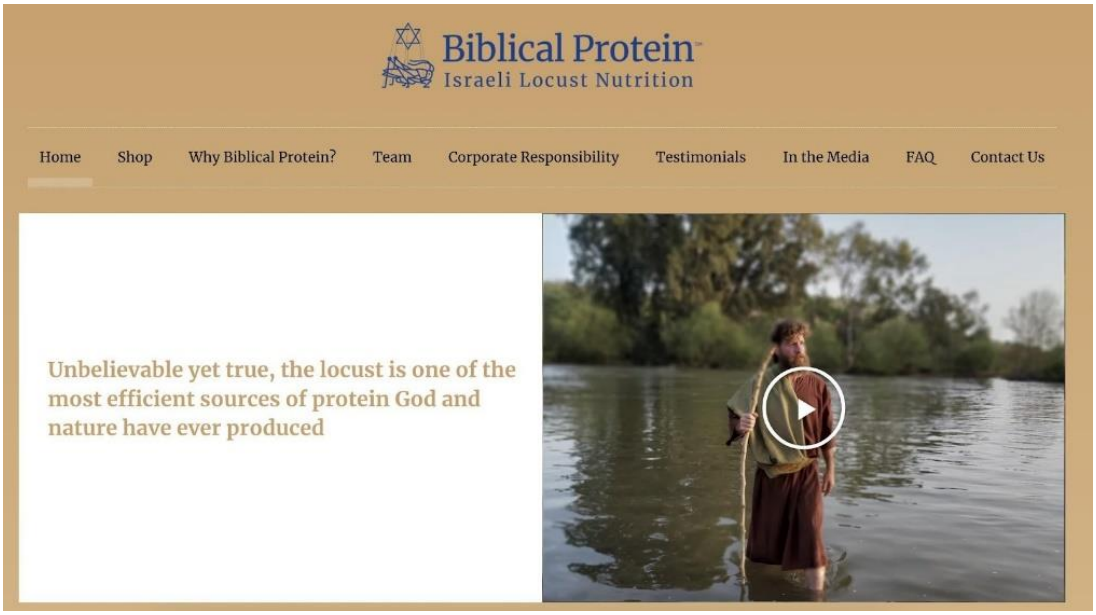

Figure 4: Biblical Protein

https://doi.org/10.14324/111.444.2755-0877.1383

A.3.3 Yumbug

Yumbug is a start-up based in London, selling cricket cooking kits as a subscription service and providing countless recipes to cook crickets in many different ways.

Figure 5: Yumbug

A.3.4 Instar Farming

Instar Farming is the largest cricket farm in the UK and supplies many of the UK's edible insect startups.

Figure 6: Instar Farming

https://doi.org/10.14324/111.444.2755-0877.1383

A.3.5. Bugvita

Bugvita is the retail brand of Instar Farming, selling whole, roasted crickets as well as cricket powder. Crickets are usually plain or flavoured and all business is made through their online store or Amazon.

Figure 7: Bugvita

A.3.6. Agriprotein

Agriprotein uses Black Soldier Flies to up-cycle organic waste. Flies feed on organic waste to produce pet food, livestock feed, fish meal, oil, and fertilisers. They chose to focus on BSF and transformed products because they recognise that consumers are not ready to eat whole insects just yet and thus use insects for different purposes other than human food.

Figure 8: Agriprotein

https://doi.org/10.14324/111.444.2755-0877.1383

A.3.7. Flyfarm

Flyfarm has a very similar offering to Agriprotein, using BSF to upcycle waste. They also extract oil, fertilisers and other by-products from BSFs.

