2021

Overview of the Insect Food and Feed Industry

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Introduction: Cro-Magnon Man Ate Insects

It's inconceivable to believe that early human ancestors did not eat insects. They are small, easy to catch, plentiful, quickly cooked (but don't have to be), and nutritious. According to William McGrew (2014) in the *Journal of Human Evolution*, using our ancestors as a lens to see into the past increases the likelihood that early humans consumed insects. Accordingly, Gorillas, lemurs, chimps, bonobos, and many other primates all practice entomophagy. Sanz et al. (2014) point out in the same issue of the *Journal of Human Evolution* that chimpanzees use tools routinely to gather termites and other insects from hard-to-reach crevices or holes. McGrew and Sanz, like many scientists researching human dietary evolution, now called anthropoentomophagy, *c*onclude that our ancestors ate insects as soon as it was possible. The hypothesis shared by most anthropologists is that before tool use, ancient human ancestors likely consumed insects.

The archeological evidence of insect-as-a-food consumption is vast. Before the great Human-Gorilla split some 9 million years ago, when *Hominidae* roamed the savannas and shrublands of Africa, insects contributed to a balanced diet consisting of proteins and amino acids not available on the largely treeless regions of north-central Africa. Insect remains were discovered in coprolites belonging to our earliest ancestors dating as far back as 12 million years ago. Much more recently, evidence of archaic humans, notably those of *Australopithecus,* living 500,000 years ago, used tools, much like Chimpanzees today, to dig into large termite mounds in Africa (Tommaseo-Ponzetta, 2005). The evidence that contemporary chimpanzees and recent ancestors consume insects suggests that prior species dating as far back as *Orrorin tugenesis*, or when the split between chimpanzees and hominid ancestors occurred, incorporated insects into their diets.

Interestingly, Tommaseo-Pozetta's (2005) research proposes that the high polyunsaturated fatty acid (PUFAs) diet propelled the expansion of early hominid brain size. The high energy density contained within insects was essentially a driving factor in developing modern *Homo sapiens* brainpower. More recently, Mesolithic cave art depicts scenes of honey collection with men on ladders near a honeycomb gathering honey, wax, and presumably bee larvae for consumption (Belles, 1997).

While the archaeological record has numerous examples of archaic ancestorial anthropoentomophagy, one has to look no further than the last 2,000 years to see that societies from Aristotle through Medieval Europe consumed insects. Costa-Neto and Dunkel (2016) state, "[i]nsect consumption by humans is historically and geographically an old, widespread phenomenon. From the earliest Chinese annals to Mexican codices, through the chronicles of naturalists and travelers and the old papyrus of ancient Egypt, we have records of insect-eating peoples." Pliny the Elder, a Roman naturalist living in the first century, described how *Cerambyx cerdos*, a longhorn beetle belonging to the Cerambycidae family with widespread native distribution, was regarded as food, especially when found sifting through grains sacks or wine barrels (DeFoliart, 2002).

Entomophagy is referenced in both the Old Testament and the New Testament. Locusts are mentioned throughout the Bible as both a plague and a food. In the New American Standard Bible, Leviticus 11:21 describes the types of locusts permitted to be eaten, stating, "Yet these you may eat among all the winged insects that walk on all fours: those which have jointed legs above their feet with which to jump on the Earth. These of them you may eat: the locust in its kinds, the devastating locust in its kinds, the cricket in its kinds, and the grasshopper in its kinds." In Mark 1:6 and Matthew 3:4, we read that John the Baptist's clothing was made of camel's hair, and his food consisted of wild honey and locusts. The word locust was often a catch-all word for numerous types of insects (NASB, 1987).

Furthermore, the Talmud references people eating locusts (those not spending much time on the ground, presumably not crickets) and gathering them for meals. Even the Quran, the most recent addition to the monotheistic religions, references consuming orthopterans, such that "whoever does not eat my locusts, my camel, and my turtle, is not worthy of me, says the Prophet" (Bergier, 1941). Nearly all sacred religious texts except for the Agamas of Jainism preaches non-violence to all living creatures—including insects—such that Jian monks carry a picchi, small brooms, to brush away insects before they sit down, mention insect consumption for one reason or another.

The last five hundred years have been no different. Scholars, explorers, and military men have described cultures they encountered worldwide, from India and China to Latin America and Africa, that made insects a staple of their diets. European colonists in the New World describe native tribes consuming insects, and to no surprise, the repulsion experienced by the authors of those texts at such a sight. In Missouri's Ozark Mountain limestone caves, archaeologists have discovered mummified remains with coprolites containing insect cuticles (Berenbaum, 1995); and, insect remains among human settlements have been found in Kentucky caves indicating that Native Indian populations consumed insects before and after European settlers began arriving in the New World (Yarnell, 1974).

In some parts of the world, not much has changed. Today, the Food and Agriculture Organization of the United Nations (FAO) estimates that as many as 3071 ethnic groups in 130 countries utilize insects in some capacity as an essential ingredient in their diets (Costa-Neto & Dunkel, 2016). With nearly 5.4 billion of the world's 7.8 billion currently living in developing countries, and about 2 billion of these population groups are estimated to consume insects routinely that entomophagy practices are not something merely related to our ancient ancestors, but, that humans continue to rely on insects for valuable food. The figure below (figure 1.1) shows the diversity of current insect consumption globally. Countries in Asia dominate consumption, with most nations consuming at least 100 different species. In contrast, countries in North American, Europe, and the Commonwealth of Independent States consume five or fewer—in most cases zero species.

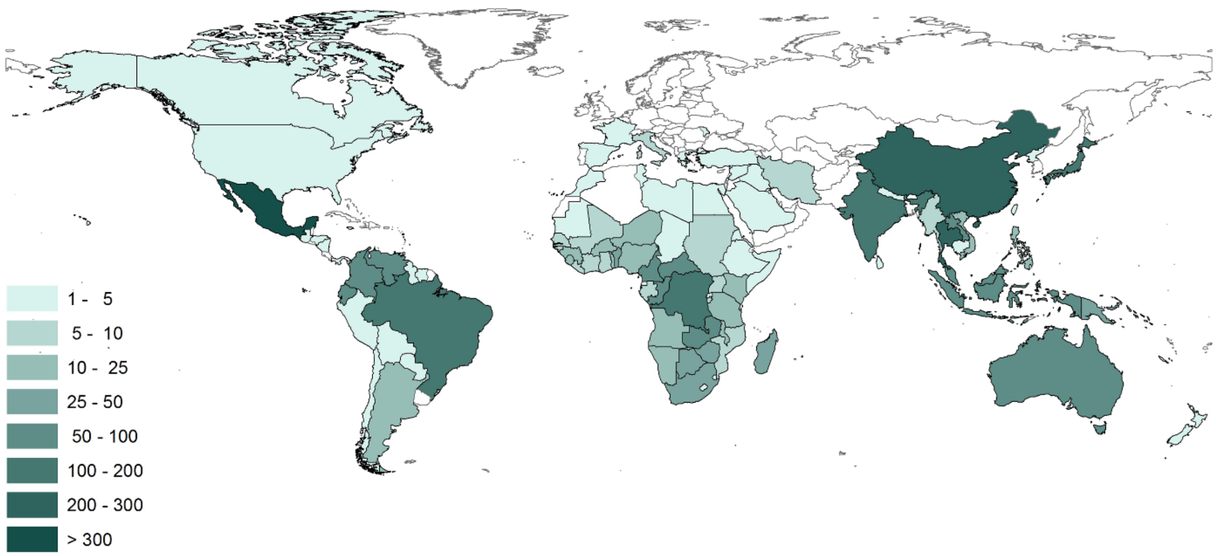

Figure 1.1 Map of world insect consumption by the number of species and geographical location (Courtesy of Ron van Lammeren, Wageningen University, the Netherlands. Based on data compiled by Yde Jongema, 2015).

It's challenging to determine consumption habits among different societies diverged and even more challenging to determine why. Most anthropoentomophagy researchers theorize that entomophagy existed through the end of the Dark Ages and abruptly ceased during the early 15th century. Historical records and paintings and scientific climate modeling suggest that Europe underwent a "little ice age" from approximately 1200 CE through the late 19th century. Paintings from this time depict Spring scenes of ice-covered water and snowy landscapes. Abraham Hondius's *The Frozen Thames* (1677) depicts men and children playing on thick blocks of ice on the banks of the Thames with Westminster in the distance in late April. The Great Famine of 1315-1317 indicates that the climate altered such that insects that once acted as a food source were no longer viable options due to the extended periods of cold weather. This period of up to 700 years would have altered European dietary habits significantly. According to figure 1.1, nearly all the countries not consuming insects in great numbers lie north of the 45th parallel in a region that would have undergone long, cold winter months devasting insect populations at higher latitudes.