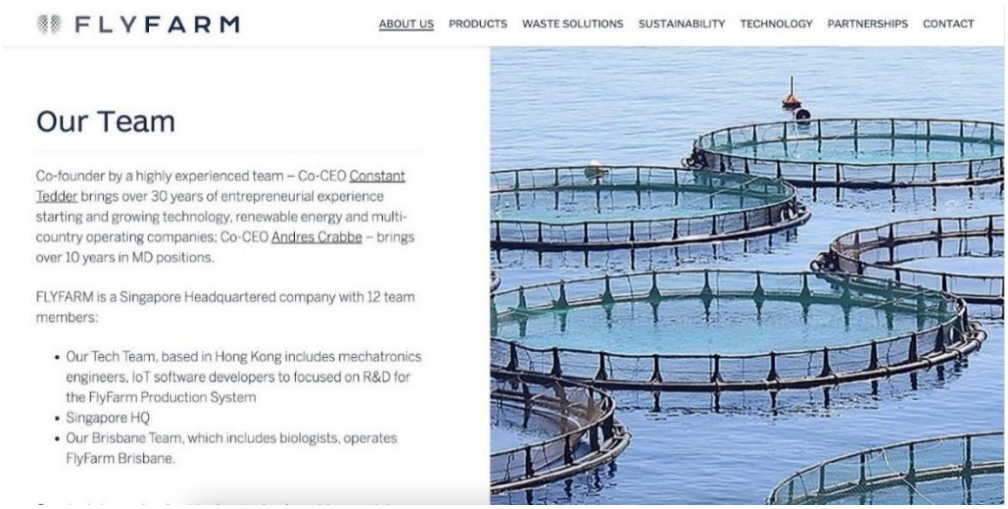

Figure 9: Flyfarm

A.4. Edible insects in the circular economy

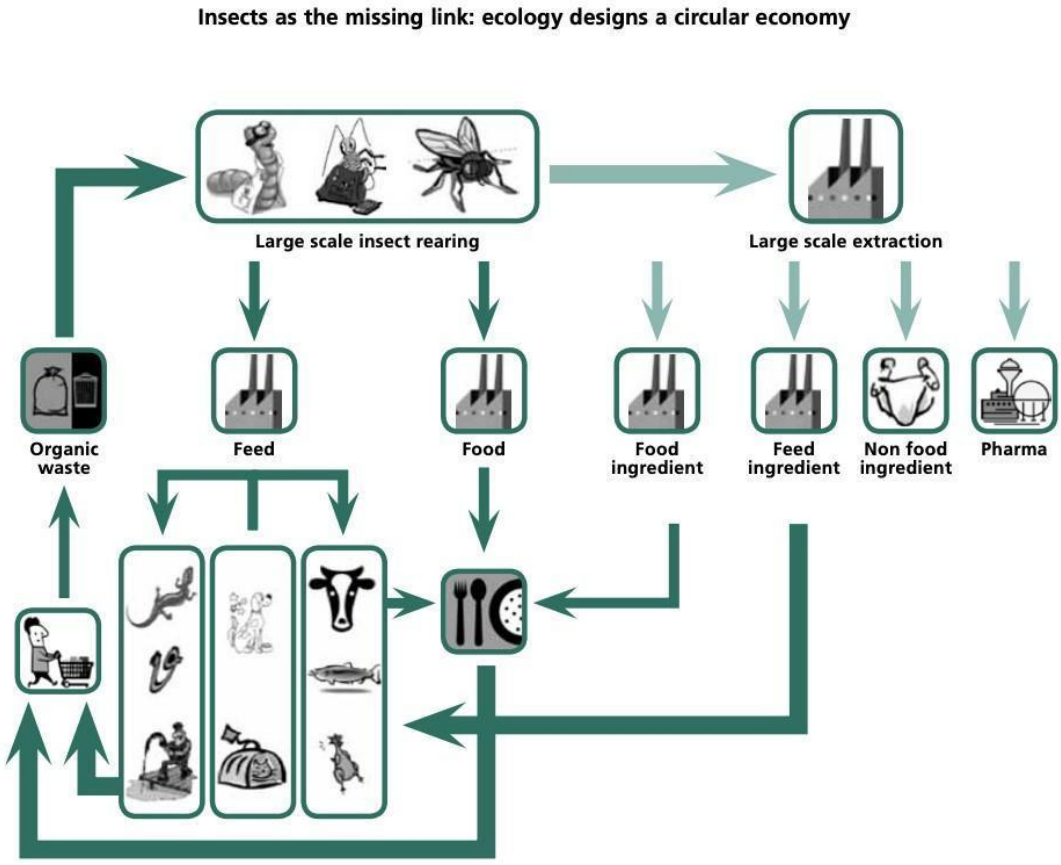

Figure 14

A model of a circular economy including insects as food and feed, (FAO, 2013)

https://doi.org/10.14324/111.444.2755-0877.1383

This diagram shows the various uses of edible insects in a new circular economy. They can be used as food or feed but also for other applications (pharmaceuticals and non-foodstuff). They are then directly consumed or used as inputs for pets, livestock or other food products. Edible insects produce minimal waste and can use the waste produced by pets, livestock and humans as their own inputs.

A.5. Blog

As part of my research, I have written a few articles on my blog:

- Entomophagy throughout the ages
- How edible insects can solve the looming shortage of agricultural land
- The Potential of Crickets as a Protein Source - Infographic

https://doi.org/10.14324/111.444.2755-0877.1383