Another possibility, or likely contributing factor, is that through global expansion during the Age of Reason and the Scientific Era of discovery, contact with diverse cultures, those often viewed as inferior, led to changes in dietary habits. Contact with indigenous societies worldwide may have persuaded Europeans to abstain from eating foods eaten by peoples from what the Europeans would have considered 'inferior' societies. The ability to produce and harvest crops and livestock near industrial scales would eliminate the need to forage for insects. By the 19th century, European and North American societies slowly industrialize, eliminating the need to think of insects as a food source. People's habits and customs related to food change, and the focus of a meal becomes less on eradicating hunger and towards celebration. Mealtime takes on an essential role within households to establish religiosity, generosity, and wealth.

We do know the transition from eating insects took place before Christopher Columbus's journeys to the New World. In Lesnik's (2018) book *Edible Insects and Human Evolution*, we read that Columbus and his co-subjugators, upon returning to Spain to describe what they found in the New World to the monarchy used West Indian indigenous tribes eating insects as evidence of their savagery. Brickell and Lawson's 1737 *Natural History of North Carolina*, representing one of the earliest Colonial works in the Americas, talks about native tribes eating wasp and bee larvae and their disgust therein (Capinera, 2008). Therefore, we can assume other Native American tribes gathered and consumed insects. While we do not have much evidence to support this assumption, we know that the Kucadikadi people of Mono Lake, California, consume salty pupae to this day. (Klein, 2019).

A contemporary entomophagous litmus test occurred during the twentieth century during World War I when global food prices increased, and many nations struggled with food shortages. While the world waged war and famine set in, there are no reports of populations (re)turning to consume insects as a food source (Dossey et al., 2016). A further test to the presence of entomophagy in Europe and even more so in the United States was during the Great Depression. The record remains absent.

Today, by developed world standards, the consumption of insects is something reserved for prime-time television or foodies. The American reality show *Fear Factor* which ran from 2001 to 2006, focused on contestants competing at stunts that often involved them eating concoctions of insects. Numerous upscale restaurants, including some boasting Michelin stars, began incorporating insects into their cuisines in the early 2000s. One such restaurant, *Aphrodite* in Nice, France, had an entire menu dedicated to meals based around insect creations, with prices starting at $120.00 a plate. In 2014, the restaurant lost its Michelin star with the head chef and owner exclaiming "Les insectes sont à blamer" (Samuel, 2018).

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In November 2014, to much fanfare, Christopher Nolan's film *Interstellar* premiered in the United States. Nolan's film accolades are numerous—he's been nominated for 34 Academy Awards taking Oscar home ten times. Additionally, he's won BAFTA and Golden Globe awards, and in 2019, he was appointed Commander of the Order of the British Empire (CBE). In 2015, one year after the release of *Interstellar*, Nolan was named one of *Time's* 100 most influential people in the world. Suffice to say, he and his films are highly respected. I saw the movie when it premiered. Like many, I enjoyed the film. The cinematography, score, and stylistics didn't leave Nolan fans disappointed. But as I left the theater, I felt perplexed—bothered. At the time, I was interested in entomology generally and fascinated abstractly by entomophagy.

Nolan's *Interstellar* takes place in 2067 in a world where crop blight, dust storms, and other environmental catastrophes—that we hypothesize about today—are a reality that plague the characters in the film. The focus on Earth becomes farming—specifically corn. Joseph Cooper, played by Matthew McConaughey, is a former rocket engineer turned farmer (like all well-educated Nolan-Earthlings in *Interstellar*) who, unlike his contemporaries, holds a fondness for the past and a belief that unless drastic changes take place, the Earth is doomed. Others have Cooper's vision and collectively attempt to travel beyond the stars, searching for a new earth for humankind.

In Nolanesque fashion, the film takes audiences on an intergalactic sojourn to Exo-plants, through wormholes, and back to Earth (sort of). It's a wild and thoroughly enjoyable ride. However, while I accepted the numerous scientific inaccuracies, the confusing (and incorrect) space-time calculations, and other mathematical impossibilities, I wasn't entirely satisfied with this specific Nolanverse. It hit me quite quickly—the movie's entire premise was false. The plot is built upon a foundation that cannot be accepted: Earth is running out of food because our only food sources are livestock and crops. So as I drove home staring at Nebraska corn and bean fields along the road, I asked a question: why didn't Nolan's Earthlings farm insects?

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As evidenced, the contemporary divide between Eastern and Western cultures consuming insects is vast. In Mexico alone, some 350 distinct species are consumed. Yet, in the United States, at most, five species are consumed, and these are largely at specialty restaurants or by indigenous tribes (Yde Jongema, 2015). Insects are more plentiful in most of the countries where they are consumed, and many of these locations have continued with traditions of entomophagy. Communities follow ancestral customs and are slow to change. Over 800 hundred years ago, Western Europe excommunicated themselves from entomophagy, and thus Western cultures are going to be slow to readopt the practice.

The Case for Insects as Food

Why should insects be consumed? Insects live and reside in soil; some consume detritus and have hard exterior bodies. Nothing about an insect looks appetizing. Yet, as we've seen, mankind has a long evidential history of entomophagy. Accordingly, many cultures have retained their customs through the ages allowing them to overcome insect-based prejudices common in Western cultures. With so many foods readily available for many communities around the globe, the question of why societies continue to farm and consume insects is more valid now than ever before. The benefits of insect consumption can be divided into three broad categories: nutritional, economic, and environmental benefits.

Insects are nutritious. Research has shown that insects contain a plethora of macromolecules, proteins, and fats necessary for healthy living. In Dossey et al. (2016), the researchers Rumpold and Schluter studied the nutritional composition of a broad spectrum of edible insect species and concluded that the data shows most edible insect contain large quantities of complex amino acids, are high in monounsaturated fatty acids and polyunsaturated fatty acids, and rich in several micronutrients such as copper, zinc, iron, selenium, phosphorus, magnesium and manganese. Further research conducted by Payne et al., as referenced in Dossey et al., concluded that the nutrient value score for mealworms and crickets (two of the most common edible insects) is greater than values consumed from beef and chicken. The United States Department of Agriculture compiles tables related to the nutrient values of edible insects. Figure 1.2 below compares species in three orders of edible insects with production animal sources of protein. Many of the edible insect species surpass commonly consumed sources of protein such as beef, chicken, and eggs in at least one if not more elemental category. For example, Turkestan cockroach nymphs (*Blatta lateralis*) have higher concentrations of sodium, potassium, calcium, phosphorus, iron, magnesium, zinc, copper, manganese, chlorine, selenium, and iodine than beef, pork, chicken, eggs, salmon, and whole liquid milk. In some cases, the nymphs have two to three times more nutrients than alternative sources. Dry whole milk surpasses the nymphs only in selenium and calcium content (Williams et al., 2016).

Additional compounds, such as Chitin, the main component of an insect's hard exoskeleton, have shown an ability to improve immunoreceptor response mechanisms in asthmatics and to reduce symptoms related to allergies (Muzzarelli, 2010). Similar to insect nutrient content, many insect species contain significant amounts of vitamins. Some lepidopteran larval species and honey bee larva are rich in vitamin A (retinol); while, other species have shown high levels of thiamin, riboflavin, and niacin (Dossey et al., 2016). While many species lack comparable quantities of vitamins compared to production animals, researchers have concluded that insect diets have a significant impact on the nutritional value for humans; accordingly, modified diets can improve health benefits for consumers (Dossey et al., 2019).

Insect	Na	K	Ca	P	Fe	Mg	Zn	Cu	Mn	Cl	Se	I
Orthoptera												
Brachytrypes membranaceus (raw crickets)	-	-	75	-	54.00	-	-	-	-	-	-	-
Locusta migratoria manillensis (roasted)	55	545	90	424	-	62	8.4	3.00	1.46	-	-	-
Acheta domesicus (nymphs)	135.0	352.0	27.5	225.0	2.12	22.6	6.80	0.51	0.89	-	-	-
Blatta lateralis (nymphs)	744	2240	385	1760	14.8	2.64	32.7	7.93	2.64	1600	0.30	0.30
Isoptera												
Macrotermes subhyalinus	1988	480	40	442	7.6	421	-	13.7	64.4	-	-	-
Macrotermis bellicosus	-	117	44.6	-	-	28.0	-	-	-	-	-	-
Hymenoptera												
Oecophylla sp.	180	541	48	517	21.8	70	10.1	0.87	9.06	-	-	-
Oecophylla verescens	270	957	79.7	936	109.00	122.1	16.9	2.17	6.30	-	-	-
Commonly Consumed Protein Sources												
Beef	57	246	7	122	1.69	17	3.59	0.062	0.015	-	12.1	-
Pork	58	297	14	181	0.91	20	2.28	0.047	0.01	-	24.6	-
Chicken	60	522	6	178	0.82	21	1.47	0.065	0.016	-	10.2	0.016
Egg	142	138	56	198	1.75	12	1.29	0.072	0.028	-	30.7	-
Salmon	44	490	12	200	0.8	29	0.64	-	-	-	-	-
whole milk-dry	371	1330	912	776	0.47	85	3.3	0.250	0.016	-	36.5	-
Whole milk-fluid	49	151	119	93	0.05	13	0.38	0.010	0.004	-	2.0 µg	-
Source: USDA National Nutrient Database, 2015, Bukkens, 1997; Finke, 2007, 2013.												

Figure 1.2 Mineral Content of Selected Insect Species and Common High-Protein Commodities (mg/100g Dry Matter) (Williams et al., 2016).

Insects are economically viable for producers and consumers. At nearly all levels of the supply chain, insects are economically more viable than production animals. Insects consume far less food and water than livestock. Facilities required to farm and rear insects are much simpler and require far less land. Insects can be farmed in urban or rural locations, further reducing transportation costs to bring entomo-products to market. Unlike large-scale animal production facilities that require many inputs and large teams of staff, insect farms require very few technical inputs. Most farms can be managed by a small number of individuals (Dossey et al., 2019).

Insects are environmentally sustainable. They have the lowest carbon footprint (even compared to most commercial crops), producing far fewer greenhouse gases and ammonia emissions and requiring very little mechanical maintenance (such as tractors) that releases secondary emissions. Additionally, insect farming requires less land than livestock, aquaculture, or crops. Insects are poikilotherm and thus possess a higher feed conversion rate than common production animals. Crickets possess a feed conversation ratio of 1.7 kilograms feed to kilograms of live weight. Livestock have much higher feed conversation ratios at poultry 2.5, swine 5, and beef 10 (Van Huis, 2013). These figures are somewhat misleading as they do not factor in that when combining a low insect feed conversation ratio, less land required to farm insects, fewer emissions, and that up to 80% of most edible insects can be consumed (as compared to 50% of most livestock) it's not surprising to see a continued interest in insect farming for consumption.

Additionally, insects require fewer water resources than production animals. According to Miglietta et al. (2015), mealworm production required 23 liters of water for every gram of edible protein. Chicken required 43 liters, pork 57 liters, and beef 112 liters of water for every gram of protein.

The Specifics: From Farm to Table

The house cricket (*Acheta domesticus*) is one of the world's most commonly farmed insects. Native to South Asia, the species is found worldwide. While they have been the staple feeder food for many pet hobbyists in Western cultures, *A. domesticus* has been a staple food source for humans in Asia for hundreds of years. Easy to rear, fast producing, and capable of tolerating a wide array of environmental and climatic conditions, *A. domesticus* has become the most farmed insect on the planet. Closely related, in terms of ease to farm, black soldier fly larva (*Hermetia illucens*) are farmed around the world for protein production and organic waste management. Other species farmed include mealworms (*Alphitobius diaperinus* and *Tenebio molitor*), African palm weevils (*Rhynchophorus* spp.), grasshoppers (*Acrida exaltata*), and many more. Farmers, researchers, and consumers are experimenting with insect varieties to determine which species is most suitable for their production objectives (van Huis and Tomberlin, 2018).

In many tropical countries collecting insects from the wild is a normal practice. Only in the last 50 years have individuals begun to farm insects at the household level. This practice has spread throughout many developing countries at tropical latitudes. The domestication process has been gradual. In central Africa, communities have been known to harvest tree branches with caterpillars and then relocate those branches closer to villages to make it easier to supplement their diets with insects (Malaisse, 1997). Indigenous populations in the Amazon rainforest set up plastic containers to encourage feeding for weevils that were then consumed by the community (Cerda et al., 2001). Gradually this semi-domestication of insects for use as food transformed into small-scale subsistence farming and then farming for sale. Small farms have grown to larger farming operations that employ from a few workers to a dozen. These medium-sized enterprises predominately sell multiple insects nationally or regionally in local markets on street carts or tiny stalls. They produce various products ranging from raw insects, cooked or powdered variants of insects. More recently, these medium-scale farms have given way to large corporate entities that often highly specialized technologies to rear insects, from maintaining constant temperatures, moister levels to automated feeding systems. As we'll see in later chapters, these technologies are essential to maintain high-quality, disease-free products.

The small-scale subsistence farmer often grows only one or two species. They grow these in their houses, often in simple housing units such as cinder block pits with netting on top or in plastic buckets augmented to support insects with water, food, and air (see figure 1.3). Both of these containers require very little care and maintenance. They are easy and cheap to build and offer suitable conditions for insects to thrive, often mimicking conditions in the wild. Farmers design the housing structures to be damp, dark, and predator-free. Often, in south Asia and Africa, female household members are in charge of carrying for and maintaining the insect populations. In the case of crickets, a generation lasts every 49 days at 28 ºC (Megido, 2018). Each generation is a cycle that repeats so long as sufficient conditions are met to propagate a new generation. The highest cost to farmers is feed. According to a study conducted by Hanboonsong et al., in Megido (2018), in Thailand, the production cost for a single life cycle of cricket rearing is approximately $2.00 per kilogram in a concrete, brick, or cinder block pen and $1.60 per kilogram in plastic container housing. The insects can be harvested and sold for up to $4.30 per kilogram. To further reduce costs, farmers often supplement feed with vegetables and fruits either discarded by the family or wild picked. There are many other cost-saving opportunities within the farming process, but farmers can generally expect returns of at least 120%.

In addition to crickets, farmers may also sell eggs for up to $1.90 per egg bowl and cricket frass as a biofertilizer. Frass commands a price of up to $1.67 per 20-30 kilogram bag in Thailand. There are additional ways for farmers to maximize profits, but most of these methods, such as processing insects, freezing them, etc., are not utilized due to a lack of specialized knowledge from farmers or financial barriers to entry (Megido, 2018). But this may not be the case for long. Slowly the small-scale farm is being scaled up. Support from Khon Kaen University in Thailand has helped many small farms grow their operations from subsistence operations to medium-sized farms that serve multiple markets domestically or regionally. In Kenya, the Government of the Netherlands set up a Flying Foods project that helped establish 50 cricket farms across the country that have grown into medium-sized enterprises. Today the Food and Agriculture Organization of the United Nations plays a crucial role in supporting farmers to expand their operations (Megido, 2018).

Medium to large enterprise farms requires extensive knowledge of the target insect, its food source, temperatures, water, needs, etc., prior to being developed on an industrial scale. Given their size, they are often contained in warehouses with sufficient space to expand operations (see figure 1.4). The greatest challenge that large farms must contend with is the supply of oxygen and the removal of heat. This is often achieved by pumping air through the substrate that filters through the soil removing chemicals released from frass and from the metabolization process. The heat transfer process is further complicated in that different amounts of transfer are required for crickets throughout their life cycles; thus, alternative processes have to be established for eggs, pupae, larvae, and adults. Large enterprises must content with waste streams, much larger scale cleaning processes, and maintenance.

Figure 1.3 Small-scale cricket farm set-up (courtesy Aaron T. Dossey)

Figure 1.4 Large-scale cricket farm set-up (courtesy Entomo Farms)

Some large insect enterprises, such as Aspire Foods, have sufficient investor capital to pioneer a new approach to insect farming—a fully automated plant that has zero human interaction. According to Fast Company (2017) Aspire has developed a robot that is capable of feeding millions of crickets 24 hours a day. The 25,000 square foot facility is capable of producing tons of cricket powder annually, all with no manual labor, which Aspire claims adversely impacts cricket growth (Peters, 2017).

Barriers: Why Isn't Everyone Eating Insects

Insect consumption, as discussed with the historical context, is generally thought of in Western cultures as something practiced by "primitive peoples." According to Maheu (2011), the cultural disgust factor, often called the *ick-factor*, is the single greatest obstacle to promoting entomophagy in the Western world. Maheu continues "These beliefs complicate the incorporation of insects in the diet because all associations and assignments related to these arthropods influence our perception of them as food, much more than their nutritional value." With this statement in hand, we can consider the overall relationship between insects and Western cultures. Most European and North American communities regard insects in a negative connotation. The word "bug" or "creepy-crawly" is used to describe all sorts of insects that often elicit images of venomous animals with dirty bodies that carry diseases. Such is Western culture naivete that many people often refer to spiders, scorpions, and sometimes even snakes as disgusting "bugs" (Costa-Neto, 2016). Much research has been conducted on why humans are predisposed to fear or disgust. Some scientists conclude that the disgust factor is a mechanism used by humans to prevent viral spread. Others argue that humans are biologically predisposed to fear animals like reptiles or insects.

In Dossey et al. (2016), the psychologist Paul Rozin captured disgust-psychology wonderfully. He states that foods are primarily classified as pleasant or unpleasant and broken down into categories that depend upon individual variations, genetics, and as appropriate, inappropriate, disgusting, dangerous or beneficial. Taste, smell, and touch also factor into these classifications. Foods, like many things, go through trends. Recently the United States underwent a massive kale trend, and more recently it was quinoa. These foods are placed into the beneficial category and involve deep emotions. People who consume them often feel more energized, healthier and psychologically happier. The same is true for insects. Given their widespread disgust by most Western cultures and the emotions derived from seeing an insect on clothes, a person's skin, or food, the barriers to Western culture adopting insects into mainstream diets will be challenging.

With the barriers established, how will Western cultures adopt entomophagous practices? Much like previous foods that used to be poorly received, there are some that will initiate the trend ahead of the masses. These individuals are key cogs in the process of shifting insects from pests to pasta. Similarly, these food pioneers helped transform pizza, 120 years ago considered a food only suitable for Sicily's poor, into one of the most important popular foods on the planet. Lobster has become a staple on coastlines around the globe but for a very long time was cherished only by monarchies (Costa-Neto, 2011). The work to bring insects to the table has already begun. In the 1970s, Ronald Taylor's book *Butterflies in my Stomach* became the cardinal text for entomophagy. The book, along with the recipe book *Entertaining with Insects* in 1976, set the stage for many more books to be published. In 1988, Gene DeFoliart began to write and publish the quarterly *The Food Insects Newsletter*, which helped explain the nutritional basis for eating insects, thus encouraging people to consume insects because they were healthy.

Today, there are dozens of "bug-feasts" or conventions hosted by universities and societal organizations dedicated to the consumption of eating insects. Purdue University hosts an annual Bug Bowl, and Montana State University hosts Bug Buffet. Events are sponsored at zoos, museums, and local parks. The Los Angeles County, Natural History Museum, hosts an annual insect-themed event that includes an insect cooking competition (Dossey et al., 2018). But this broader adoption, beyond the mere food pioneers, is still a long way from total or even partial adoption in restaurants, grocery stores and on the table.

Two additional hurdles beyond the ick-factor prevent insects from joining us at the dinner table: health risks and concerns therein and the regulatory and legal framework of using insects as food and feed. Health risks can further be broken down into two subcategories: those intrinsically associated with insects and those that are introduced during the farming and harvesting phase of production. The bacteria *Salmonella*, *Campylobacter,* and strains of *Escherichia coli* are the most common bacteria that are found on insects and pathogenic to humans. These bacteria are often found in lower quantities on insects, and research has concluded that they do not replicate in insects; the potential for insect-to-human transmission is possible. Viruses also pose a concern. But, much like bacteria, they are not known to replicate in insects and thus may only be transmitted to humans if the insect is infected with the virus.

There are also concerns related to hazardous chemicals being introduced to insects during the rearing, farming or harvesting phases. Concerns about substrate-to-insect chemical transmission, the use of chemicals during the rearing phase, and the self-production of toxins by insects. While there are no current studies indicating that farm-reared insects have been contaminated, many regulators are concerned that heavy metals (lead, arsenic, and mercury) may be introduced to insects through substrates. Additionally, regulators have raised concerns about the introduction of drugs and hormones used in rearing insects. Other concerns related to dioxins, hydrocarbons, and packaging contaminants have been raised by regulators in both the US and Europe.

There are two bodies that regulate food in the United States. The United States Department of Agriculture (USDA) is responsible for the certification, grading and inspection of all agricultural products. This includes the facilities, animals, and procedures related to agriculture production. The USDA established meat laws in 1906 governing interstate trade at the federal level. At the State level, each individual State is unilaterally allowed to establish laws, regulations, and policies governing the production and sale of livestock. The Food and Drug Administration (FDA) is responsible for ensuring foods are safe and stored under sanitary conditions. This mandate extends to ensuring that all packaging, additives, and labeling are safe and accurate. Jointly these two agencies work to ensure that America's food and supply chain from farm to table is safe, wholesome and as consumers, we're informed about these products. Insects broadly come under the jurisdiction of both agencies when the sole purpose of the insect is to be used as food or feed.

The Future

Without a doubt, the greatest hurdles to widespread adoption remain convincing consumers to set aside their disgust and give entomophagy a try. Accordingly, insect food producers are spending a considerable amount of effort to lobby consumers to adopt the practice. Yet, additional challenges remain. The industry is largely unregulated, and many companies that are involved in the industry have significant technological gaps at one or more links in the supply chain. Additionally, given that the market in Western cultures has to be manufactured by the industry itself, it remains unclear which insect species to target, products to produce or consumers to lobby. As the number of consumers increase, there are has been an interest in the ethical treatment of insects during the farming process. Insects are animals and in accordance with the Farm Animal Welfare Committee (FAWC, 2009), the five freedoms for animals must be maintained: 1) freedom from hunger and thirst, 2) from discomfort, 3) from pain, injury, and disease, 4) from fear and distress, and 5) to express normal behavior. Accordingly, producers are now mandated to establish animal ethical policies to ensure that FAWC criteria are maintained.

While these challenges make real pose threats to the insect-based food and feed industry, there remains immense potential beyond simple production and consumption. One such potential remains in mankind's last frontier—space. Insects are essentially micro livestock and, as such, have the potential to be a suitable food source for spacefaring communities. Studies have shown that insects can reproduce in zero gravity environments, can serve as a sufficient source of protein for astronauts and insects can act as a tool for recycling waste materials and producing fertilizer for the soil.

Conclusion

The entomophagy field is one that when you immerse yourself in it, you will feel like the entire world is talking about insects as food and feed. Yet, from the outside, the industry is virtually nonexistent. In the United States, the North American Coalition for Insect Agriculture (NACIA) is the leading organization dedicated to growing the insect food and feed sector. While the organization has grown extensively in recent years, most individuals in the food, feed, and entomological industry have never heard of the organization. The Wall Street Journal presents the annual Food Forum, which aims to "tackle the critical issue of sustainability from seed research to farming practices to packaging to the food we eat," the title of the forum this year is "Sustainability: A Global Imperative." Guest speakers include some of the leading authorities on how our food is grown, harvested, packaged, and sold. The US Secretary of Agriculture will be joined by the CEOs of Nestle, Archer-Daniels-Midland, and Danone. Yet, not a single speaker represents the entomophagy industry, and the agenda fails to consider the option of an insect as food or feed in its list of topics to be discussed (The Wall Street Journal, 2021).

But, a trend is taking shape in Western cultures, and an industry is developing. Ynsect, a French company specializing in breeding insects for feed for production animals, has secured more than $250,000 in investment capital since its founding in 2011 (Ernst Young, 2019). In the United States, companies such as Entomo Farms, EnviroFlight, NextProtein, and many more are spearheading an initiative to transform America's adversity to insects as food. Through direct sales to restaurants and on websites, they are reaching consumers who have evolved from food pioneers into individuals directly interested in the nutritional benefits of insect consumption. One of the most receptive audiences to early insect food adoption has been from athletes. Bodybuilders focused on high nutrient, and protein diets have found insect protein bars, and cricket powders have quickly integrated insects into their diets. Other athletes are following their lead.

Mainstream society remains elusive. Even those deemed to be one of the 100 most influential. Adoption of insect-based foods is mandatory, if not inevitable. Suppose the universe created by Nolan in Interstellar holds true, and mankind may face extinction through starvation (or through planetary destruction). In that case, the time to adopt sustainable entomophagous practices could not come soon enough. To avoid what may become a catastrophic misstep in the evolution of humankind, societies will need to set aside their prejudice, ignorance, and disgust.

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